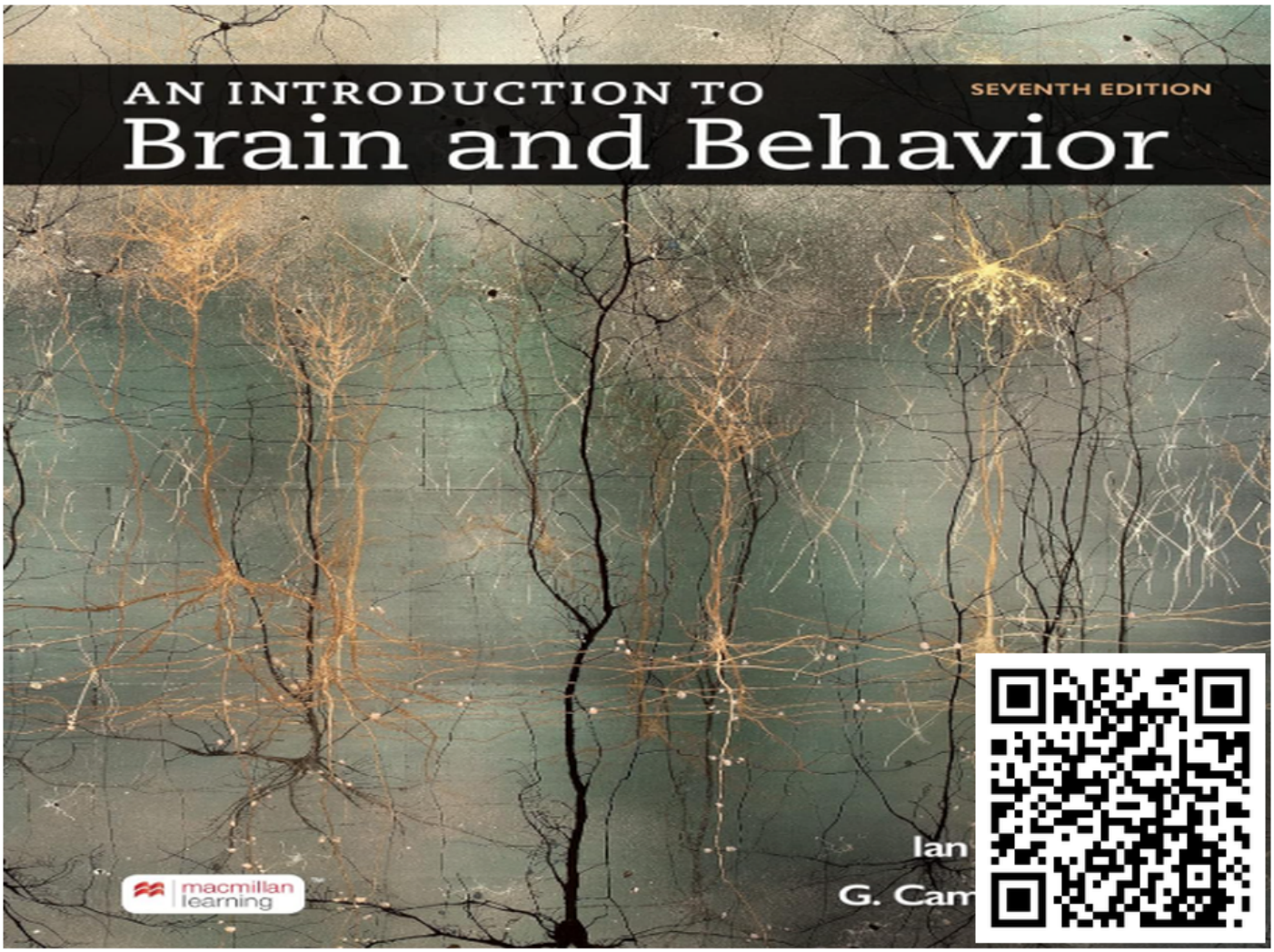

Preface

Seventh Edition Key Revisions

Chapter 1

REVISED Section 1-1 touches on the topic of neurodiversity and artificial intelligence in the discussion of why we study brain and behavior.

REVISED Section 1-2 concludes with a discussion of contemporary theories of consciousness.

NEW subsection in Section 1-4 explores the significance of human intelligence, and issues related to our ability to define and measure it.

Chapter 2

UPDATED Clinical Focus 2-3 discusses new neuroimaging and other treatments for stroke, and explains the FAST method for detecting stroke.

REVAMPED discussion of the 10 principles of the nervous system, with revised order, updated descriptions throughout, and a new Principle 1 highlighting the role of neuronal circuits.

Chapter 3

UPDATED discussion in Section 3-1 on Barbara Webb's work and approaches to robot intelligence and AI.

UPDATED discussion of glial cells and functions in Section 3-1, including discussion of tripartite synaptosomics in the study of astrocytes.

UPDATED discussion of genetic engineering techniques in Section 3-3, including an expanded presentation of CRISPR (with figure).

Chapter 4

REORGANIZED discussion of electrical activity at the synapse across Sections 4-2 and 4-3, which now presents integration and summation of inputs before explaining action potentials.

UPDATED Clinical Focus 4-4 discusses recent clinical trials focusing on the brain–machine interface in the treatment of ALS.

Chapter 5

REVISED Clinical Focus 5-2 highlights the work of Joy Milne in identifying biomarkers associated with Parkinson disease.

NEW subsection on neuromodulation as part of the discussion of neurotransmitter systems in Section 5-3.

REVISED discussion of hormones, which has been moved from Chapter 6 to Section 5-4.

