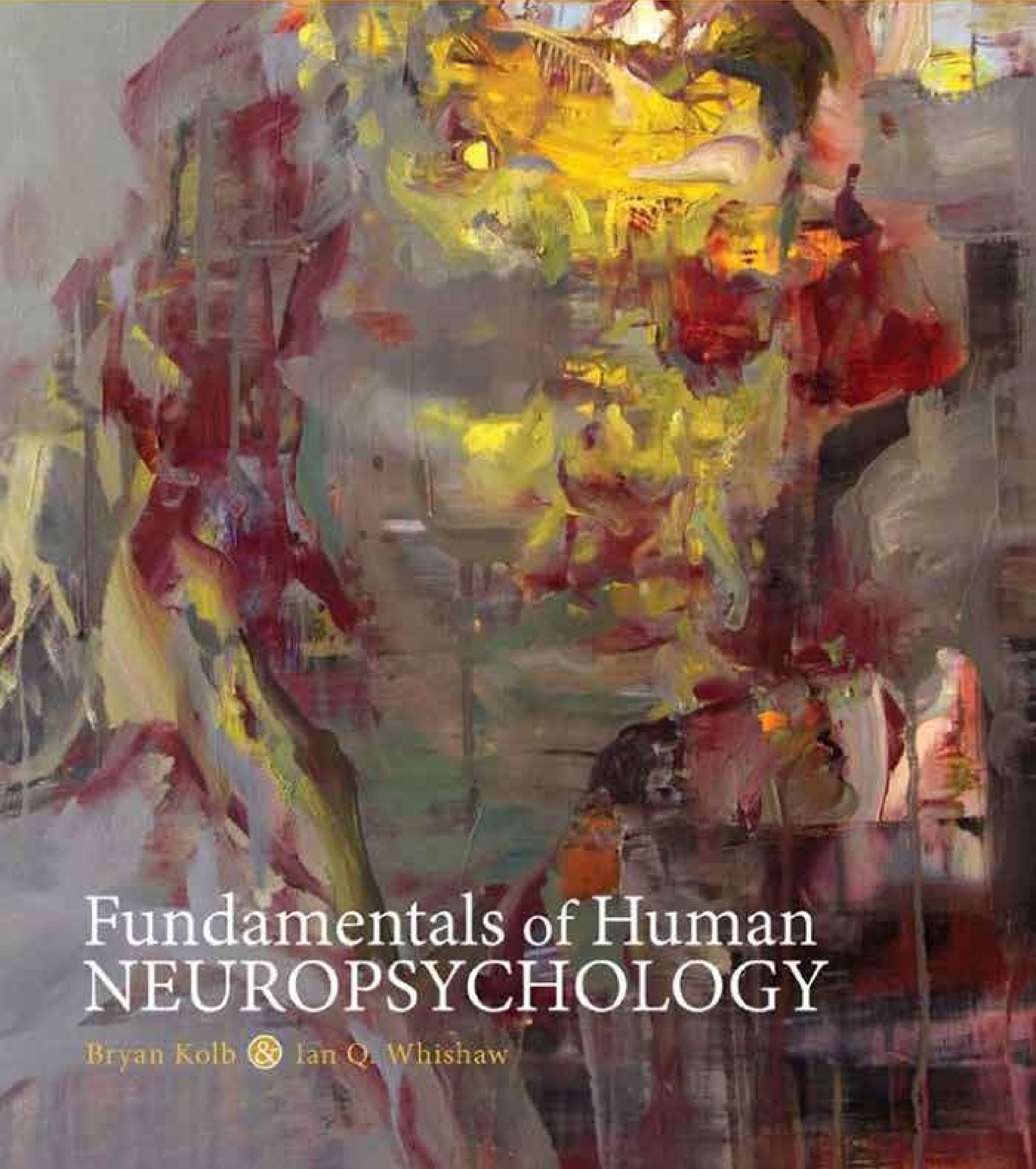
Seventh Edition



Fundamentals of Human NEUROPSYCHOLOGY

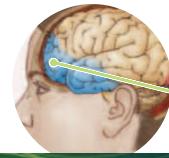
Bryan Kolb & Ian Q. Whishaw

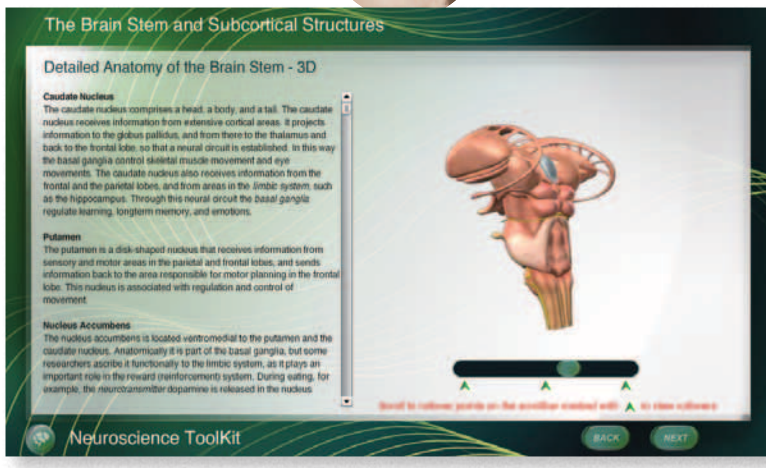
Page intentionally left blank

Witness Neuroscience Firsthand

Macmillan Education LaunchPadSolo NEUROSCIENCE

Available at www.macmillanhighered.com/launchpadsolo/neurotk





The Macmillan Education LaunchPadSolo for Neuroscience is a powerful web-based tool for learning the core concepts of behavioral neuroscience—by witnessing them firsthand. These thirty interactive tutorials allow students to see the nervous system in action via dynamic illustrations, animations, and models that demystify the neural mechanisms behind behavior. Each activity is accompanied by a set of carefully crafted multiple choice questions for assessment that is easy to assign and instantly graded. Based on Worth Publishers' groundbreaking *Foundations of Behavioral Neuroscience CD-ROM*, the Macmillan Education LaunchPadSolo for Neuroscience is a valuable accompaniment to any course.

