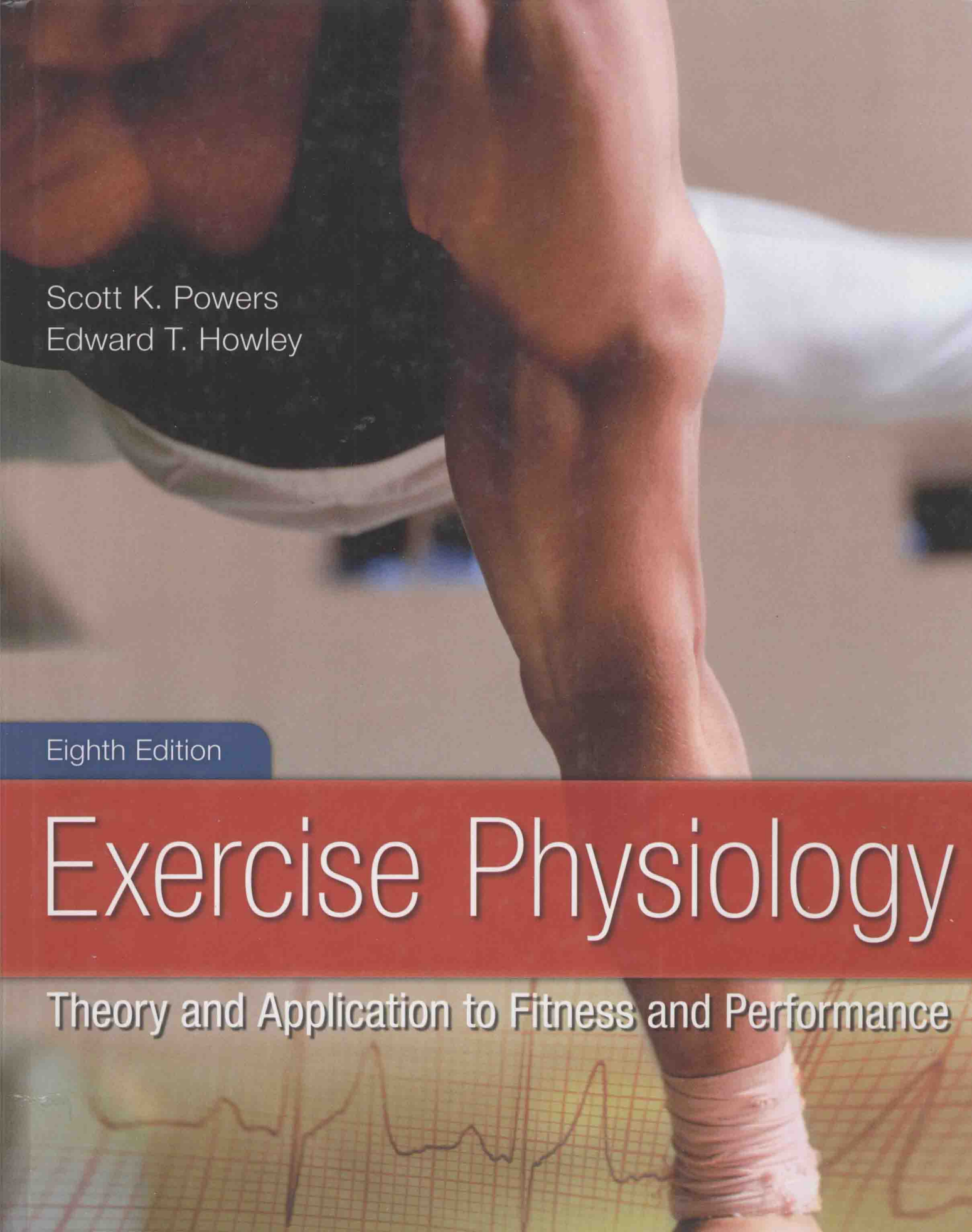


Scott K. Powers
Edward T. Howley

Eighth Edition

Exercise Physiology

Theory and Application to Fitness and Performance

EXERCISE PHYSIOLOGY

Theory and Application to Fitness and Performance

EIGHTH EDITION

Scott K. Powers
University of Florida

Edward T. Howley
University of Tennessee, Knoxville

Mc Graw Hill
Connect
Learn
Succeed™

The McGraw-Hill Companies

This book is printed on acid-free paper.

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

ISBN: 978-0-07-802253-1
MHID: 0-07-802253-3

Executive Editor: *Christopher Johnson*
Marketing Manager: *Caroline McGillen*
Developmental Editor: *Gary O'Brien, Van Brien & Associates*
Production Editor: *Ruth Sakata Corley*
Production Service: *Scratchgravel Publishing Services*
Cover Designer: *Preston Thomas*
Photo Research: *PoYee Oster*
Buyer: *Tandra Jorgensen*
Media Project Manager: *Jennifer Barrick*
Digital Product Manager: *Roja Mirzadeh*
Composition: *10/12 Novarese Nook by MPS Limited, a Macmillan Company*
Printing: *45# New Era Matte Plus, R. R. Donnelley & Sons*

Vice President Editorial: *Michael Ryan*
Publisher: *David Patterson*

Cover: Gymnastic image: © Jupiterimages; Heatbeat image: © Brand X Pictures

Credits: The credits section for this book begins on page C-1 and is considered an extension of the copyright page.

Library of Congress Cataloging-in-Publication Data

Powers, Scott K. (Scott Kline), 1950–
Exercise physiology : theory and application to fitness and performance / Scott K. Powers. — 8th ed.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-07-802253-1 (hardback)
1. Exercise—Physiological aspects. I. Howley, Edward T., 1943– II. Title.
QP301.P64 2011
612'.044—dc23

2011040085

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

Preface

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

This book is intended for a one-semester, upper-level undergraduate or beginning graduate exercise physiology course. Clearly, the text contains more material than can be covered in a fifteen-week semester. This is by design. The book was written to be comprehensive to afford instructors the freedom to select the material that they consider to be the most important for the composition of their class.

NEW TO THIS EDITION

The eighth edition of our book has undergone *major* revisions and highlights the latest research in exercise physiology. Indeed, every chapter contains new and expanded discussions, new text boxes, new figures, updated references, and contemporary suggested readings. Furthermore, we have added an additional chapter to this book that focuses on exercise and the immune system. Also in this eighth edition, students are exposed to new information on the cell signaling events leading to skeletal muscle adaptation to both resistance and endurance exercise training.

New Topics and Updated Content

The content of this new edition has been expanded and updated. The following list describes some of the major changes that have made the eighth edition more complete and up to date:

- The central theme of the book remains regulation of homeostasis during exercise, and the revised text now contains a detailed discussion of how signaling pathways regulate cellular homeostasis and lead to exercise-induced muscle adaptation to exercise.
- Numerous new and revised box features added to chapters throughout the book.
- A new chapter to discuss the impact of exercise on the immune system.
- New information on the size principle of motor unit recruitment.
- Updated and new information on the causes of exercise-induced muscle fatigue.
- Expanded and revised chapter on endocrine function during exercise along with a new and detailed discussion of muscle as an endocrine organ.
- New information on the cause of exercise-induced muscle cramps.
- Updated material on heart rate variability during exercise.
- New information on the age-related changes in skeletal muscle.
- Updated information on the regulation of the cardiovascular and ventilatory responses to exercise.