Chapter 6

UPDATES made throughout the presentation of psychoactive drugs in Section 6-2, including discussion of the harmful effects of e-cigarettes and the use of SSRIs to treat major depression.

REVISED Research Focus 6-3 on ADHD moved to this chapter from Chapter 7.

NEW Clinical Focus 6-5 explores the opioid epidemic and innovative interventions and treatments related to it.

UPDATED discussion of substance use disorder and addiction in Sections 6-3 and 6-4, including new table on the DSM criteria for substance use disorder.

Chapter 7

UPDATED presentation of brain manipulation techniques, including new discussions of CRISPR, HIFU, miniscopes, and rodent touchscreen devices, in Section 7-1.

UPDATED Research Focus 7-2, Brainbow: Rainbow Neurons (moved from Chapter 3).

UPDATED Research Focus 7-1 discusses new studies on language development in newborns using fNIRS.

NEW discussion of GRAB technology (including figure) in the presentation of genetic manipulations in Section 7-1.

NEW Clinical Focus 7-3 covers brain organoids and personalized medicine.

NEW Section 7-7 explores the emerging field of computational neuroscience and deep learning.

REVISED Section 7-8 now includes a discussion of the field of neuroethics.

Chapter 8

UPDATED Clinical Focus 8-2 discusses the connection between gray-matter volume and ASD.

NEW subsection in Section 8-2 discusses research into neurogenesis in adulthood.

NEW subsection in Section 8-4 focuses on environmental influences on brain development, including a discussion of SES and cognitive enrichment, and expanded coverage (and new figure) on the relationships between gut bacteria and brain development.

Chapter 9

NEW Figure 9-2 depicts a flowchart for simplified sensory pathways.

UPDATED Clinical Focus 9-3 discusses treatments for glaucoma involving the mTOR signaling pathway and other treatments.

NEW Section 9-6 on plasticity in the visual pathways.

Chapter 10

REVISED Research Focus 10-1 focuses on the connection between music and language in the cognitive mechanisms that allow rhythmic vocalizations in hominins.

NEW Clinical Focus 10-5 describes the experience of cochlear implants for a child who was born deaf.

Chapter 11

UPDATED Clinical Focus 11-1 on the brain–computer interface and the computer–brain interface.

UPDATED discussion of the use of nanotechnology in the treatment for spinal cord injury in Section 11-1.

EXPANDED discussion of pain gates in Section 11-4.

REVISED presentation of body and action maps in Section 11-5.

Chapter 12

UPDATED Research Focus 12-1 describes the connection between neural structures for physical and social pain.

REORGANIZED chapter structure now puts the discussion of chemical senses after the discussion of motivated behavior in Sections 12-2 and 12-3.

REVISED introduction to chemical senses in Section 12-3 presents the evolutionary development of disgust, and a new subsection covers impairments of the chemical senses.

UPDATED discussion of sexual differences, including new Research Focus 12-3, the Brain Gender Continuum, and extended discussion of structural differences in cisgender and transgender individuals.

REVISED presentation of theories of emotion in Section 12-6, including coverage of the multicomponent emotion process model (with figure).

Chapter 13

UPDATED Clinical Focus 13-2 describes recent research on and interventions for seasonal affective disorder.

UPDATED discussion of SCN and anthropogenic light in Section 13-2.

NEW discussion of lucid dreaming in Section 13-3.

NEW discussion of sleep memory storage theory and synaptic homeostasis memory theory of sleep in Section 13-4.

EXPANDED discussion of RAS pathways in Section 13-5.

REORGANIZED presentation of sleep disorders in Section 13-6.

Chapter 14

UPDATED Clinical Focus 14-1, Remediating Dyslexia.

NEW presentation of trace transformation theory in Section 14-3.

REVISED discussion of habituation and sensitization, moved from Chapter 5 and now presented in the context of brain plasticity.

Chapter 15

REVISED discussion of executive function in the presentation of planning in Section 15-2.

UPDATED discussion of mirror neurons in Section 15-2.

UPDATED discussion of brain connectomes, mapping, and parcellation in Section 15-3.

REVISED Clinical Focus 15-3 on neuropsychological assessment.

NEW presentation of network neuroscience theory in Section 15-6.

REVAMPED discussion of the neural basis of consciousness in Section 15-7, with a new presentation of global neuronal workspace theory.

Chapter 16

EXPANDED discussion of clinical neuroscience in Section 16-1.

UPDATES throughout the discussions of psychiatric disorders and neurological disorders and their treatments in Sections 16-2 and 16-3.

REVISED presentation of multiple sclerosis under the new subheading "Disorders of Myelin."

NEW presentation of amyloid beta and tau protein in the discussion of prion disorders in Section 16-3.

REVAMPED Section 16-5, which now addresses recovery in terms of posttraumatic growth.

Like the prior editions, this seventh edition of *An Introduction to Brain and Behavior* incorporates the latest research and technological

advancements to give students a foundation in behavioral neuroscience as it is understood and practiced today. New material on genetics and epigenetics, genetic mutations, connectomics, brain imaging, genetic engineering and transgenic techniques, and our understanding and categorization of diseases and disorders of the brain are included throughout the text.