TOPICS AND ACTIVITIES

Neural Communication

- Structure of a Neuron
- The Membrane Potential
- Conduction of the Action Potential
- Synaptic Transmission
- Neural Integration

Central Nervous System

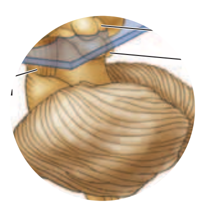
- Subdivisions of the Central Nervous System
- Subcortical Structures
- Sensory Systems–Vision
- Sensory Systems–Audition
- Sensory Systems–Somatosenses
- Sensory Systems–Olfaction
- Motor System
- Limbic System
- Language
- The Cortex
- Brain Stem
- The Spinal Cord

Visual System

- The Eye
- Retina
- Optic Chiasm
- Lateral Geniculate Nucleus
- Superior Colliculus
- Primary Visual Cortex
- Higher Order Visual Areas

Control of Movement

- Organization of the Motor Systems
- Muscle and Receptor Anatomy
- Muscle Contraction
- Spinal Reflexes
- Descending Motor Tracts
- Primary Motor Cortex
- Higher Order Motor Cortex
- Basal Ganglia
- Cerebellum



Page intentionally left blank

Fundamentals of HUMAN NEUROPSYCHOLOGY

SEVENTH EDITION

BRYAN KOLB & IAN Q. WHISHAW
University of Lethbridge

WORTH PUBLISHERS
A Macmillan Education Imprint
New York

Publisher: Rachel Losh
Senior Acquisitions Editor: Daniel DeBonis
Development Editor: Barbara Brooks
Assistant Editor: Nadina Persaud
Editorial Assistant: Katie Pachnos
Executive Marketing Manager: Katherine Nurre
Executive Media Editor: Rachel Comerford
Director of Editing, Design, and Media Production for the Sciences and Social Sciences: Tracey Kuehn
Managing Editor: Lisa Kinne
Project Editors: Enrico Bruno, Andrew Roney, and Janice Stangel
Production Manager: Sarah Segal
Associate Media Editor: Anthony Casciano
Photo Editor: Cecilia Varas
Photo Researcher: Richard Fox
Art Director: Diana Blume
Interior Designer: Tamara Newnam
Cover Designer: Kevin Kall
Art Manager: Matthew McAdams
Illustrations: Dragonfly Media
Composition: Northeastern Graphic, Inc.
Printing and Binding: RR Donnelley
Cover Art: *Orla* by Cian McLoughlin

Library of Congress Preassigned Control Number: 2014946473

ISBN-10: 1-4292-8295-9
ISBN-13: 978-1-4292-8295-6

Printed in the United States of America

Worth Publishers
41 Madison Avenue
New York, NY 10010
www.worthpublishers.com

To all the students whose interest in how the brain produces
the mind and controls behavior makes this book possible.

ABOUT THE AUTHORS


DEBORAH MUIRHEAD

Bryan Kolb received his Ph.D. from The Pennsylvania State University and conducted postdoctoral work at the University of Western Ontario and the Montreal Neurological Institute. In 1976 he moved to the University of Lethbridge, Alberta, where he is a professor of neuroscience and holds a Board of Governors Chair in Neuroscience. His current research examines how perinatal factors—including tactile stimulation, psychoactive drugs, stress, and injury—modify the developing cerebral cortex and how these changes are related to behavior. Kolb is a fellow of the Royal Society of Canada, the Canadian Psychological Association (CPA), the American Psychological Association, and the Association of Psychological Science. Currently a senior fellow of the Child Brain Development program of the Canadian Institute for Advanced Research, he is a recipient of the Hebb Prize from the CPA and from the Canadian Society for Brain, Behaviour, and Cognitive Science (CSBBCS). He has received honorary doctorates from the University of British Columbia, Thompson Rivers University, and Concordia University. He is a recipient the Ingrid Speaker Gold Medal for research, the distinguished teaching medal from the University of Lethbridge, and the Key to the City of Lethbridge. He and his wife train and show horses in Western riding performance events.


DAVID BENARD

Ian Q. Whishaw received his Ph.D. from Western University and is a professor of neuroscience at the University of Lethbridge. He has held visiting appointments at the University of Texas, the University of Michigan, the University of Cambridge, and the University of Strasbourg. He is a fellow of Clair Hall, Cambridge, the Canadian Psychological Association, the American Psychological Association, and the Royal Society of Canada. He is a recipient the Canadian Humane Society Bronze Medal for bravery, the Ingrid Speaker Gold Medal for research, the distinguished teaching medal from the University of Lethbridge, and the Donald O. Hebb Prize. He has received the Key to the City of Lethbridge and has honorary doctorates from Thompson Rivers University and the University of Lethbridge. His research addresses the neural basis of skilled movement and the neural basis of brain disease. The Institute for Scientific Information includes him in its list of most-cited neuroscientists. His hobby is training and showing horses for Western performance events.

BRIEF CONTENTS

CONTENTS

Coverage links neuropsychological theory and assessment

PREFACE

Looking back to 1980, when *Fundamentals of Human Neuropsychology*'s first edition appeared, reminds us that in the 1970s, human neuropsychology did not yet exist as a unified body of knowledge about the human brain. The field had coalesced around hunches and inferences based on laboratory studies of monkeys, cats, and rats as well as on scattered studies of humans with assorted brain injuries. Over the past 40 years, as neuropsychology expanded, cognitive and social neuroscience have emerged as disciplines. Advances in and ever-more incisive use of noninvasive neuroimaging and abundant research innovations all have improved our understanding of brain anatomy.

Studies of nonhuman species remain central to human neuropsychology's core principles, especially in understanding the structure and connectivity of the primate brain, but are more focused on mechanisms than behavioral phenomena. Many researchers may share a bias that functional neuroimaging can replace studying brain-injured humans and laboratory animals. To others, this seems unlikely given the complexity of brain processes and the nature of subtraction methods used in imaging. The two approaches have become complementary, and this seventh edition reflects their intellectual evolution:

- *Neuroimaging has led the renaissance in understanding neural networks and appreciating the brain's connectome.* In this edition, we have expanded Chapter 7, Imaging the Brain's Activity, both to include new methods and to consider the pros and cons of different techniques in light of their relevant uses and costs (see Section 7.5). Coverage of dynamic neural networks appears throughout the book, especially in Chapters 10, 16 to 22, and 27.
- *Epigenetics explains how our behaviors change our brains.* We introduce basic genetics and epigenetic principles in Section 2.3 and highlight both factors throughout the book to reflect the expanding emphasis on epigenetics as a factor in cerebral organization.
- *Neuropsychological assessment is vital for evaluating patients with focal brain injuries.* One unexpected consequence of the cognitive neuroscience revolution is a declining appreciation for neuropsychological theory and clinical focus. In this new edition, we employ the venerable maze as a graphic icon (shown at right) to identify for the reader particular discussions, cases, tables, and figures that link theory and assessment throughout the book.

Content and Structure

Fundamentals differs from other textbooks of psychology, cognitive neuroscience, or neuroscience. In our experience, students find it helpful to see the brain from two organizational perspectives, anatomical and behavioral.