- Updated information on the role of inflammation related to atherosclerosis and other chronic diseases
- Expanded discussion of the new U.S. Physical Activity Guidelines, including the link of physical activity to reduction in chronic disease risk and death from all causes.
- Update on guidelines related to exercise testing and prescription for specific diseases (e.g., diabetes, COPD) and populations (older individuals, pregnant women).
- Expanded discussion of nutritional factors related to managing exercise-induced asthma.
- Update on the new Dietary Guidelines for Americans; expanded discussion of possible role of high fructose corn syrup on obesity; latest information on the prevalence of overweight and obesity in children and adults; update on drugs, exercise, and weight loss.
- Contemporary information on the laboratory testing of athletes.
- New information on training for performance in both young and masters athletes.
- Up-to-date material on the impact of aging on performance.
- New discussion of carbohydrate loading in female athletes; expanded debate of water and carbohydrate intake prior to and immediately following performance; and expanded discussion of hyponatremia.
- Expanded discussion of how altitude natives acclimatize to altitude exposure over generations, with clear differences between Andean and Tibetan populations.

CREATE, BECAUSE CUSTOMIZATION MATTERS

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

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

INSTRUCTOR AND STUDENT ONLINE RESOURCES

www.mhhe.com/powers8e

The Online Learning Center at **www.mhhe.com/powers8e** includes valuable teaching and learning tools including assessment tools, classroom presentations, practice quizzes, and updated reference materials.

ACKNOWLEDGEMENTS

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

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

Tom Ball
De Pauw University

Burch Oglesby
University of Tennessee, Chattanooga

Justus Ortega
Humboldt State University

Linda Romaine
Raritan Valley Community College

Hank Williford
Auburn University, Montgomery

Robert Chapman
Indiana University, Bloomington

Charles Darracott
Augusta State University

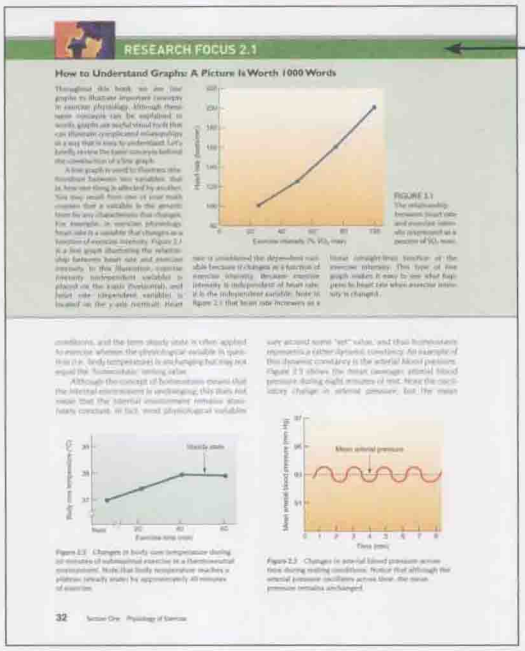
Steven Hawkins
California Lutheran University

Robert Lehnhard
University of Maine

Brian McFarlin
University of Houston

Clay Nicks
Columbus State University

Engaging Presentation of Key Concepts Supported by the Latest Research


RESEARCH FOCUS 2.1

How to Understand Graphs: A Picture Is Worth 1000 Words

Research Focus

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


A CLOSER LOOK 0.1

PHYSICAL EDUCATION TO EXERCISE SCIENCE AND KINESIOLOGY

A Closer Look

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


ASK THE EXPERT 4.1

Oxygen Uptake Kinetics at the Onset of Constant Work-Rate Exercise: Questions and Answers with Dr. Bruce Gladden

RECOVERY FROM EXERCISE: METABOLIC RESPONSES

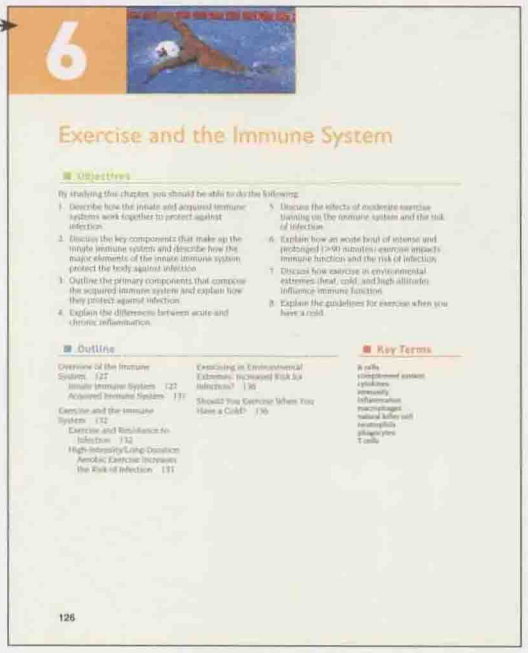
Ask the Expert

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

Practical Applications of Exercise Physiology

New Chapter

A new Chapter 6 presents the growing body of research on exercise-induced changes in the immune system and its significance for applied exercise physiology.


6

Exercise and the Immune System

Objectives

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

1. Describe how the innate and acquired immune systems work together to protect against infection.
2. Discuss the key components that make up the innate immune system and describe how the major elements of the innate immune system protect the body against infection.
3. Outline the primary components that compose the acquired immune system and explain how they protect against infection.
4. Explain the differences between acute and chronic inflammation.
5. Discuss the effects of moderate exercise training on the immune system and the risk of infection.
6. Explain how an acute bout of intense and prolonged (>90 minutes) exercise impacts immune function and the risk of infection.
7. Discuss how exercise in environmental extremes (heat, cold, and high altitudes) influence immune function.
8. Explain the guidelines for exercise when you have a cold.

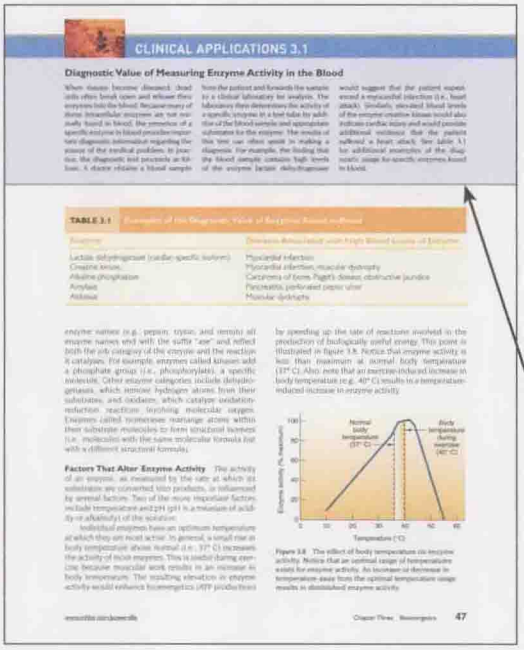
Outline

Overview of the Immune System 127
Innate Immune System 127
Acquired Immune System 131
Exercise and the Immune System 132
Exercise and Resistance to Infection 132
High-Intensity/Long-Duration Aerobic Exercise Increases the Risk of Infection 133
Exercising in Environmental Extremes: Increased Risk for Infection? 136
Should You Exercise When You Have a Cold? 136

Key Terms

B cells
complement system
cytokines
immunity
inflammation
macrophages
natural killer cell
neutrophils
phagocytes
T cells