In addition to these updates, we have made some significant changes within some sections to reflect the current understanding of the concepts and better communicate that knowledge to the student. For example, the list of 10 principles of nervous system function, a hallmark of the text that is referenced throughout the chapters, has been revised to highlight the central role of neuronal circuits in the processes of sensation, integration, and movement. Chapter 4 has been reorganized to give students a complete understanding of excitation and inhibition in graded potentials before detailing the propagation and phases of an action potential. The discussion of hormones has been moved from Chapter 6 to Chapter 5, where it facilitates a comparison of the functions of hormones and neurotransmitters. The discussion of habituation and sensitization has been moved from Chapter 5 to Chapter 14, where it is presented in the context of brain plasticity. Chapter 7 includes a new section on computational neuroscience and deep learning, and includes a discussion of the emerging field of neuroethics. The discussion of sleep disorders in Chapter 13 has been revamped to adhere more closely to the broad categories outlined in the *International*

Classification of Sleep Disorders. These examples are just a few of the updates and revisions found throughout the seventh edition.

The range of updates and new coverage in the seventh edition exposition and Focus features is listed, chapter by chapter, in the margins of these Preface pages. You can easily see the breadth and scope of the revision. Yet these changes have not added to the length of the text. To keep the student focused on the material, judicious cuts have been made throughout to compensate for the new additions.

Changes in each new edition are always made with the goal of maintaining the voice and style that have helped make *An Introduction to Brain and Behavior* successful, and this seventh edition preserves the tools and features developed in the prior editions. Reflecting the encouraging feedback received from readers, the book's learning apparatus continues to feature sets of self-test questions at the end of the major sections in each chapter. These Section Reviews help students track their understanding as they progress through the text and the course. Answers appear at the back of the book.

We continue to expand the popular margin notes. Beyond offering useful asides to the text narrative, these marginalia increase the reader's ease in finding information, especially when related concepts are introduced early in the text and then elaborated on in later chapters. Readers can return quickly to an earlier discussion to refresh their knowledge or jump ahead to learn more. The margin notes also help instructors move through the book to preview later

discussions. Margin callouts are also deployed to highlight places where the 10 principles of nervous system functioning, introduced in Chapter 2, correspond directly to the material in each chapter. Although this feature is by no means comprehensive, by reiterating these principles in key places where the connection is sharpest, we help students gain a deeper understanding of these core concepts and the nervous system functioning they reflect.

The illustrated Experiments, another of the book's most popular features, show readers how researchers design experiments—that is, how they approach the study of brain–behavior relationships. The Basics features let students brush up or get up to speed on their science foundation—knowledge that helps them comprehend behavioral neuroscience.

We have made some big changes, but much of the book remains familiar. Shaping the content throughout is our ongoing emphasis on examining the nervous system with a focus on function, on how our behavior and our brain interact. Along the way, we ask the key questions that both students and neuroscientists ask:

- Why do we have a brain?
- How is the nervous system organized—functionally as well as anatomically?
- How do drugs affect our brain and our behavior?
- How does the brain learn?
- How does the brain think?
- Why do we sleep and dream?

Every chapter's central question highlights the brain–behavior relationship. When we first describe how neurons communicate in Chapter 5, for example, we also describe how synapses can change based on experience. Later, in Section 14-4, we expand on synaptic plasticity as we explore learning and memory.

Just as it was when we wrote the first edition, our goal in this new edition is to bring coherence to a vast subject by helping students understand the big picture. Asking fundamental questions about the brain has another benefit: it piques students' interest and challenges them to join us on the journey of discovery that is brain science.

Scientific understanding of the human brain and human behavior continues to grow at an exponential pace. We want to communicate the excitement of recent breakthroughs in brain science as well as relate some of our own experiences of studying brain and behavior, both to make the field's developing core concepts and latest revelations understandable and to transport uninitiated students to the frontiers of physiological psychology.

Areas of Emphasis

To convey the excitement of neuroscience as researchers understand it, we interweave evolution, genetics, and epigenetics; psychopharmacology; and neural plasticity and connectivity, including central nervous system (CNS) and enteric nervous system (ENS) interactions, throughout the book.

Evolution

Our perspective—neuroscience in an evolutionary context—recurs in almost every chapter. Focusing on comparative behavior and anatomy, we address nervous system evolution in depth in Chapters 1 and 2, evolution of the synapse in Section 5-1, and evolution of visual pathways in Section 9-2. We discuss how evolution might have influenced behaviors related to aggression and mate selection in Section 12-1, the evolutionary theories of sleeping and dreaming in Section 13-4, and the evolutionary origins of memory in Section 14-3. We describe the evolution of sex differences in spatial cognition and language in Section 15-5 and links between our evolved reactions to stress and anxiety disorders in Section 16-2.

Genetics and Epigenetics

We introduce the foundations of genetic and epigenetic research in Sections 1-3 and 2-1, and then begin to elaborate on them in Section 3-3. Chapter 5 discusses metabotropic receptors and DNA. The interplay of genes and drug action is integral to Chapter 6, as are the developmental roles of genes and gene methylation to Chapter 8. Section 9-4 explains the genetics of color vision, and the genetics of sleep disorders anchors Section 13-6. Section 14-4 highlights the role of epigenetics in memory. Section 16-3 considers the roles of genetics and of prions in understanding the causes of behavioral disorders.

Psychopharmacology

Chapter 5 explores the roles of hormones in regulating behavior, and Chapter 6 continues this investigation by examining the effects of drugs on behavior, topics we revisit often throughout the book. You will find coverage of drugs and cellular communication in Section 5-3, and synthetic biology and drug manipulations in Section 7-1. Section 12-7 covers drugs and emotional behavior; Section 13-6, drugs and sleep disorders; and Section 14-4, neuronal changes with drug use. Sections 16-2 and 16-3 explore drugs used as treatments for a range of behavioral disorders.