- We continue to provide the requisite basic background—about history, evolution, genetics and epigenetics, anatomy, physiology, pharmacology, and methodology—in Part I, Chapters 1 to 7.

- Equally fundamental to understanding subsequent material, Part II, Chapters 8 to 12, outlines the general organization and functions of the cerebral cortex.
- Part III, Chapters 13 to 17, focuses on the anatomically defined cortical regions. Understanding the organization of the cerebral cortex is central to appreciating how the brain functions to produce the complex processes that underlie complex behaviors.
- The psychological constructs presented in Part IV, Chapters 18 to 22, including language, memory, social behavior and affect, spatial behavior, and attention and consciousness, emerge from the neuronal networks explored in Part III. Shifting from anatomy to psychological processes naturally means revisiting material from earlier parts, but this time in the context of psychological theory rather than anatomy.
- Part V, Chapters 23 to 28, considers brain development and plasticity and includes more-detailed discussions of brain disorders introduced earlier in the book. Chapters on neurological and psychiatric disorders and on neuropsychological assessment continue the book's emphasis on approaching human brain functions from an interdisciplinary perspective.

We have updated all of the chapters and the glossary that follows, both to correspond to new material that reflects the changing face of neuropsychology and to include some unexpected topics—neuroeconomics in Section 22.4 and micronutrients in Section 27.9 are two. Maintaining a manageable length meant sacrificing some detail that may have been prominent in previous editions, sometimes reaching back to the first edition.

To address the challenge inherent in using a comprehensive text and to facilitate access to information, we added section numbers to each chapter's main headings. Readers can easily locate interrelated material relevant across several topics, refresh their knowledge, or jump ahead to learn more.

Acknowledgments

As in the past, we must sincerely thank many people who have contributed to the development of this edition. We are particularly indebted to colleagues from around the world who have been so supportive and have strongly encouraged us to include their favorite topics. We have done so wherever possible.

We also thank the reviewers solicited by our editors on the sixth edition of *Fundamentals*. Their anonymous comments contributed varied perspectives and valuable points of consensus that helped us shape the new edition.

Julie Alvarez
Tulane University

Marlene Behrmann
Carnegie Mellon University

Edward Castañeda
The University of Texas at El Paso

Pauline Dibbets
Maastricht University

Peter Donovick
The State University of New York at Binghamton

Amanda Higley
Point Loma Nazarene University

Jamie Lillie
Argosy University, Schaumburg

Salvatore Massa
Marist College

Taryn Myers
Virginia Wesleyan College

Martin Paczynski
George Mason University

Rosie Reid
Dublin Business School

Tony Robertson
Vancouver Island University

Joe Wayand
Walsh University

Robin Wellington
St. John's University

The staff at Worth Publishers and W. H. Freeman and Company are amazing and have made this task far more enjoyable than it would be without them. These folks include our sponsoring editor, Daniel DeBonis, assistant editor Nadina Persaud, and editorial assistant Katie Pachnos; our project editors, Enrico Bruno, Andrew Roney, and Janice Stangel; and our production manager, Sarah Segal. Our thanks to art director Diana Blume and interior designer Tamara Newnam for a fresh, inviting, accessible new book design, and to Kevin Kall for a striking cover.

Once again, Cecilia Varas coordinated photo research, ably assisted by researcher Richard Fox. They found photographs and other illustrative materials that we would not have found on our own. We remain indebted to art manager Matt McAdams and the artists at Dragonfly Media for their excellent work in expanding the illustration program and to Kate Scully and her team at Northeastern Graphic for their talents in translating the manuscript onto the page.

Our manuscript editor, Martha Solonche, has contributed to the book's clarity and consistency and proofreader Kate Daly to its accuracy. And as in the past, our gratitude to Barbara Brooks, our development editor, knows no bounds. She has provided a strong guiding hand to our thinking and organization and has done so with humor and a commitment to excellence that shows its stamp all over the book. Thank you, Barbara, for reminding us that the book is for students, not senior investigators, and thus requires us to write simply and clearly, and for keeping us abreast of topical news items that we might otherwise not encounter in our reading of the field's diverse literature.

Once again, errors remain solely attributable to us. In a field that has expanded so dramatically since our first edition, we hope that readers continue to acquire a breadth of knowledge in the ever-expanding world of human neuropsychology. Finally, we thank our students, who have motivated us to continue the journey of *Fundamentals of Human Neuropsychology* for nearly 40 years. Seeing the faces of students light up when they begin to understand how the marvelous brain can produce cognition and behavior continues to be rewarding and is what this endeavor is all about. Once again, we must thank our wives for putting up with us when we were distracted by deadlines and may not always have been our "usual" selves.

Bryan Kolb and Ian Q. Whishaw

Page intentionally left blank

MEDIA AND SUPPLEMENTS

Fundamentals of Human Neuropsychology, Seventh Edition, features a variety of supplemental materials for students and teachers of the text. For more information about any of the items below, please visit Macmillan's online catalog at http://www.macmillanhighered.com.

Macmillan Education LaunchPadSolo

Available at www.macmillanhighered.com/launchpadsolo/neurotk

LaunchPad Solo is a powerful Web-based tool for learning the core concepts of behavioral neuroscience—by witnessing them firsthand. These 30 interactive tutorials allow students to see the nervous system in action via dynamic illustrations, animations, and models that demystify the neural mechanisms behind behavior. These interactive simulations enhance students' understanding of complex biological mechanisms, and carefully crafted multiple-choice questions make it easy to assign and assess each activity. Based on Worth Publishers' groundbreaking *Foundations of Behavioral Neuroscience* CD-ROM, LaunchPad Solo is a valuable accompaniment to any biopsychology course.

Topics and Activities

Neural Communication
- Structure of a Neuron
- The Membrane Potential
- Conduction of the Action Potential
- Synaptic Transmission
- Neural Integration

Central Nervous System
- Subdivisions of the Central Nervous System
- Subcortical Structures
- Sensory Systems—Vision
- Sensory Systems—Audition
- Sensory Systems—Somatosenses
- Sensory Systems—Olfaction
- Motor System
- Limbic System
- Language
- The Cortex
- Brain Stem and Subcortical Structures
- The Spinal Cord

Visual System
- The Eye
- Retina
- Optic Chiasm
- Lateral Geniculate Nucleus
- Superior Colliculus
- Primary Visual Cortex
- Higher Order Visual Areas

Control of Movement
- Organization of the Motor Systems
- Muscle and Receptor Anatomy
- Muscle Contraction
- Spinal Reflexes
- Descending Motor Tracts
- Primary Motor Cortex
- Higher Order Motor Cortex
- Basal Ganglia
- Cerebellum

Fundamentals of Human Neuropsychology, Seventh Edition, can be ordered with LaunchPad Solo at no additional cost by using the following ISBNs.