126


CLINICAL APPLICATIONS 3.1

Diagnostic Value of Measuring Enzyme Activity in the Blood

TABLE 3.1

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

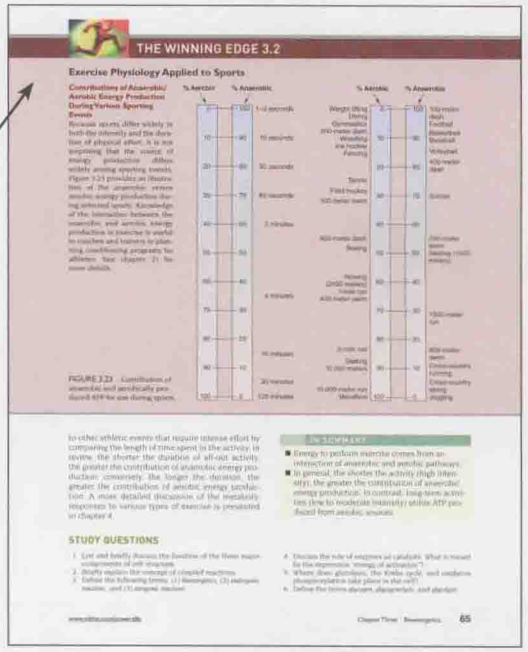
Factors That Alter Enzyme Activity

Figure 3.8 The effect of body temperature on enzyme activity. Notice that an optimal range of temperatures exists for enzyme activity. An increase or decrease in temperature away from the optimal temperature range results in diminished enzyme activity.

47

Clinical Applications

Learn how exercise physiology is used in the clinical setting.


THE WINNING EDGE 3.2

Exercise Physiology Applied to Sports

Contributions of Anaerobic/Aerobic Energy Production During Various Sporting Events

FIGURE 3.23

IN SUMMARY

STUDY QUESTIONS

65

The Winning Edge

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

Glossary

absolute $\dot{V}O_2$ the amount of oxygen consumed over a given time period; expressed as liters · min^{-1}.

acclimation the change that occurs in response to repeated environmental stresses and results in the improved function of an existing homeostatic system. In general, acclimation is commonly used to refer to a rapid physiological adaptation that occurs within days to a few weeks.

acclimatization a gradual, long-term adaptation of an organism (e.g., humans) to a change in the environment (e.g., heat exposure). Acclimatization results in the improved function of an existing homeostatic system. Although acclimatization and acclimation are similar terms, acclimatization is often used to describe a gradual physiological adaptation that occurs within months to years of exposure to the environmental stress.

acidosis an abnormal increase in blood hydrogen ion concentration (i.e., arterial pH below 7.35).

acids compounds capable of giving up hydrogen ions into solution.

acromegaly a condition caused by hypersecretion of growth hormone from the pituitary gland; characterized by enlargement of the extremities, such as the jaw, nose, and fingers.

actin a structural protein of muscle that works with myosin in permitting muscular contraction.

action potential the all-or-none electrical event in the neuron or muscle cell in which the polarity of the cell membrane is rapidly reversed and then reestablished.

activation energy Energy required to initiate a chemical reaction. The term *activation energy* is sometimes referred to as the *energy of activation*.

adenosine diphosphate (ADP) a molecule that combines with inorganic phosphate to form ATP.

adenosine triphosphate (ATP) the high-energy phosphate compound synthesized and used by cells to release energy for cellular work.

adenylate cyclase enzyme found in cell membranes that catalyzes the conversion of ATP to cyclic AMP.

adequate intake (AI) recommendations for nutrient intake when insufficient information is available to set an RDA standard.

adrenal cortex the outer portion of the adrenal gland. Synthesizes and secretes corticosteroid hormones, such as cortisol, aldosterone, and androgens.

adrenaline *see* epinephrine.

adrenocorticotrophic hormone (ACTH) a hormone secreted by the anterior pituitary gland that stimulates the adrenal cortex.

aerobic in the presence of oxygen.

afferent fibers nerve fibers (sensory fibers) that carry neural information back to the central nervous system.

afferent neuron sensory neuron carrying information toward the central nervous system.

aldosterone a corticosteroid hormone involved in the regulation of electrolyte balance.

alkalosis an abnormal increase in blood concentration of OH^- ions, resulting in a rise in arterial pH above 7.45.

alpha receptors a subtype of adrenergic receptors located on cell membranes of selected tissues.

alveolar ventilation ($\dot{V}_A$) the volume of gas that reaches the alveolar region of the lung.

alveoli microscopic air sacs located in the lung where gas exchange occurs between respiratory gases and the blood.

amenorrhea the absence of menses.

AMPK (5'adenosine monophosphate activated protein kinase) an important signaling molecule that is activated during exercise due to changes in muscle fiber phosphate/energy levels. AMPK regulates numerous energy producing pathways in muscle by stimulating glucose uptake and fatty acid oxidation during exercise and is also linked to the control of muscle gene expression by activating transcription factors associated with fatty acid oxidation and mitochondrial biogenesis.

anabolic steroid a prescription drug that has anabolic, or growth-stimulating, characteristics similar to that of the male androgen, testosterone.

anaerobic without oxygen.

anaerobic threshold a commonly used term meant to describe the level of oxygen consumption at which there is a rapid and systematic increase in blood lactate concentration. Also termed the *lactate threshold*.

anatomical dead space the total volume of the lung (i.e., conducting airways) that does not participate in gas exchange.

androgenic steroid a compound that has the qualities of an androgen; associated with masculine characteristics.

androgens male sex hormones. Synthesized in the testes and in limited amounts in the adrenal cortex. Steroids that have masculinizing effects.

angina pectoris chest pain due to a lack of blood flow (ischemia) to the myocardium.

angiotensin I and II these compounds are polypeptides formed from the cleavage of a protein (angiotensinogen) by the action of the enzyme renin produced by the kidneys, and converting enzyme in the lung, respectively.

anorexia nervosa an eating disorder characterized by rapid weight loss due to failure to consume adequate amounts of nutrients.

anterior hypothalamus the anterior portion of the hypothalamus. The hypothalamus is an area of the brain below the thalamus that regulates the autonomic nervous system and the pituitary gland.

anterior pituitary the anterior portion of the pituitary gland that secretes follicle-stimulating hormone, luteinizing hormone, adrenocorticotrophic hormone, thyroid-stimulating hormone, growth hormone, and prolactin.

antidiuretic hormone (ADH) hormone secreted by the posterior pituitary gland that promotes water retention by the kidney.

aortic bodies receptors located in the arch of the aorta that are capable of detecting changes in arterial PO_2.

apophyses sites of muscle-tendon insertion in bones.

arrhythmia abnormal electrical activity in the heart (e.g., a premature ventricular contraction).

arteries large vessels that carry arterialized blood away from the heart.

arterioles a small branch of an artery that communicates with a capillary network.

articular cartilage cartilage that covers the ends of bones in a synovial joint.

atherosclerosis a pathological condition in which fatty substances collect in the layer (intima) of arteries.

atmospheric pressure Downward force exerted in the earth's surface due to the weight of the air above that point.

ATPase enzyme capable of breaking down ATP to ADP + P_i + energy.