Connectivity

Neural plasticity is a hallmark of this book. We introduce this concept in Section 1-1, detail it in Section 2-1, develop it further in Section 2-6, and expand on it throughout. At the conclusion of Section 14-4, we elaborate seven guiding principles of brain plasticity. In Section 1-4, we introduce the emerging field of connectomics, which we explore further throughout Chapter 15. The new field of psychobiotics, which identifies the connection between the gut microbiome and its effects on the ENS, as well as on the CNS, appears in Sections 2-5. The emerging study of computational neuroscience, which explores the organization of neural networks and applies that knowledge to research in deep learning and artificial intelligence, is covered in Section 7-7.

Scientific Background Provided

We describe the journey of discovery in neuroscience in a way that students beginning to study the brain and behavior can understand; and we provide clinical examples to tie its relevance problems we face. Our approach provides the background that students need to understand introductory brain science. Multiple illustrated Experiments (found in 13 chapters) help students in visualizing the scientific method with how scientists think. The Basics features (found in 6 chapters) address the fact that understanding brain function requires understanding information from all the basic sciences.

Some encounters with neuroscience can be surprising to students who come to the course without a science background. The Basics features in Chapters 1 and 2 address relevant evolutionary and anatomical background. In Chapter 3, The Basics provides a short introduction to chemistry before the text describes the brain's chemical activities. In Chapter 4, The Basics addresses electricity before exploring the brain's electrical activity.

Readers already comfortable with this material can easily skip it; less experienced readers can learn it and use it as a context for neuroscience. Students with this background can tackle brain science with greater confidence. For students with limited knowledge of basic psychology, we review the stages of behavioral development in Chapter 8 and forms of learning and memory in Chapter 14.

Students in social science disciplines often remark on the amount of biology and chemistry in the book, and an equal number of students in biological sciences remark on the amount of psychology. More than half the students enrolled in the bachelor of science in neuroscience program at the University of Lethbridge switched from an initial biochemistry or psychology major after taking this course. Neuroscience is exciting!

Chapter 7 showcases the range of methods that behavioral neuroscientists use to measure and manipulate brain and behavior—both traditional methods and cutting-edge techniques such as optogenetics, optical tomography, resting-state fMRI, chemogenetics, GRAB, DREADD, and CRISPR. Expanded discussions of these techniques appear where appropriate, especially in the Research Focus features, including Focus 4-2, Optogenetics and Light-Sensitive Ion Channels; Focus 7-2, Brainbow: Rainbow Neurons; Focus 7-3, Brain Organoids and Personalized Medicine; Focus 11-1, Neuroprosthetics; and Focus 16-1, Posttraumatic Stress Disorder, which includes treatments based on virtual reality (VR) exposure therapies.

Because critical thinking is vital to progress in science, selected discussions throughout the book center on the philosophical problems addressed by brain research. Section 1-2 concludes with "The Separate Realms of Science and Belief." Section 7-8 presents a variety of ethical considerations in neuroscience research and practice now being explored under the umbrella of neuroethics, as

well as issues related to animal welfare in scientific research. Section 15-2 discusses the rise and fall of mirror neurons, demonstrating how the media—and even scientists—can fail to question the validity of research results. Section 12-5—and particularly Research Focus 12-3, The Brain Gender Continuum—explores the idea that gender identity comprises a broad spectrum rather than a simple female–male dichotomy.

Clinical Focus Maintained

Neuroscience is a human science. Everything in this book is relevant to our lives and the lives of those we know, and everything in our lives is relevant to neuroscience. Understanding neuroscience helps us understand how we learn, how we develop, and how we can help people with brain and behavioral disorders. Knowledge of how we learn, how we develop, and what the symptoms of brain and behavioral disorders provide insights into neuroscience.

Clinical material also helps make neurobiology relevant to students who plan to seek a career in psychology, social work, or another profession related to mental health, as well as to students of the biological sciences. We integrate clinical information throughout the text with Clinical Focus features, and we expand on it in Chapter 16, the book's capstone, as well.

In *An Introduction to Brain and Behavior*, the placement of some topics is novel relative to traditional treatments. We include brief

descriptions of brain diseases close to discussions of basic associated processes. For example, coverage of Parkinson disease is integrated throughout Chapter 5, How Do Neurons Communicate and Adapt? This strategy helps first-time students repeatedly forge close links between what they are learning and real-life issues.

To provide a consistent disease nomenclature, the seventh edition follows the system advocated by the World Health Organization for diseases named after their putative discoverers. “Down syndrome,” for example, has largely replaced “Down’s syndrome” in the popular and scientific literature. We extend that convention to Parkinson disease and Alzheimer disease, among other eponymous diseases and disorders.

The nearly 150 disorders we cover are cross-referenced in the Index of Disorders inside the book’s front cover. Chapter 16 expands on the nature of neuroscience research and the multidisciplinary treatment methods for neurological and psychiatric disorders described in preceding chapters.

We emphasize questions that relate to the biological bases of behavior. For us, the excitement of neuroscience lies in understanding how the brain explains what we do, whether it is talking, sleeping, seeing, or learning. Readers will therefore find nearly as many illustrations focusing on behavior as illustrations depicting the brain. This emphasis on explaining the biological foundations of behavior is

another reason we include a mix of Clinical, Research, and Comparative Focus features throughout the text.

Abundant Chapter Pedagogy

Building on the innovative teaching devices described so far, numerous in-text pedagogical aids adorn every chapter, beginning with an outline and an opening Focus feature that draws students into the chapter's topic. Focus features dot each chapter to connect brain and behavior to relevant clinical or research experience. Within chapters, definitions of boldface key terms introduced in the text appear in the margins as reinforcement, margin notes link topics together, and end-of-section Review self-tests help students check their grasp of major points.