Hardcover Text & LaunchPad Solo Access Card

ISBN-10: 1-3190-1715-0 / ISBN-13: 978-1-3190-1715-6

CourseSmart e-Book A complete electronic version of *Fundamentals of Human Neuropsychology*, Seventh Edition, can be previewed and purchased at **www.coursesmart.com**. Students can choose to view the CourseSmart e-Book online or download it to a personal computer or a portable media player such as a smartphone or iPad. This flexible, easy-to-use format makes the text more portable than ever before!

Psychology and the Real World: Essays Illustrating Fundamental Contributions to Society, Second Edition, is a superb collection of essays by major researchers that describes their landmark studies. Published in association with the not-for-profit FABBS Foundation, this engaging reader includes Bruce McEwen's work on the neurobiology of stress and adaptation, Elizabeth Loftus's own reflections on her study of false memories, and Jeremy Wolfe on his study of visual search. The new edition also features the new essay, "Can the Mind Be Read in the Brain Waves?" by Emanual Donchin, among many others. A portion of all proceeds is donated to FABBS to support societies of cognitive, psychological, behavioral, and brain sciences.

Revised! Test Bank Prepared by Tony Robertson of Vancouver Island University and Robin Wellington of St. John's University, the revised test bank includes over 50 questions per chapter including multiple-choice and short-answer questions. Each item is keyed to the page in the textbook on which the answer can be found. All of the questions have been thoroughly reviewed and edited for accuracy and clarity.

PowerPoint Slide Sets For download on the book's catalog page (http://www.macmillanhighered.com/Catalog/product/fundamentalsofhumanneuropsychology-seventhedition-kolb/instructorresources) we offer two sets of PowerPoint © presentations. For each chapter, there is a set that includes chapter art and illustrations and a final lecture presentation set that merges detailed chapter outlines with text illustrations and artwork from the book. Each set can be used directly or customized to fit your needs.

Course Management Aids The various resources for this textbook are available in the appropriate format for users of Blackboard, WebCT, Angel, Desire2Learn, and other systems. For more information, please visit our Web site at **www.macmillanhighered.com/lms.**

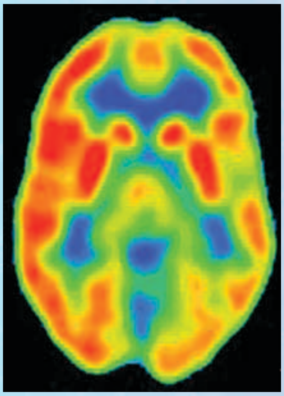
1 The Development of Neuropsychology

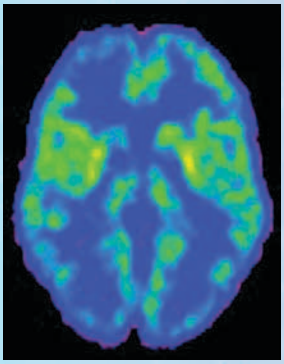
PORTRAIT Living with Traumatic Brain Injury

L.D., an aspiring golfer, had worked as a cook. Following brain damage, the lawyers negotiating his case puzzled over how L.D. continued to excel at golf but at the same time was unable to return to his former work as a cook.

Four years earlier, when he was 21, L.D. had been invited to participate in a sports promotion at a pub. He became ill and was helped onto a balcony by a pub employee. On the balcony, he slipped out of the employee's grasp and fell down five flights of stairs, striking his head against the stairs and wall. He was taken, unconscious, to the emergency ward of the local hospital, where his concussion was assessed on the Glasgow Coma Scale rating as 3, the lowest score on a scale from 3 to 15.

A computed tomography (CT) scan revealed bleeding and swelling on the right side of L.D.'s brain. A neurosurgeon performed a craniotomy (skull removal) over his right frontal cortex to relieve pressure and remove blood. A subsequent CT scan revealed further bleeding on the left side of his brain, and a second craniotomy was performed.


COURTESY DR. MARVIN BERGSNEIDER


COURTESY DR. MARVIN BERGSNEIDER

When discharged from the hospital 6 weeks later, L.D.'s recall of the events consisted only of remembering that he had entered the pub and then becoming aware that he was in a hospital 3 weeks later. L.D. was unable to return to work because he found the multitasking involved in preparing meals too difficult. He was seeking compensation from the company that had hosted the sports promotion and from the pub where he had been injured.

We found that L.D. became frustrated and annoyed when attempting to cook. He had lost his sense of smell and taste and was not interested in socializing. He and his girlfriend had ended their 4-year relationship. We administered a comprehensive neuropsychological examination, and his scores on most tests were typical, except for tests of verbal memory and attention. Magnetic resonance imaging (MRI), a brain-scanning method that can reveal the brain's structure in detail, showed some diffuse damage to both sides of his brain. The accompanying positron emission tomography (PET) images contrast blood flow in a healthy brain (top) to blood flow in patients like L.D. (bottom).

Based on previous patients with traumatic brain injuries and behavioral and brain symptoms similar to L.D.'s, we recommended compensation, which L.D. did receive, in addition to assistance in finding work less demanding than cooking. He was able to live on his own and successfully returned to playing golf.

According to National Institute of Neurological Disorders and Stroke estimates, 1.7 million U.S. residents receive medical attention each year after suffering **traumatic brain injury** (TBI), a wound to the brain that results from a blow to the head (detailed in Section 26.3, including *concussion*, the common term for mild TBI). TBI is a contributing factor in 30% of deaths due to accidents and can result from head blows while playing sports, from falls, and from vehicle accidents. While also the most common cause of discharge from military service

(Gubata et al., 2013), TBI most frequently occurs in children under the age of 6, young adults, and those over age 65. The number of people who endure TBI each year but do not report an injury is not known.

L.D. is not unusual in that, in his own view and in the view of acquaintances, he has mainly recovered, but lingering problems prevent him from resuming his former level of employment. L.D. is also not unusual in that he puzzles both friends and experts with his ability to do some things well while being unable to do other things that appear less difficult. Finally, L.D. is not unusual in that the diffuse brain injury revealed by brain-scanning methods (see Chapter 7) does not predict his abilities and disabilities well.

Neuropsychological testing is required to confirm that he has enduring cognitive deficits and to identify those deficits. L.D.'s poor scores on tests of memory and attention are associated with his difficulty in everyday problem solving, a mental skill referred to as *executive function*. Thus, L.D. can play golf at a high level because it requires that he execute only one act at a time, but he cannot prepare a meal, which requires him to multitask.