ATP-PC system term used to describe the metabolic pathway involving muscle stores of ATP and the use of phosphocreatine to rephosphorylate ADP. This pathway is used at the onset of exercise and during short-term, high-intensity work.

atrioventricular node (AV node) a specialized mass of muscle tissue located in the interventricular septum of the heart; functions in the transmission of cardiac impulses from the atria to the ventricles.

autocrine signaling signaling that occurs when a cell produces and releases a chemical messenger into the extracellular fluid that acts upon the cell producing the signal. The autocrine agent refers to the chemical messenger that is released by the cell.

autologous transfusion blood transfusion whereby the individual receives his or her own blood.

autonomic nervous system portion of the nervous system that controls the actions of visceral organs.

autoregulation mechanism by which an organ regulates blood flow to match the metabolic rate.

axon a nerve fiber that conducts a nerve impulse away from the neuron cell body.

basal metabolic rate (BMR) metabolic rate measured in supine position following a 12-hour fast, and 8 hours of sleep.

bases compounds that ionize in water to release hydroxyl ions (OH^-) or other ions that are capable of combining with hydrogen ions.

beta oxidation breakdown of free fatty acids to form acetyl-CoA.

beta receptor agonist (β-agonist) a molecule that is capable of binding to and activating a beta receptor.

beta receptors adrenergic receptors located on cell membranes. Combine mainly with epinephrine and, to some degree, with norepinephrine.

bioenergetics the chemical processes involved with the production of cellular ATP.

biological control systems a control system capable of maintaining homeostasis within a cell or organ system in a living creature.

blood boosting a term that applies to the increase of the blood's hemoglobin concentration by the infusion of additional red blood cells. Medically termed *induced erythrocythemia*.

blood doping *see* blood boosting.

blood packing *see* blood boosting.

Bohr effect the right shift of the oxyhemoglobin dissociation curve due to a decrease of blood pH. Results in a decreased affinity for oxygen.

bradycardia a resting heart rate less than 60 beats per minute.

brain stem portion of the brain that includes midbrain, pons, and medulla.

buffer a compound that resists pH change.

bulimia an eating disorder characterized by eating and forced regurgitation.

bulk flow mass movement of molecules from an area of high pressure to an area of lower pressure.

calcitonin hormone, released from the thyroid gland, that plays a minor role in calcium metabolism.

calciuneurin a phosphatase activated by increases in cytosolic calcium; it participates in several adaptive responses in muscle, including fiber growth/regeneration and the fast-to-slow fiber type transition that occurs as a result of exercise training.

calmodulin Calmodulin-dependent kinase (CaMK) is activated during exercise in an intensity-related manner. This important kinase exerts influence on exercise-induced muscle adaptation by contributing to the activation of PCG-1α. The primary upstream signal to activate CaMK is increased cytosolic calcium levels.

capillaries microscopic blood vessels that connect arterioles and venules. Portion of vascular system where blood/tissue gas exchange occurs.

cardiac accelerator nerves part of the sympathetic nervous system that stimulates the SA node to increase heart rate.

cardiac output the amount of blood pumped by the heart per unit of time; equal to product of heart rate and stroke volume.

cardiovascular control center the area of the medulla that regulates the cardiovascular system.

carotid bodies chemoreceptors located in the internal carotid artery; respond to changes in arterial PO_2, PCO_2, and pH.

catecholamines organic compounds, including epinephrine, norepinephrine, and dopamine.

cell body the soma, or major portion of the body of a nerve cell. Contains the nucleus.

cell membrane the lipid-bilayer envelope that encloses cells. Called the *sarcolemma* in muscle cells.

cell signaling a system of communication that governs cellular activities and coordinates cell actions. Cell signaling can occur via numerous signaling pathways, including direct contact of cells.

cellular respiration process of oxygen consumption and carbon dioxide production in cells (i.e., bioenergetics).

central command the control of the cardiovascular or pulmonary system by cortical impulses.

central fatigue factors located prior to the neuromuscular junction that impair the force generating capacity of muscle.

central nervous system (CNS) portion of the nervous system that consists of the brain and spinal cord.

cerebellum portion of the brain that is concerned with fine coordination of skeletal muscles during movement.

cerebrum superior aspect of the brain that occupies the upper cranial cavity. Contains the motor cortex.

chemiosmotic hypothesis the mechanism to explain the aerobic formation of ATP in mitochondria.

cholesterol a 27-carbon lipid that can be synthesized in cells or consumed in the diet. Cholesterol serves as a precursor of steroid hormones, and plays a role in the development of atherosclerosis.

clo unit that describes the insulation quality of clothing.

complement system part of the innate immune system; it forms a second line of defense against infection .The more than twenty proteins that make up the complement system are present in high concentrations in the blood and tissues. When the body is exposed to a foreign agent (e.g. bacterium), the complement system is activated to attack the invader.

concentric action occurs when a muscle is activated and shortens.

conduction transfer of heat from warmer to cooler objects that are in contact with each other. This term may also be used in association with the conveyance of neural impulses.

conduction disturbances refers to a slowing or blockage of the wave of depolarization in the heart, e.g., first-degree AV block, or bundle branch block.

conductivity capacity for conduction.

convection the transmission of heat from one object to another through the circulation of heated molecules.

Cori cycle the cycle of lactate-to-glucose between the muscle and liver.

coronary artery bypass graft surgery (CABGS) the replacement of a blocked coronary artery with another vessel to permit blood flow to the myocardium.

cortisol a glucocorticoid secreted by the adrenal cortex upon stimulation by ACTH.

coupled reactions the linking of energy-liberating chemical reactions to "drive" energy-requiring reactions.

critical power a specific submaximal power output that can be maintained without fatigue.

cromolyn sodium a drug used to stabilize the membranes of mast cells and prevent an asthma attack.

cycle ergometer a stationary exercise cycle that allows accurate measurement of work output.

cyclic AMP a substance produced from ATP through the action of adenylate cyclase that alters several chemical processes in the cell.

cytokines hormone messengers that regulate the immune system by facilitating communication with other cells within the immune system.

cytoplasm the contents of the cell surrounding the nucleus. Called *sarcoplasm* in muscle cells.

Daily Value a standard used in nutritional labeling.

deficiency a shortcoming of some essential nutrient.

degenerative diseases diseases not due to infection that result in a progressive decline in some bodily function.

delayed-onset muscle soreness (DOMS) muscle soreness that occurs 12 to 24 hours after an exercise bout.

dendrites portion of the nerve fiber that transmits action potentials toward a nerve cell body.

dental caries tooth decay; related to sugar content in foods.

deoxyhemoglobin hemoglobin not in combination with oxygen.

diabetes mellitus a condition characterized by high blood glucose levels due to inadequate insulin. Type I diabetics are insulin dependent, whereas Type II diabetics are resistant to insulin.

diabetic coma unconscious state induced by a lack of insulin.

diacylglycerol a molecule derived from a membrane-bound phospholipid, phosphatidylinositol, that activates protein kinase C and alters cellular activity.

diaphragm the major respiratory muscle responsible for inspiration. Dome-shaped—separates the thoracic cavity from the abdominal cavity.

diastole period of filling of the heart between contractions (i.e., resting phase of the heart).

diastolic blood pressure arterial blood pressure during diastole.

Dietary Guidelines for Americans general statements related to food selection that are consistent with achieving and maintaining good health.