Each chapter ends with a Summary (several of which include summarizing tables or illustrations to help students visualize or review big-picture concepts); a list of Key Terms, each referencing the page number on which the term is defined; and a list of dynamic digital resources available through Macmillan's Achieve platform. Following this Preface, the Media and Supplements section describes the wide array of supplemental materials designed exclusively for students and teachers using the seventh edition.

Superb Visual Reinforcement

Our most important learning aid appears on nearly every page in the book: an expansive and, we believe, exceptional set of illustrations. Overwhelmingly, readers agree that, hand in hand with our words,

these diagrams vividly describe and illuminate the nervous system. Important anatomical illustrations are presented in a large format to ease their perusal. We have selected relevant and engaging photos that enliven and enrich the discussion, ranging from a dance class for individuals with Parkinson disease in Section 5-3, to VR clinic rooms that allow patients and neurosurgeons to interact directly with VR models in Section 7-3, to a seniors' bridge game to illustrate the discussion of cognitively stimulating activities in Section 16-3.

Illustrations are presented in a consistent manner from chapter to chapter so that they reinforce one another. We consistently color-code diagrams that illustrate each aspect of the neuron, depict each structural region in the brain, and demarcate nervous system divisions. We include many varieties of micrographic images to show what a particular neural structure actually looks like. These illustrations and images are included in our PowerPoint presentations and integrated as labeling exercises in our Study Guide and Testing materials.

Teaching Through Metaphors, Examples, and Principles

If a textbook is not enjoyable, it has little chance of teaching well. We heighten students' interest through abundant use of metaphors and examples. Students read about patients whose brain injuries offer insights into brain function, and we examine car engines, robots, and prehistoric flutes for the same purpose. A wealth of illustrated

Experiments, comparative biology examples, and representative Comparative Focus features help students understand how much we humans have in common with creatures as distant from us as sea slugs and as close to us as chimpanzees.

We also facilitate learning by reemphasizing the main points and by distilling sets of principles about brain function that offer a framework to guide students' thinking. Thus, Section 2-6 introduces 10 key principles that explain how the parts of the nervous system work together. Section 14-4 summarizes seven guiding principles of neuroplasticity. Collectively, these sets of principles form the basis of many discussions throughout the book. Margin notes also remind readers when they encounter these principles again—and indicate where they can review them in depth.

Big-Picture Emphasis

One challenge in writing an introductory book on any topic is deciding what to include and what to exclude. We have organized the discussions in this text to focus on the bigger picture—a focus exemplified by the 10 principles of nervous system function introduced in Section 2-6, revised for this edition, and echoed throughout the book. Any set of principles may be arbitrary yet nevertheless afford students a useful framework for understanding the brain's activities.

In Chapters 8 through 16, we tackle behavioral topics in a more general way than most contemporary books do. In Section 16-4, Research Challenges, we outline the challenges in the treatment of brain diseases. In Chapter 12, for instance, we revisit experiments and ideas from the 1960s to understand why animals behave as they do, then consider emotional and motivated behaviors as diverse as eating and anxiety attacks in humans. In Chapter 14, the larger picture of learning and memory is presented alongside a discussion of recovery from traumatic brain injury.

This broad focus helps students grasp the big picture that behavioral neuroscience paints. While broadening our focus requires us to leave out some details, our experience with students and teachers through six earlier editions confirms that discussing the larger problems and issues in brain and behavior is of greater interest to students—especially those new to this field—and is more often remembered than are myriad details without context.

As in preceding editions, we have been selective in our citations of the truly massive literature on the brain and behavior in this seventh edition, because we believe that too many citations can disrupt the text's flow, distracting students from the task of mastering concepts. We provide citations to classic works by including the names of the researchers and by mentioning where the research was performed. In areas where controversy or new breakthroughs predominate, we include detailed citations to papers (especially reviews) from the years 2018 to 2021. An end-of-book References section lists, by chapter, all

the literature used in developing the book, reflecting the addition of many new citations in this edition and the elimination of other, now superseded, research.

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Bryan Kolb, Ian Q. Whishaw, G. Campbell Teskey

Media and Supplements

An Introduction to Brain and Behavior, Seventh Edition, features a wide array of supplemental materials designed exclusively for students and teachers of the text. For more information about any of the items, please visit the Macmillan Learning catalog at www.macmillanlearning.com.