This book's objective is to describe **neuropsychology**, the scientific study of the relations between brain function and behavior. Neuropsychology draws information from many disciplines—anatomy, biology, biophysics, ethology, pharmacology, physiology, physiological psychology, and philosophy among them. Neuropsychological investigations into the brain–behavior relationship can identify impairments in behavior that result from brain trauma and from diseases that affect the brain.

Neuropsychology is strongly influenced by two experimental and theoretical investigations into brain function: the **brain theory**, which states that the brain is the source of behavior; and the **neuron theory**, the idea that the unit of brain structure and function is the **neuron**, or nerve cell. This chapter traces the development of these two theories and introduces neuropsychology's major principles, which have emerged from investigating brain function and which we apply in subsequent chapters.

1.1 The Brain Theory

People knew what the brain looked like long before they had any idea of what it did. Early in human history, hunters must have noticed that all animals have brains and that the brains of different animals, including humans, although varying greatly in size, look quite similar. Over the past 2000 years, anatomists have produced drawings of the brain, named its distinctive parts, and developed methods to describe the functions of those parts.

What Is the Brain?

Brain is an Old English word for the tissue found within the skull (cranium). **Figure 1.1**A shows a human brain as oriented in the skull of an upright human. Just as your body is symmetrical, having two arms and two legs, so is your brain. Its two almost symmetrical halves are called **hemispheres**, one on the left side of the body and the other on the right, as shown in the frontal view. If you make your right hand into a fist and hold it up with the thumb pointing toward the front, the fist can represent the brain's left hemisphere as positioned within the skull (Figure 1.1B).

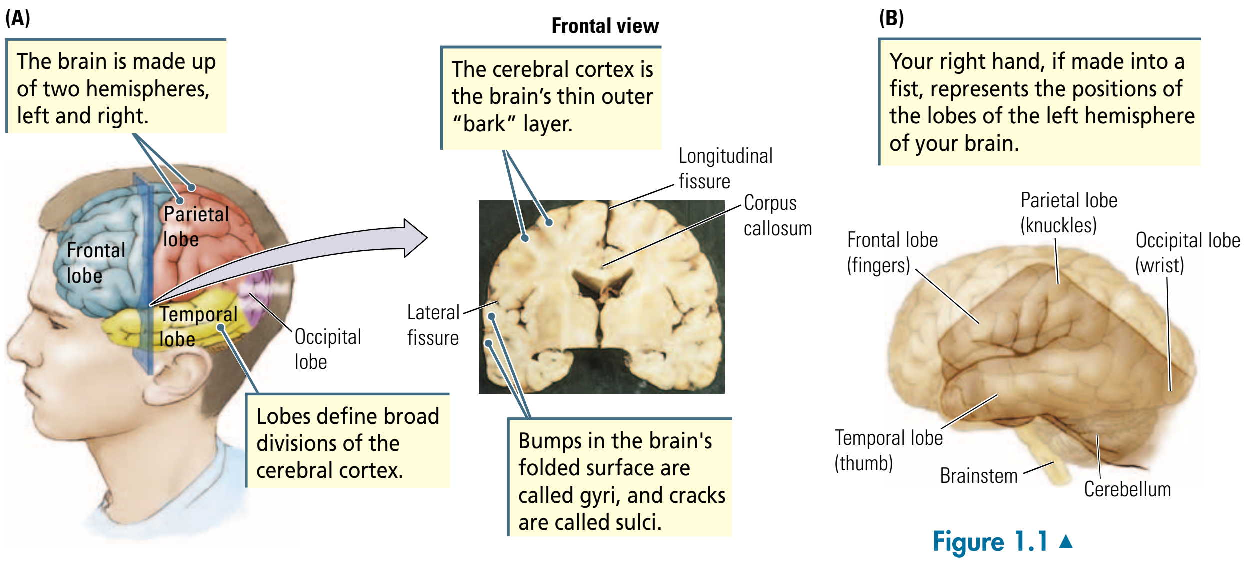


Figure 1.1 ▲

The Human Brain (A) The human brain, as oriented in the head. The visible part of the intact brain is the cerebral cortex, a thin sheet of tissue folded many times and fitting snugly inside the skull. (B) Your right fist can serve as a guide to the orientation of the brain and its cerebral lobes. (Photograph: Arthur Glauberman/ Science Source.)

The brain's basic plan is that of a tube filled with salty fluid called **cerebrospinal fluid** (CSF), which cushions the brain and assists in removing metabolic waste. Parts of the tube's covering have bulged outward and folded, forming the more complicated-looking surface structures that initially catch the eye in Figure 1.1A. The brain's most conspicuous outer feature is the crinkled tissue that has expanded from the front of the tube to such an extent that it folds over and covers much of the rest of the brain (Figure 1.1A at right). This outer layer is the **cerebral cortex** (usually referred to as just the cortex). The word *cortex*, meaning "bark" in Latin, is apt, because the cortex's folded appearance resembles the bark of a tree and because, as bark covers a tree, cortical tissue covers most of the rest of the brain.

The folds, or bumps, in the cortex are called **gyri** (*gyrus* is Greek for "circle"), and the creases between them are called **sulci** (*sulcus* is Greek for "trench"). Some large sulci are called fissures: the **longitudinal fissure**, shown in the Figure 1.1 frontal view, divides the two hemispheres, and the **lateral fissure** divides each hemisphere into halves. (In our fist analogy, the lateral fissure is the crease separating the thumb from the other fingers.) Pathways called *commissures*, the largest of which is the **corpus callosum**, connect the brain's hemispheres.

The cortex of each hemisphere forms four lobes, each named after the skull bones beneath which they lie. The **temporal lobe** is located below the lateral fissure at approximately the same place as the thumb on your upraised fist (Figure 1.1B). Lying immediately above the temporal lobe is the **frontal lobe**, so called because it is located at the front of the brain beneath the frontal bones. The **parietal lobe** is located behind the frontal lobe, and the **occipital lobe** constitutes the area at the back of each hemisphere.

The cerebral cortex constitutes most of the **forebrain**, so named because it develops from the front part of the neural tube that makes up an embryo's primitive brain. The remaining "tube" underlying the cortex is the **brainstem**. The brainstem is in turn connected to the **spinal cord**, which descends down the back within the vertebral column. To visualize the relations among these parts of the brain, again imagine your upraised fist: the folded fingers represent the cortex, the heel of the hand represents the brainstem, and the arm represents the spinal cord.