Dietary Reference Intakes the framework for nutrient recommendations being made as a part of the revision of the 1989 RDA.

diffusion random movement of molecules from an area of high concentration to an area of low concentration.

direct calorimetry assessment of the body's metabolic rate by direct measurement of the amount of heat produced.

dose the amount of drug or exercise prescribed to have a certain effect (or response).

double-blind research design an experimental design in which the subjects and the principal investigator are not aware of the experimental treatment order.

double product the product of heart rate and systolic blood pressure; estimate of work of the heart.

dynamic refers to an isotonic muscle action.

dynamic stretching stretching that involves controlled movement.

dynamometer device used to measure force production (e.g., used in the measurement of muscular strength).

dysmenorrhea painful menstruation.

dyspnea shortness of breath or labored breathing. May be due to various types of lung or heart diseases.

eccentric action occurs when a muscle is activated and force is produced but the muscle lengthens.

ectomorphy category of somatotype that is rated for linearity of body form.

effect change in variable (e.g., $\dot{V}O_2$ max) due to a dose of exercise (e.g., 3 days per week, 40 min/day at 70% $\dot{V}O_2$ max).

effector organ or body part that responds to stimulation by an efferent neuron (e.g., skeletal muscle in a withdrawal reflex).

efferent fibers nerve fibers (motor fibers) that carry neural information from the central nervous system to the periphery.

efferent neuron conducts impulses from the CNS to the effector organ (e.g., motor neuron).

ejection fraction the proportion of end-diastolic volume that is ejected during a ventricular contraction.

electrocardiogram (ECG) a recording of the electrical changes that occur in the myocardium during the cardiac cycle.

electron transport chain a series of cytochromes in the mitochondria that are responsible for oxidative phosphorylation.

element a single chemical substance composed of only one type of atom (e.g., calcium or potassium).

endergonic reactions energy-requiring reactions.

endocrine gland a gland that produces and secretes its products directly into the blood or interstitial fluid (ductless glands).

endocrine signaling occurs when cells release chemical signals (hormones) into the blood, which are carried in the blood to all tissues in the body. However, only the cells with a receptor to which the hormone can bind will respond.

endomorphy the somatotype category that is rated for roundness (fatness).

endomysium the inner layer of connective tissue surrounding a muscle fiber.

endorphin a neuropeptide produced by the pituitary gland having pain-suppressing activity.

end-plate potential (EPP) depolarization of a membrane region by a sodium influx.

energy of activation energy required to initiate a chemical reaction.

energy wasteful systems metabolic pathways in which the energy generated in one reaction is used up in another that leads back to the first, creating a futile cycle and requiring a higher resting metabolic rate.

enzymes proteins that lower the energy of activation and, therefore, catalyze chemical reactions. Enzymes regulate the rate of most metabolic pathways.

epidemiology the study of the distribution and determinants of health-related states or events in specified

populations, and the application of this study to the control of health problems.

epilepsy a neurological disorder manifested by muscular seizures.

epimysium the outer layer of connective tissue surrounding muscle.

epinephrine a hormone synthesized by the adrenal medulla; also called *adrenaline*.

epiphyseal plate (growth plate) cartilaginous layer between the head and shaft of a long bone where growth takes place.

EPOC an acronym for "excess post-exercise oxygen consumption"; often referred to as the *oxygen debt*.

EPSP excitatory post-synaptic potential. A graded depolarization of a post-synaptic membrane by a neurotransmitter.

ergogenic aid a substance, appliance, or procedure (e.g., blood doping) that improves performance.

ergometer instrument for measuring work.

ergometry measurement of work output.

erythrocythemia an increase in the number of erythrocytes in the blood.

erythropoietin hormone that stimulates red blood cell production.

Estimated Average Requirement (EAR) the average daily nutrient intake level estimated to meet the requirement of half the healthy individuals in a particular group. This value is needed to set the RDA values.

estrogens female sex hormones, including estradiol and estrone. Produced primarily in the ovary and also produced in the adrenal cortex.

evaporation the change of water from a liquid form to a vapor form. Results in the removal of heat.

exercise a subclass of physical activity.

exergonic reactions chemical reactions that release energy.

extensors muscles that extend a limb—that is, increase the angle at a joint.

FAD flavin adenine dinucleotide. Serves as an electron carrier in bioenergetics.

fasciculi a small bundle of muscle fibers.

fast-twitch fibers one of several types of muscle fibers found in skeletal muscle; also called Type II fibers; characterized as having low oxidative capacity but high glycolytic capacity.

female athlete triad a syndrome in which amenorrhea, eating disorders, and bone mineral loss are collectively present.

ferritin the iron-carrying molecule used as an index of whole-body iron status.

field test a test of physical performance performed in the field (outside the laboratory).

flexors muscle groups that cause flexion of limbs—that is, decrease the angle at a joint.

follicle-stimulating hormone (FSH) a hormone secreted by the anterior pituitary gland that stimulates the development of an ovarian follicle in the female and the production of sperm in the male.

food records the practice of keeping dietary food records for determining nutrient intake.

free fatty acid (FFA) a type of fat that combines with glycerol to form triglycerides. Is used as an energy source.

free radicals highly reactive molecules that contain an unpaired electron in their outer orbital.

G protein the link between the hormone-receptor interaction on the surface of the membrane and the subsequent events inside the cell.

gain refers to the amount of correction that a control system is capable of achieving.

General Adaptation Syndrome (GAS) a term defined by Selye in 1936 that describes the organism's response to chronic stress. In response to stress the organism has a three-stage response: (1) alarm reaction; (2) stage of resistance; and (3) readjustment to the stress, or exhaustion.

glucagon a hormone produced by the pancreas that increases blood glucose and free fatty acid levels.

glucocorticoids any one of a group of hormones produced by the adrenal cortex that influences carbohydrate, fat, and protein metabolism.

gluconeogenesis the synthesis of glucose from amino acids, lactate, glycerol, and other short carbon-chain molecules.

glucose a simple sugar that is transported via the blood and metabolized by tissues.

glucose polymer a complex sugar molecule that contains multiple simple sugar molecules linked together.

glycogen a glucose polymer synthesized in cells as a means of storing carbohydrate.

glycogenolysis the breakdown of glycogen into glucose.

glycolysis a metabolic pathway in the cytoplasm of the cell that results in the degradation of glucose into pyruvate or lactate.

Golgi tendon organ (GTOs) a tension receptor located in series with skeletal muscle.

graded exercise test *see* incremental exercise test.

gross efficiency a simple measure of exercise efficiency defined as the ratio of work performed to energy expended, expressed as a percent.

growth hormone hormone synthesized and secreted by the anterior pituitary that stimulates growth of the skeleton and soft tissues during the growing years. It is also involved in the mobilization of the body's energy stores.

HDL cholesterol (high-density lipoprotein cholesterol) cholesterol that is transported in the blood via high-density proteins; related to low risk of heart disease.

heat cramps painful muscle cramps in the abdomen, legs, or arms following strenuous activity in the heat; use direct pressure on cramps, stretch muscles, and gentle ice massage

heat exhaustion symptoms include heavy sweating, rapid pulse, dizziness, and nausea; it is linked to dehydration and can develop into heatstroke. Move to cool or shaded area, place in supine position with legs raised, and provide fluids and cooling.

heat shock proteins an important family of stress proteins that are produced in cells in response to cellular stresses. Following synthesis, heatshock protein can protect cells against disturbances in homeostasis.

heatstroke (also called exertional heatstroke) a life-threatening heat illness in which body temperature is extremely elevated (104 °F or 40 °C); possibility of central nervous system disturbances and organ failure. Rapid whole-body cooling measures should be initiated immediately; treat as medical emergency.

heat syncope sudden dizziness or fainting during or after exercising in the heat related to a drop in blood pressure; may be accompanied by feelings of excessive thirst, fatigue, headache, nausea, and vomiting. Move to cool area and provide fluids.

hemoglobin a heme-containing protein in red blood cells that is responsible for transporting oxygen to tissues. Hemoglobin also serves as a weak buffer within red blood cells.