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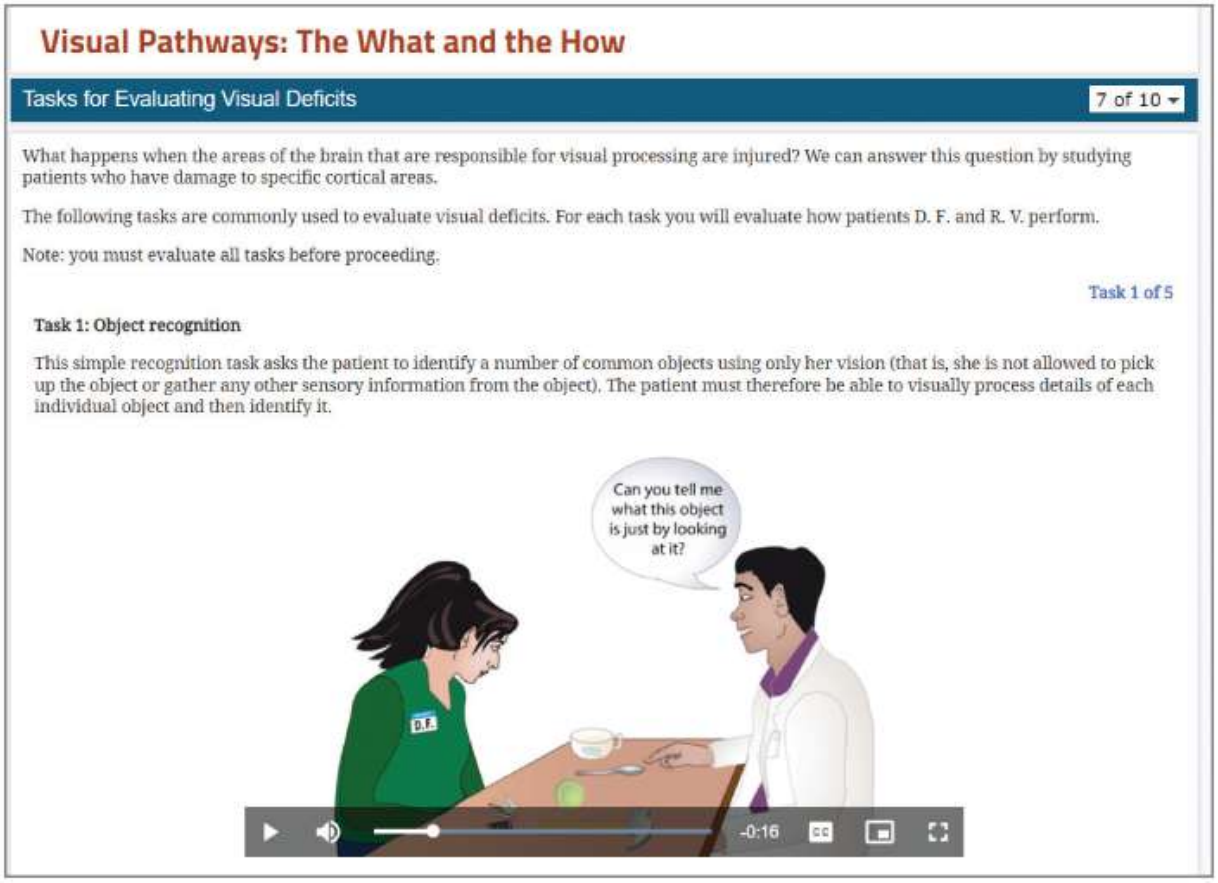

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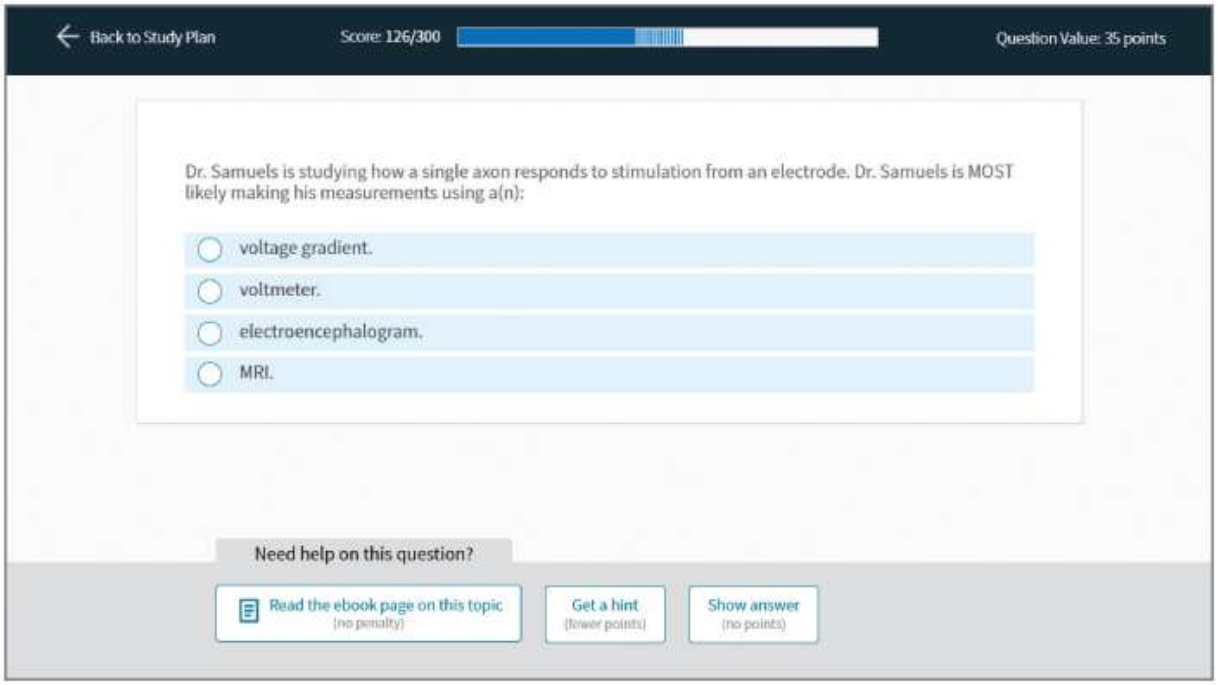


Achieve for *An Introduction to Brain and Behavior*, Seventh Edition, includes the following resources:

- **NEW! NEUROSCIENCE IN ACTION ACTIVITIES, VOLUMES I AND II,** are a collection of online activities that enable students to deepen their understanding of neuronal processes. The seventh edition features the debut of Volume II of the collection, adding more than 10 new activities and bringing the total collection to over 25. These activities show, through vivid animations, the foundational processes that the reader can only imagine when reading the text. Students come away with a fuller understanding of topics such as the conduction of the action potential, the integration of neural inputs, synaptic transmission, and the action of neurotransmitters. A perfect accompaniment to an online or hybrid course, each activity is fully assessable with multiple-choice questions. This collection is indispensable for bringing fundamental neuroscience concepts to life.