This three-part brain is conceptually useful evolutionarily, anatomically, and functionally. Evolutionarily, animals with only spinal cords preceded those with brainstems, which preceded those with forebrains. Anatomically, in prenatal development, the spinal cord forms before the brainstem, which forms before the forebrain. Functionally, the forebrain mediates cognitive functions; the brainstem mediates regulatory functions such as eating, drinking, and moving; and the spinal cord conveys sensory information into the brain and sends commands from the brain to the muscles to move.

How Does the Brain Relate to the Rest of the Nervous System?

The brains and spinal cords of mammals are encased in protective bones: the skull protects the brain, and vertebrae protect the spinal cord. Together, the brain and spinal cord are called the **central nervous system**, or CNS. The CNS is connected to the rest of the body through nerve fibers.

Some fibers carry information away from the CNS; others bring information into it. These nerve fibers constitute the **peripheral nervous system**, or PNS. One distinguishing feature between the central and peripheral nervous systems is that PNS tissue will regrow after damage, whereas the CNS does not regenerate lost tissue. Thus the long-term prospect for L.D. is that he will show little further recovery in higher brain functions such as planning, but his golf game may improve.

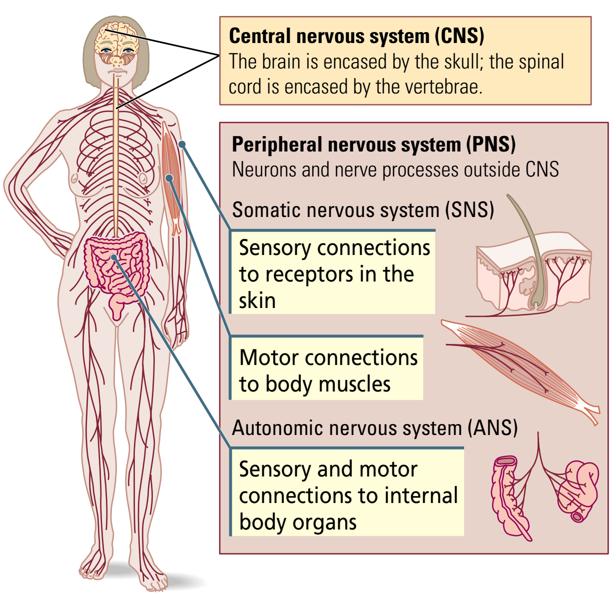
Nerve fibers that bring information to the CNS are extensively connected to sensory receptors on the body's surface and to muscles, enabling the brain to sense the world and to react. This subdivision of the PNS is called the **somatic nervous system** (SNS). Organized into **sensory pathways**, collections of fibers carry messages for specific senses, such as hearing, vision, and touch. Sensory pathways carry information collected on one side of the body mainly to the cortex in the *opposite* hemisphere. The brain uses this information to construct perceptions of the world, memories of past events, and expectations about the future.

Motor pathways are groups of nerve fibers that connect the brain and spinal cord to the body's muscles through the SNS. Movements produced by motor pathways include the eye movements that you are using to read this book, the hand movements that you make while turning or scrolling through the pages, and your body's posture as you read. The parts of the cortex that produce movement mainly send information out via motor pathways to muscles on the opposite side of the body. Thus, one hemisphere uses muscles on the opposite side of the body to produce movement.

Sensory and motor pathways also influence the muscles of your internal organs—the beating of your heart, contractions of your stomach, raising and lowering of your diaphragm to inflate and deflate your lungs. The pathways that control these organs are a subdivision of the PNS called the **autonomic nervous system** (ANS). **Figure 1.2** diagrams these major divisions of the human nervous system.

Figure 1.2 ▼

Major Divisions of the Human Nervous System
The brain and spinal cord together make up the CNS. All the nerve processes radiating from it and the neurons outside it connect to the sensory receptors and muscles in the SNS and to internal organs in the ANS. This constitutes the peripheral nervous system (PNS).



1.2 Perspectives on the Brain and Behavior

The central topic in neuropsychology is how brain and behavior are related. We begin with three classic theories—mentalism, dualism, and materialism—representative of the many attempts scientists and philosophers have made to relate brain and behavior. Then we explain why contemporary brain investigators subscribe to the materialist view. In reviewing these theories, you will recognize that some "commonsense" ideas you might have about behavior are derived from one or another of these perspectives (Finger, 1994).

Aristotle: Mentalism

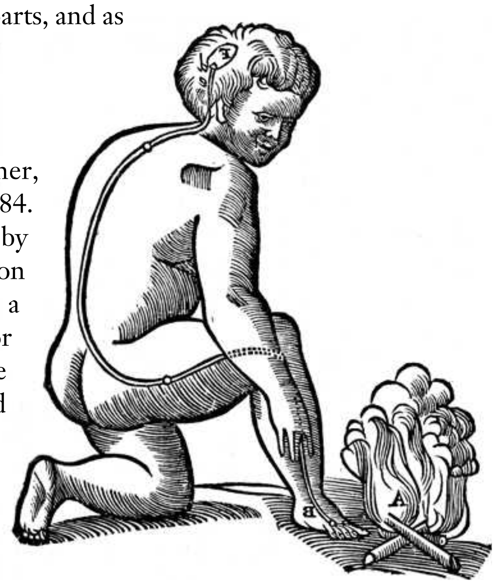
The Greek philosopher Aristotle (384–322 B.C.E.) was the first person to develop a formal theory of behavior. He proposed that a nonmaterial *psyche* is responsible for human thoughts, perceptions, and emotions and for such processes as imagination, opinion, desire, pleasure, pain, memory, and reason.

The psyche is independent of the body but in Aristotle's view, works through the heart to produce action. As in Aristotle's time, heart metaphors serve to this day to describe our behavior: "put your heart into it" and "she wore her heart on her sleeve" are but two. Aristotle's view that this nonmaterial psyche governs behavior was adopted by Christianity in its concept of the soul and has been widely disseminated throughout the world. *Mind* is an Anglo-Saxon word for memory, and, when "psyche" was translated into English, it became *mind*.

The philosophical position that a person's mind is responsible for behavior is called *mentalism*, meaning "of the mind." Mentalism still influences modern neuropsychology: many terms—sensation, perception, attention, imagination, emotion, memory, and volition among them—are still employed as labels for patterns of behavior. (Scan some of the chapter titles in this book.) Mentalism also influences people's ideas about how the brain might work, because the mind was proposed to be nonmaterial and so have no "working parts." We still use the term *mind* to describe our perceptions of ourselves as having unitary consciousness despite recognizing that the brain is composed of many parts, and as we describe in Section 1.3, has many separate functions.