high-density lipoproteins (HDL) proteins used to transport cholesterol in blood; high levels appear to offer some protection from atherosclerosis.

homeostasis the maintenance of a constant internal environment.

homeotherms animals that maintain a fairly constant internal temperature.

homologous transfusion a blood transfusion using blood of the same type but from another donor.

hormone a chemical substance that is synthesized and released by an endocrine gland and transported to a target organ via the blood.

hydrogen ion (H^+) a free hydrogen ion in solution that results in a decrease in pH of the solution.

hyperbaric chamber chamber where the absolute pressure is increased above atmospheric pressure.

hyperoxia oxygen concentration in an inspired gas that exceeds 21%.

hyperplasia an increase in the number of cells in a tissue.

hyperthermia elevated body temperature due to heat loss not keeping up with heat load from exercise and the environment; linked to heat illnesses.

hypertrophy an increase in cell size.

hypothalamic somatostatin hypothalamic hormone that inhibits growth hormone secretion.

hypothalamus brain structure that integrates many physiological functions to maintain homeostasis; site of secretion of hormones released by the posterior pituitary; also releases hormones that control anterior pituitary secretions.

hypothermia decreased body temperature due to heat loss being greater than heat production; defined clinically as body temperature below 35°C.

hypoxia a relative lack of oxygen (e.g., at altitude).

IGF-1/Akt/mTOR signaling pathway a pathway that plays an important role in the regulation of muscle growth (i.e., protein synthesis) resulting from resistance training. Contractile activity (i.e., muscle stretch) stimulates the secretion of IGF-1 from the active muscle fibers, which acts as an autocrine/paracrine signaling molecule, binding to its membrane receptor and initiating a cascade of molecular events to promote muscle protein synthesis. Binding of IGF-1 to its receptor on the muscle membrane activates the important signaling kinase, Akt. Active Akt then activates another downstream kinase called *mammalian target of rapamycin* (mTOR), which then promotes protein synthesis by improving translational efficiency.

immunity refers to all the mechanisms used in the body to protect against environmental agents that are foreign to the body. Immunity is achieved by a precise coordination of the innate and acquired immune system.

immunotherapy procedure in which the body is exposed to specific substances to elicit an immune response in order to offer better protection upon subsequent exposure.

incremental exercise test an exercise test involving a progressive increase in work rate over time. Often graded exercise tests are used to determine the subject's $\dot{V}O_2$ max or lactate threshold. (Also called *graded exercise test*.)

indirect calorimetry estimation of heat or energy production on the basis of oxygen consumption, carbon dioxide production, and nitrogen excretion.

induced erythrocythemia causing an elevation of the red blood cell (hemoglobin) concentration by infusing blood; also called *blood doping* or *blood boosting*.

infectious diseases diseases due to the presence of pathogenic microorganisms in the body (e.g., viruses, bacteria, fungi, and protozoa).

inflammation part of the complex biological response to harmful stimuli such as bacteria entering the body through a wound in the skin, damaged cells, or other irritants. Clinical signs of local inflammation are redness, swelling, heat, and pain around the injured tissue.

inorganic relating to substances that do not contain carbon (C).

inorganic phosphate (P_i) a stimulator of cellular metabolism; split off, along with ADP, from ATP when energy is released; used with ADP to form ATP in the electron transport chain.

inositol triphosphate a molecule derived from a membrane-bound phospholipid, phosphatidylinositol, that causes calcium release from intracellular stores and alters cellular activity.

insulin hormone released from the beta cells of the islets of Langerhans in response to elevated blood glucose and amino acid concentrations; increases tissue uptake of both.

insulin-like growth factors groups of growth-stimulating peptides released from the liver and other tissues in response to growth hormone.

insulin shock condition brought on by too much insulin, which causes an immediate hypoglycemia; symptoms include tremors, dizziness, and possibly convulsions.

integrating center the portion of a biological control system that processes the information from the receptors and issues an appropriate response relative to its set point.

intercalated discs portion of cardiac muscle cell where one cell connects to the next.

intermediate fibers muscle fiber type that generates high force at a moderately fast speed of contraction, but has a relatively large number of mitochondria (Type IIa).

intracrine signaling a hormone that acts inside a cell. Steroid hormones act through intracellular (mostly nuclear) receptors and, thus, are considered to be intracrines. In contrast, peptide or protein hormones, in general, act as endocrines, autocrines, or paracrines by binding to their receptors present on the cell surface.

ion a single atom or small molecule containing a net positive or negative charge due to an excess of either protons or electrons, respectively (e.g., Na^+, Cl^-).

IPSP inhibitory post-synaptic potential that moves the post-synaptic membrane farther from threshold.

irritability a trait of certain tissues that enables them to respond to stimuli (e.g., nerve and muscle).

isocitrate dehydrogenase rate-limiting enzyme in the Krebs cycle that is inhibited by ATP and stimulated by ADP and P_i.

isokinetic action in which the rate of movement is constantly maintained through a specific range of motion even though maximal force is exerted.

isometric action in which the muscle develops tension, but does not shorten; also called a *static contraction*. No movement occurs.

isotonic contraction in which a muscle shortens against a constant load or tension, resulting in movement.

juxtracrine signaling a type of cell signaling that occurs between two adjacent cells that are in direct contact via a junction across the cell membrane that connects the cytoplasm of the two cells.

ketosis acidosis of the blood caused by the production of ketone bodies (e.g., acetoacetic acid) when fatty acid mobilization is increased, as in uncontrolled diabetes.

kilocalorie (kcal) a measure of energy expenditure equal to the heat needed to raise the temperature of 1 kg of water 1 degree Celsius; also

equal to 1,000 calories and sometimes written as calorie rather than kilocalorie.

kilogram-meter a unit of work in which 1 kg of force (1 kg mass accelerated at 1 G) is moved through a vertical distance of 1 meter; abbreviated as kg-m, kg · m, or kgm.

kinesthesia a perception of movement obtained from information about the position and rate of movement of the joints.

Krebs cycle metabolic pathway in the mitochondria in which energy is transferred from carbohydrates, fats, and amino acids to NAD for subsequent production of ATP in the electron transport chain.

lactate a 3-carbon molecule that is a potential end-product of glucose metabolism.

lactate threshold a point during a graded exercise test when the blood lactate concentration increases abruptly.

lateral sac *see* terminal cisternae.

LDL cholesterol form of low-density lipoprotein responsible for the transport of plasma cholesterol; high levels are indicative of a high risk of coronary heart disease.

lipase an enzyme responsible for the breakdown of triglycerides to free fatty acids and glycerol.

lipolysis the breakdown of triglycerides in adipose tissue to free fatty acids and glycerol for subsequent transport to tissues for metabolism.

lipoprotein protein involved in the transport of cholesterol and triglycerides in the plasma.

low-density lipoproteins (LDL) form of lipoprotein that transports a majority of the plasma cholesterol; *see* LDL cholesterol.

low-grade chronic inflammation characterized by a two- to three-fold increase in inflammatory cytokines (e.g., tumor necrosis factor alpha [TNF-α) and Interleukin-6 [IL-6]) and C-reactive protein (CRP).

luteinizing hormone (LH) also called "interstitial cell stimulating hormone"; a surge of LH stimulates ovulation in middle of menstrual cycle; LH stimulates testosterone production in men.

macrophages phagocytes that engulf and kill invading bacteria. Macrophages are considered to be a portion of the innate immune system.

major minerals dietary minerals including calcium, phosphorus, potassium, sulfur, sodium, chloride, and magnesium.

mast cell connective tissue cell that releases histamine and other chemicals in response to certain stimuli (e.g., injury).

maximal oxygen uptake ($\dot{V}O_2$ max) greatest rate of oxygen uptake by the body measured during severe dynamic exercise, usually on a cycle ergometer or a treadmill; dependent on maximal cardiac output and the maximal arteriovenous oxygen difference.

mesomorphy one component of a somatotype that characterizes the muscular form or lean body mass aspect of the human body.