- **THE LEARNINGCURVE** adaptive quizzing system is designed based on the latest findings from learning and memory research. It combines adaptive question selection, immediate and valuable feedback, and a gamelike interface to engage students in a learning experience that is unique to them. Students experience learning that is customized to their level of knowledge, and instructors receive state-of-the-art reporting on the progress of each student, as well as the class as a whole.
- **PRACTICE QUIZZES** provide another way for students and instructors to rehearse their knowledge. Each quiz is written on the topics discussed throughout each chapter and features a

variety of multiple-choice questions presented to students randomly from question pools. Valuable to both student and instructor, these practice quizzes are fully editable and make robust assessment quick and easy to set up.

- **AN INTERACTIVE E-BOOK** allows students to highlight, bookmark, and make notes, just as they would with a printed textbook. The search function and in-text glossary definitions make the text ready for the digital age.
- **STUDENT VIDEO ACTIVITIES** include engaging modules that instructors can easily assign for student assessment. Videos cover a variety of topics and are sure to spark discussion and encourage critical thinking.

For Instructors

Instructor's Resources

This invaluable tool, for new and experienced instructors alike, was revised by Catherine Smith of Carleton University. It includes chapter-by-chapter learning objectives and chapter overviews, detailed lecture outlines, thorough chapter summaries, chapter key terms, in-class demonstrations and activities, springboard topics for discussion and debate, ideas for research and term paper projects, homework assignments and exercises, and suggested readings from journals and periodicals. Course-planning suggestions and a guide to videos and Internet resources are also included.

Assessment Tools

Test Bank

The entire Test Bank for the seventh edition has been revised by text author G. Campbell Teskey and Simon Spanswick (both of the University of Calgary). The collection comprises more than 1300 multiple-choice and short-answer test questions. Each item is keyed to the page in the textbook on which the answer can be found. All the questions have been thoroughly reviewed and edited for accuracy and clarity.

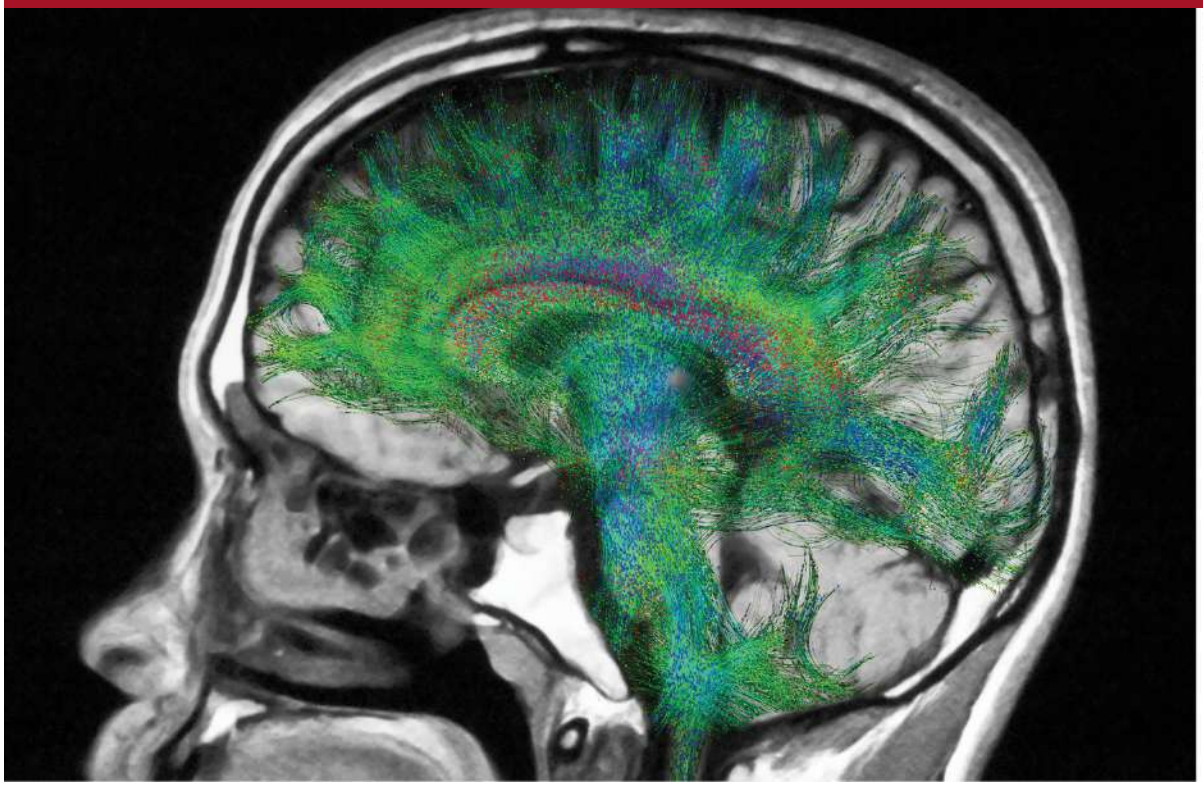
Presentation

Illustration Slides and Lecture Slides

Available for download from Achieve, these slides can either be used as they are or customized to fit the needs of your course. They feature the main points of the chapter with selected figures and illustrations.