Figure 1.3 ▼

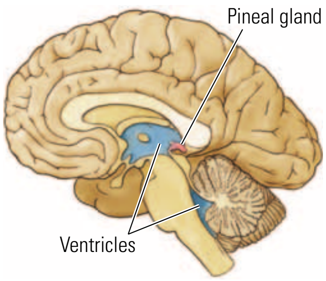
Descartes's Concept of Reflex Action In this mechanistic depiction, heat from the flame causes a thread in the nerve to be pulled, releasing ventricular fluid through an opened pore. The fluid flows through the nerve, causing not only the foot to withdraw but the eyes and head to turn to look at it, the hands to advance, and the whole body to bend to protect it. Descartes ascribed to reflexes behaviors that today are considered too complex to be reflexive, whereas he did not conceive of behavior described as reflexive today. (From Descartes, 1664. Print Collector/Getty Images.)



Descartes: Dualism

René Descartes (1596–1650), a French anatomist and philosopher, wrote what could be considered the first neuropsychology text in 1684. In it he gave the brain a prominent role. Descartes was impressed by machines made in his time, such as those encased in certain statues on display for public amusement in the water gardens of Paris. When a passerby stopped in front of one particular statue, for example, his or her weight depressed a lever under the sidewalk, causing the statue to move and spray water at the person's face. Descartes proposed that the body is like these machines. It is material and thus clearly has spatial extent, and it responds mechanically and reflexively to events that impinge on it (**Figure 1.3**).

Described as nonmaterial and without spatial extent, the mind, as Descartes saw it, was different from the body. The body operated on principles similar to those of a machine, but the mind decided what movements the machine should make. Descartes located the site of action of the mind in the *pineal body*, a small structure high in the brainstem. His choice was based on the logic that the pineal body is the only structure in the nervous system not composed of two bilaterally symmetrical halves and moreover that it is located close to the ventricles. His idea was that the mind, working through the pineal body, controlled valves that allowed CSF to flow from the ventricles through nerves to muscles, filling them and making them move.



For Descartes, the cortex was not functioning neural tissue but merely a covering for the pineal body. People later argued against Descartes's hypothesis by pointing out that no obvious changes in behavior occur when the pineal body is damaged. Today, the pineal body, now called the *pineal gland*, is known to influence daily and seasonal biorhythms. And the cortex became central to understanding behavior as scientists began to discover that it performs the functions Descartes attributed to a nonmaterial mind.

Descartes's position that mind and body are separate but can interact is called **dualism**, to indicate that behavior is caused by two things. Dualism originated a quandary known as the **mind–body problem**: for Descartes, a person is capable of consciousness and rationality only because of having a mind, but how can a nonmaterial mind produce movements in a material body?

To understand the mind–body problem, consider that for the mind to affect the body, it must expend energy, adding new energy to the material world. The spontaneous creation of new energy violates a fundamental law of physics, the law of conservation of matter and energy. Thus, dualists who argue that mind and body interact causally cannot explain how.

Other dualists avoid this problem by reasoning either that the mind and body function in parallel, without interacting, or that the body can affect the mind but the mind cannot affect the body. These dualist positions allow for both a body and a mind by sidestepping the problem of violating the laws of physics.

Descartes's theory also spawned unforeseen and unfortunate consequences. In proposing his dualistic theory of brain function, Descartes also proposed that animals do not have minds and therefore are only machinelike, that the mind develops with language in children, and that mental disease impairs rational processes of the mind. Some of his followers justified the inhumane treatment of animals, children, and the mentally ill on the grounds that they did not have minds: an animal did not have a mind, a child developed a mind only at about 7 years of age when able to talk and reason, and the mentally ill had "lost their minds." Likewise misunderstanding Descartes's position, some people still argue that the study of animals cannot be a source of useful insight into human neuropsychology.

Descartes himself, however, was not so dogmatic. He was kind to his dog, Monsieur Grat. He suggested that whether animals had minds could be tested experimentally. He proposed that the key indications of the presence of a mind are the use of language and reason. He suggested that, if it could be demonstrated that animals could speak or reason, then such demonstration would indicate that they have minds. Exciting lines of research in modern experimental neuropsychology, demonstrated throughout this book, are directed toward the comparative study of animals and humans with respect to language and reason.

Darwin: Materialism

By the mid-nineteenth century, our contemporary perspective of **materialism** was taking shape. The idea is that rational behavior can be fully explained by the workings of the nervous system. No need to refer to a nonmaterial mind. Materialism has its roots in the evolutionary theories of two English naturalists, Alfred Russel Wallace (1823–1913) and Charles Darwin (1809–1892).

Evolution by Natural Selection

Darwin and Wallace looked carefully at the structures of plants and animals and at animal behavior. Despite the diversity of living organisms, the two were struck by their many similarities. For example, the skeleton, muscles, internal organs, and nervous systems of humans, monkeys, and other mammals are similar. These observations support the idea that living things must be related, an idea widely held even before Wallace and Darwin. More importantly, these same observations led to the idea that the similarities could be explained if all animals had evolved from a common ancestor.

Darwin elaborated his theory in *On the Origin of Species by Means of Natural Selection, or the Preservation of Favored Races in the Struggle for Life*, originally published in 1859. He argued that all organisms, both living and extinct, are descended from an ancestor that lived in the remote past. Animals have similar traits because those traits are passed from parents to their offspring. The nervous system is one such trait, an adaptation that emerged only once in animal evolution. Consequently, the nervous systems of living animals are similar because they are descendants of that first nervous system. Those animals with brains likewise are related, because all animals with brains descend from the first animal to evolve a brain.

Natural selection is Darwin's theory for explaining how new species evolve and how they change over time. A **species** is a group of organisms that can breed among themselves but usually not with members of other species. Individual organisms within a species vary in their **phenotype**, the traits we can see or measure. Some are big, some are small, some are fat, some are fast, some are light colored, some have large teeth. Individual organisms whose traits best help them to survive in their environment are likely to leave more offspring that feature those traits.

Natural Selection and Heritable Factors

Beginning about 1857, Gregor Mendel (1822–1884), an Austrian monk, experimented with plant traits, such as the flower color and height of pea plants, and determined that such traits are due to heritable factors we now call *genes* (elaborated in Section 2.3). Thus, the unequal ability of individual organisms to survive and reproduce is related to the different genes they inherit from their parents and pass on to their offspring.

Mendel realized that the environment plays a role in how genes express traits: planting tall peas in poor soil reduces their height. Likewise, experience affects gene expression: children who lack educational opportunities may not adapt as well in society as children who attend school. The science that studies differences in *gene expression* related to environment and experience is **epigenetics** (see Section 2.3). Epigenetic factors do not change the genes individuals inherit, but they do affect whether a gene is active—turned on or off—and in this way influence an individual's phenotypic traits.