MET an expression of the rate of energy expenditure at rest; equal to 3.5 ml · kg^{-1} · min^{-1}, or 1 kcal · kg^{-1} · hr^{-1}.

metabolism the total of all cellular reactions that occur in cells and includes chemical pathways that result in the synthesis of molecules (anabolic reactions) as well as the breakdown of molecules (catabolic reactions).

mineralocorticoids steroid hormones released from the adrenal cortex that are responsible for Na^+ and K^+ regulation (e.g., aldosterone).

mitochondrion the subcellular organelle responsible for the production of ATP with oxygen; contains the enzymes for the Krebs cycle, electron transport chain, and the fatty acid cycle.

mixed venous blood a mixture of venous blood from both the upper and lower extremities; complete mixing occurs in the right ventricle.

molecular biology branch of biochemistry involved with the study of gene structure and function.

motor cortex portion of the cerebral cortex containing large motor neurons whose axons descend to lower brain centers and spinal cord; associated with the voluntary control of movement.

motor neuron the somatic neuron that innervates skeletal muscle fibers (also called an *alpha motor neuron*).

motor unit a motor neuron and all the muscle fibers innervated by that single motor neuron; responds in an "all-or-none" manner to a stimulus.

muscle action term used to describe the muscle movement (e.g., shortening versus lengthening).

muscle spindle a muscle stretch receptor oriented parallel to skeletal muscle fibers; the capsule portion is surrounded by afferent fibers, and intrafusal muscle fibers can alter the length of the capsule during muscle contraction and relaxation.

muscular strength the maximal amount of force that can be generated by a muscle or muscle group.

myocardial infarction death of a portion of heart tissue that no longer conducts electrical activity nor provides force to move blood.

myocardial ischemia a condition in which the myocardium experiences an inadequate blood flow; sometimes accompanied by irregularities in the electrocardiogram (arrhythmias and ST-segment depression) and chest pain (angina pectoris).

myocardium cardiac muscle; provides the force of contraction to eject blood; muscle type with many mitochondria that is dependent on a constant supply of oxygen.

myofibrils the portion of the muscle containing the thick and thin contractile filaments; a series of sarcomeres where the repeating pattern of the contractile proteins gives the striated appearance to skeletal muscle.

myoglobin protein in muscle that can bind oxygen and release it at low PO_2 values; aids in diffusion of oxygen from capillary to mitochondria.

myosin contractile protein in the thick filament of a myofibril that contains the cross-bridge that can bind actin and split ATP to cause tension development.

NAD coenzyme that transfers hydrogen and the energy associated with those hydrogens; in the Krebs cycle, NAD transfers energy from substrates to the electron transport chain.

natural killer cells an important part of the innate immune system because they are versatile "killers" of foreign agents, including bacteria, viruses, cancer cells, and other unwanted invaders of the body.

negative feedback describes the response from a control system that reduces the size of the stimulus, e.g., an elevated blood glucose concentration causes the secretion of insulin which, in turn, lowers the blood glucose concentration.

net efficiency the mathematical ratio of work output divided by the energy expended above rest.

neuroendocrinology study of the role of the nervous and endocrine systems in the automatic regulation of the internal environment.

neuromuscular junction synapse between axon terminal of a motor neuron and the motor end plate of a muscle's plasma membrane.

neuron nerve cell; composed of a cell body with dendrites (projections) that bring information to the cell body, and axons that take information away from the cell body to influence neurons, glands, or muscles.

neutrophils short-lived leukocytes that participate in phagocytosis of bacteria.

NFκB nuclear factor kappa B is a transcriptional activator that promotes the expression of several antioxidant enzymes that protect muscle fibers against free-radical mediated injury.

nitroglycerin drug used to reduce chest pain (angina pectoris) due to lack of blood flow to the myocardium.

norepinephrine a hormone and neurotransmitter; released from postganglionic nerve endings and the adrenal medulla.

normocythemia a normal red blood cell concentration.

normoxia a normal PO_2.

nucleus membrane-bound organelle containing most of the cell's DNA.

nutrient density the degree to which foods contain selected nutrients, e.g., protein, relative to the number of kilocalories.

open-circuit spirometry indirect calorimetry procedure in which either inspired or expired ventilation is measured and oxygen consumption and carbon dioxide production are calculated.

organic describes substances that contain carbon.

osteoporosis a decrease in bone density due to a loss of cortical bone; common in older women and implicated in fractures; estrogen, exercise, and Ca^{++} therapy are used to correct the condition.

overload a principle of training describing the need to increase the load (intensity) of exercise to cause a further adaptation of a system.

overtraining an accumulation of training stress that impairs an athlete's ability to perform training sessions and results in long-term decrements of performance.

oxidative phosphorylation mitochondrial process in which inorganic phosphate (P_i) is coupled to ADP as energy is transferred along the electron transport chain in which oxygen is the final electron acceptor.

oxygen debt the elevated post-exercise oxygen consumption (*see* EPOC); related to replacement of creatine phosphate, lactate resynthesis to glucose, and elevated body temperature, catecholamines, heart rate, breathing, etc.

oxygen deficit refers to the lag in oxygen uptake at the beginning of exercise.

oxyhemoglobin hemoglobin combined with oxygen; 1.34 ml of oxygen can combine with 1 g Hb.

p38 mitogen activated kinase p38 (p38) is an important signaling molecule that is activated in muscle fibers during endurance exercise. Once activated, p38 can contribute to mitochondrial biogenesis by activating PGC-1α.

pancreas gland containing both exocrine and endocrine portions; exocrine secretions include enzymes and bicarbonate to digest food in the small intestine; endocrine secretions include insulin, glucagon, and somatostatin, which are released into the blood.

paracrine signaling occurs when signals produced by cells act locally on nearby cells to bring about cellular responses.

parasympathetic nervous system portion of the autonomic nervous system that primarily releases acetylcholine from its postganglionic nerve endings.

partial pressure the fractional part of the barometric pressure due to the presence of a single gas, e.g., PO_2, PCO_2, and PN_2.

percent grade a measure of the elevation of the treadmill; calculated as the sine of the angle.

percutaneous transluminal coronary angioplasty (PTCA) a balloon-tipped catheter is inserted into a blocked coronary artery and plaque is pushed back to artery wall to open the blood vessel.

perimysium the connective tissue surrounding the fasciculus of skeletal muscle fibers.

peripheral fatigue factors located after the neuromuscular junctions that impair the force generating capacity of muscle (also called *muscular fatigue*).

peripheral nervous system (PNS) portion of the nervous system located outside the spinal cord and brain.