Environment and experience play an important role in how animals adapt and learn. Adaptation and learning are in turn enabled by the brain's ability to form new connections and pathways. This **neuroplasticity** is the nervous system's potential for physical or chemical change that enhances its adaptability to environmental change and its ability to compensate for injury. Epigeneticists are especially involved in describing how genes express the brain's plastic changes under the influence of environment and experience.

Contemporary Perspectives

As a scientific theory, contemporary brain theory is both materialistic and neutral with respect to beliefs, including religious beliefs. Science is not a belief system but rather a set of procedures designed to allow investigators to confirm answers to questions independently. Behavioral scientists, both those with and those without religious beliefs, use the scientific method to examine relations between the brain and behavior and to *replicate* (repeat) others' work on brain–behavior relationships. Today, when neuroscientists use the term *mind*, most are not referring to a nonmaterial entity but using it as shorthand for the collective functions of the brain.

1.3 Brain Function: Insights from Brain Injury

You may have heard statements such as, "Most people use only 10% of their brains" or "He put his entire mind to the problem." Both statements arise from early suggestions that people with brain damage often get along quite well. Nevertheless, most people who endure brain damage will tell you that some behavior is lost and some survives, as it did for L.D., whose case begins this chapter. Our understanding of brain function has its origins in individuals with brain damage. We now describe some fascinating neuropsychological concepts that have emerged from studying such individuals.

Localization of Function

The first general theory to propose that different parts of the brain have different functions was developed in the early 1800s by German anatomist Franz Josef Gall (1758–1828) and his partner Johann Casper Spurzheim (1776–1832) (Critchley, 1965). Gall and Spurzheim proposed that the cortex and its gyri were functioning parts of the brain and not just coverings for the pineal body. They supported their position by showing through dissection that the brain's most distinctive motor pathway, the *corticospinal* (cortex to spinal cord) *tract*, leads from the cortex of each hemisphere to the spinal cord on the opposite side of the body. Thus, they suggested, the cortex sends instructions to the spinal cord to command muscles to move. They also recognized that the two symmetrical hemispheres of the brain are connected by the corpus callosum and can thus interact.

Gall's ideas about behavior began with an observation made in his youth. Reportedly, he observed that students with good memories had large, protruding eyes and surmised that a well-developed memory area of the cortex located behind the eyes would cause them to protrude. Thus, he developed his hypothesis, called **localization of function**, that a different, specific brain area controls each kind of behavior.

Gall and Spurzheim furthered this idea by collecting instances of individual differences that they related to other prominent features of the head and skull. They proposed that a bump on the skull indicated a well-developed underlying cortical gyrus and therefore a greater capacity for a particular behavior; a depression in the same area indicated an underdeveloped gyrus and a concomitantly reduced faculty.

Thus, just as a person with a good memory had protruding eyes, a person with a high degree of musical ability, artistic talent, sense of color, combativeness, or mathematical skill would have large bumps in other areas of the skull. **Figure 1.4** shows where Gall and Spurzheim located the trait of amativeness (sexiness). A person with a bump there would be predicted to have a strong sex drive, whereas a person low in this trait would have a depression in the same region.

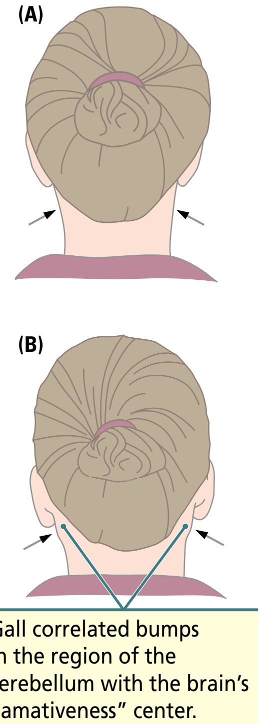


Figure 1.4 ◄

Gall's Theory Depressions (A) and bumps (B) on the skull indicate the size of the underlying area of brain and thus, when correlated with personality traits, indicate the part of the brain controlling the trait. While examining a patient (who because of her behavior became known as "Gall's Passionate Widow"), Gall found a bump at the back of her neck that he thought located the center for "amativeness" in the cerebellum. (Research from Olin, 1910.)

Gall and Spurzheim identified a long list of behavioral traits borrowed from the English or Scottish psychology of the time. They assigned each trait to a particular part of the skull and, by inference, to the underlying brain part. Spurzheim called this study of the relation between the skull's surface features and a person's mental faculties **phrenology** (*phren* is a Greek word for "mind"). **Figure 1.5** shows the resulting phrenological map that he and Gall devised.

Some people seized on phrenology as a means of making personality assessments. They developed a method called *cranioscopy*, in which a device was placed around the skull to measure its bumps and depressions. These measures were then correlated with the phrenological map to determine the person's likely behavioral traits. The faculties described in phrenology—characteristics such as faith, self-love, and veneration—are impossible to define and to quantify objectively. Phrenologists also failed to recognize that the superficial features on the skull reveal little about the underlying brain. Gall's notion of localization of function, although inaccurate scientifically, laid the conceptual foundation for modern views of functional localization, beginning with the localization of language.

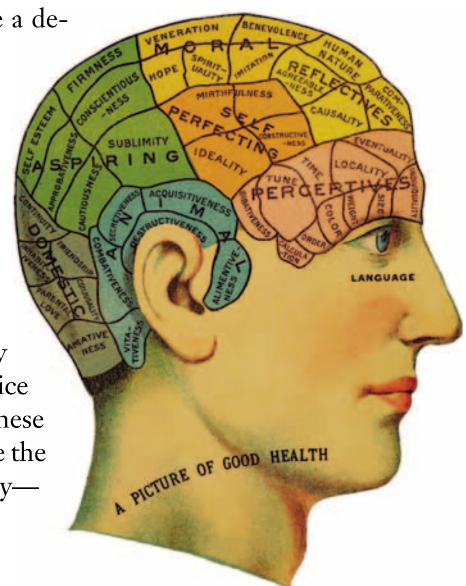


Figure 1.5 ▲

Phrenology Bust Originally, Gall's system identified putative locations for 27 faculties. As the study of phrenology expanded, the number of faculties increased. Language, indicated at the front of the brain, below the eye, actually derived from one of Gall's case studies. A soldier had received a knife wound that penetrated the frontal lobe of his left hemisphere through the eye. The soldier lost the ability to speak. (Mary Evans Picture Library/Image Works.)

Among his many observations, Gall gave the first account of a case in which frontal-lobe brain damage was followed by loss of the ability to speak. The patient was a soldier whose brain was pierced by a sword driven through his eye. Note that, on the phrenological map in Figure 1.5, language is located below the eye. Gall gave the