PGC-1α (peroxisome proliferator-activated receptor-gamma coactivator 1α (PGC-1α) an important signaling molecule activated by endurance exercise and is considered the master regulator of mitochondrial biogenesis in cells.

pH a measure of the acidity of a solution; calculated as the negative $\log_{10}$ of the $|H^+|$ in which 7 is neutral; values that are >7 are basic and <7 are acidic.

phagocytes cells that eat (engulf) foreign agents, such as bacteria.

phosphocreatine a compound found in skeletal muscle and used to resynthesize ATP from ADP.

phosphodiesterase an enzyme that catalyzes the breakdown of cyclic AMP, moderating the effect of the hormonal stimulation of adenylate cyclase.

phosphofructokinase rate-limiting enzyme in glycolysis that is responsive to ADP, P_i, and ATP levels in the cytoplasm of the cell.

phospholipase C membrane-bound enzyme that hydrolyzes phosphatidylinositol into inositol triphosphate and diacylglycerol that, in turn, bring about changes in intracellular activity.

physical activity characterizes all types of human movement; associated with living, work, play, and exercise.

physical fitness a broad term describing healthful levels of cardiovascular function, strength, and flexibility; fitness is specific to the activities performed.

pituitary gland a gland at the base of the hypothalamus of the brain having an anterior portion that produces and secretes numerous hormones that regulate other endocrine glands and a posterior portion that secretes hormones that are produced in the hypothalamus.

placebo an inert substance that is used in experimental studies, e.g., drug studies, to control for any subjective reaction to the substance being tested.

pleura a thin lining of cells that is attached to the inside of the chest wall and to the lung; the cells secrete a fluid that facilitates the movements of the lungs in the thoracic cavity.

posterior hypothalamus area of the brain responsible for regulation of the body's response to a decrease in temperature.

posterior pituitary gland portion of the pituitary gland secreting oxytocin and antidiuretic hormone (vasopressin) that are produced in the hypothalamus.

power a rate of work; work per unit time; P = W/t.

power test a test measuring the quantity of work accomplished in a time period; anaerobic power tests include the Margaria stair climb test and the Wingate test; aerobic power tests include the 1.5-mile run and cycle ergometer and treadmill tests in which power output and oxygen consumption are measured.

primary risk factor a sign (e.g., high blood pressure) or a behavior (e.g., cigarette smoking) that is directly related to the appearance of certain diseases independent of other risk factors.

progressive resistance exercise (PRE) a training program in which the muscles must work against a gradually increasing resistance; an implementation of the overload principle.

prolactin hormone secreted from the anterior pituitary that increases milk production from the breast.

proprioceptive neuromuscular facilitation technique of preceding a static stretch with an isometric contraction.

proprioceptors receptors that provide information about the position and movement of the body; includes muscle and joint receptors as well as the receptors in the semicircular canals of the inner ear.

protein kinase C part of second messenger system that is activated by diacylglycerol and results in the activation of proteins in the cell.

provitamin a precursor of a vitamin.

pulmonary circuit the portion of the cardiovascular system involved in the circulation of blood from the right ventricle to the lungs and back to the left atrium.

pulmonary respiration term that refers to ventilation (breathing) of the lung.

Quebec 10-second test a maximal effort 10-second cycle test designed to assess ultra short-term anaerobic power during cycling.

radiation process of energy exchange from the surface of one object to the surface of another that is dependent on a temperature gradient but does not require contact between the objects; an example is the transfer of heat from the sun to the earth.

receptor in the nervous system, a receptor is a specialized portion of an afferent neuron (or a special cell attached to an afferent neuron) that is sensitive to a form of energy in the environment; *receptor* is also a term that applies to unique proteins on the surface of cells that can bind specific hormones or neurotransmitters.

reciprocal inhibition when extensor muscles (agonists) are contracted, there is a reflex inhibition of the motor neurons to the flexor muscles (antagonists), and vice versa.

Recommended Dietary Allowances (RDA) standards of nutrition associated with good health for the majority of people. Standards exist for protein, vitamins, and minerals for children and adults.

relative $\dot{V}O_2$ oxygen uptake (consumption) expressed per unit body weight (e.g., $ml \cdot kg^{-1} \cdot min^{-1}$).

releasing hormone hypothalamic hormones released from neurons into the anterior pituitary that control the release of hormones from that gland.

renin enzyme secreted by special cells in the kidney that converts angiotensinogen to angiotensin I.

repetition the number of times an exercise is repeated within a single exercise "set."

residual volume (RV) volume of air in the lungs following a maximal expiration.

respiration external respiration is the exchange of oxygen and carbon dioxide between the lungs and the environment; internal respiration describes the use of oxygen by the cell (mitochondria).

respiratory compensation the buffering of excess H^+ in the blood by plasma bicarbonate (HCO_3^-), and the associated elevation in ventilation to exhale the resulting CO_2.

respiratory exchange ratio (R) the ratio of CO_2 production to O_2 consumption; indicative of substrate utilization during steady-state exercise in which a value of 1.0 represents 100% carbohydrate metabolism and 0.7 represents 100% fat metabolism.

resting membrane potential the voltage difference measured across a membrane that is related to the concentration of ions on each side of the membrane and the permeability of the membrane to those ions.

resting metabolic rate (RMR) metabolic rate measured in the supine position following a period of fasting (4–12 hours) and rest (4–8 hours).

rest interval the time period between bouts in an interval training program.

reversibility a principle of training that describes the temporary nature of a training effect; adaptations to training are lost when the training stops.

sarcolemma the cell (plasma) membrane surrounding a muscle fiber.

sarcomeres the repeating contractile unit in a myofibril bounded by Z-lines.

sarcopenia the loss of muscle mass associated with aging. Sarcopenia occurs primarily due to muscle atrophy but can also occur due to a loss of muscle fibers.

sarcoplasmic reticulum a membranous structure that surrounds the myofibrils of muscle cells; location of the terminal cisternae or lateral sacs that store the Ca^{++} needed for muscle contraction.

satellite cells undifferentiated cell found adjacent to skeletal muscle fibers. These cells can fuse with existing muscle fibers and contribute to muscle growth (hypertrophy). It may also be possible that these fibers can differentiate and form a new muscle fiber following muscle injury.

Schwann cell the cell that surrounds peripheral nerve fibers, forming the myelin sheath.

second messenger a molecule (cyclic AMP) or ion (Ca^{++}) that increases in a cell as a result of an interaction between a "first messenger" (e.g., hormone or neurotransmitter) and a receptor that alters cellular activity.

secondary risk factor a characteristic (age, gender, race) or behavior that increases the risk of coronary heart disease when primary risk factors are present.

set a basic unit of a workout containing the number of times (repetitions) a specific exercise is done (e.g., do three sets of five repetitions with 100 pounds).

sex steroids a group of hormones, androgens and estrogens, secreted from the adrenal cortex and the gonads.

sham reinfusion an experimental treatment at the end of a blood doping experiment in which a needle is placed in a vein, but the subject does not receive a reinfusion of blood.

sham withdrawal an experimental treatment at the beginning of a blood doping experiment in which a needle is placed in a vein, but blood is not withdrawn.

sinoatrial node (SA node) specialized tissue located in the right atrium of the heart that generates the electrical impulse to initiate the heartbeat. In a normal, healthy heart, the SA node is the heart's pacemaker.

SI units system used to provide international standardization of units of measure in science.

size principle the progressive recruitment of motor units beginning with the smallest motor neurons and progressing to larger and larger motor neurons.

sliding filament model a theory of muscle contraction describing the sliding of the thin filaments (actin) past the thick filaments (myosin).

slow-twitch fibers muscle fiber type that contracts slowly and develops relatively low tension but displays great endurance to repeated stimulation; contains many mitochondria, capillaries, and myoglobin.

somatostatin hormone produced in the hypothalamus that inhibits growth hormone release from the