CHAPTER 1

What Are the Origins of Brain and Behavior?



Callista Images/Cultura/Getty Images

The purpose of this book is to take you on a journey toward understanding the link between brain and behavior — to explore

how the brain is organized to produce behavior. This book also invites you to become a participant in the study of your own brain and behavior. Understanding the brain will change how you think about yourself and others, change how you view education and social interactions, and perhaps spur your interest in a career in neuroscience.

As you work through this book, it will become clear that neuroscience is not merely the study of brain function and brain disease — such as those described in Clinical Focus 1-1: Living with Traumatic Brain Injury — but is also intertwined with many other areas of study, including philosophy, psychology, and economics, to name a few.

Clinical Focus 1-1

Living with Traumatic Brain Injury

Fred Linge, a clinical psychologist with a degree in brain research, wrote this description 12 years after the car crash that resulted in his head injury:

> In the second it took for my car to crash head-on, my life was permanently changed, and I became another statistic in what has been called "the silent epidemic."
>
> During the next months, my family and I began to understand something of the reality of the experience of head injury. I had begun the painful task of recognizing and accepting my physical, mental, and emotional deficits. I couldn't taste or smell. I couldn't read even the simplest sentence without forgetting the beginning before I got

> to the end. I had a hair-trigger temper that could ignite instantly into rage over the most trivial incident….
>
> Two years after my injury, I wrote a short article: "What Does It Feel Like to Be Brain Damaged?" At this point in my life, I began to involve myself with other brain-damaged people. It brought me an enormous outpouring of letters, phone calls, and personal visits that continue to this day. Many were struggling as I had struggled, with no diagnosis, no planning, no rehabilitation, and most of all, no hope…. The catastrophic effect of my injury was such that I was shattered and then remolded by the experience, and I emerged from it a profoundly different person with a different set of convictions, values, and priorities. (Linge, 1990)

Adapting to an injured brain can come to dominate the lives of those who experience brain injury and disease as well as the lives of their friends and family members. In the absence of proper diagnosis and treatment, the challenges of brain injury often exceed the support that health systems and the community can provide.

Globally, brain disease and injury is the leading cause of disability and the second leading cause of death (GBD 2016 Neurology Collaborators, 2019). The National Institute of Neurological Disorders and Stroke estimates that 1.7 million U.S. residents receive medical attention each year after experiencing a **traumatic brain injury (TBI)** — a wound to the brain that results from a blow to the head or a **concussion**.

TBI frequently occurs from playing sports, from falls, and from vehicle accidents, and is the most common cause of discharge from military service. Throughout this book, you will encounter many of the 2000 or more disorders of the brain (see the index of major disorders on the inside front cover of this book). Disorders of the brain are among the challenges faced by individuals working in the field of *neuroscience*, the multidisciplinary study of the brain. Most people who suffer from TBI have to cope, at least to some degree, with Linge's forecast of "no diagnosis, no planning, no rehabilitation, and most of all, no hope."

Neuroscience looks at not only brain disease, but also the anatomy of the brain, its chemistry, physics, computational processes, influences on psychological functioning, and influences on sociological and economic factors. Neuroscience research can provide insights into individual differences, including differences in sexual orientation, cognitive function, and social behavior, and consciousness. It can address the challenges outlined by Linge by, for example, supporting improved diagnoses through imaging the anatomy, chemistry, and

electrical activity of the brain and rehabilitation using computer-assisted training and prosthetics.

Fred Linge died in 2021 at the age of 84, but during his life he displayed *posttraumatic growth*—he came to terms with his TBI and found meaning in life with the nontraditional therapy of “faith, hope and love.” We take up posttaumatic growth in Section 16-5.

1-1 The Brain in the Twenty-First Century

Learning Objectives

- Describe the research and societal benefits of the study of brain and behavior.
- Describe the human brain by identifying some of the defining components and by explaining its relationship to behavior.

The purpose of this chapter is to describe the relationship between brain and behavior. In this opening section, we first present the ideas that led to our current understanding of the role of the brain in behavior. Next, we describe the brains or brain-like structures of some of the 1.5 million animal species that have one. We end by discussing what makes the brain of each animal species, including humans, special.

The developing field of *neuroethics* addresses issues related to diversity, equity, and inclusion both with respect to training in neuroscience and with respect to research. A growing number of programs in research-funding agencies and in universities are directed toward making the field of neuroscience more diverse in terms of the research that is funded and through efforts to expand networks and career opportunities for historically underrepresented groups (Jones-London, 2020). In 2021, the National Institutes of Health (NIH) launched its UNITE initiative to help combat historical racial

inequalities across a wide variety of biomedical and health sciences. Recent diversity and inclusion efforts by the Society for Neuroscience and other institutions have sought to address inequities in representation and enhance career and research opportunities among historically under-represented groups. We will address neuroethical issues throughout this introduction to brain and behavior.

Why Study Brain and Behavior?

The *brain* is a physical object, a living tissue, a body organ. *Behavior* is action, momentarily observable but fleeting. Brain and behavior differ greatly, yet are also linked. They have evolved together: one is responsible for the other, which is responsible for the other, and so on. There are five reasons for linking the study of the brain to the study of behavior:

> Illustrated Experiments throughout the book reveal how neuroscientists conduct research, beginning with Experiment 1-1 in Section 1-2.

1. *How the brain produces behavior is a major scientific question.* Scientists and students study the brain to understand humanity. A better understanding of brain function will allow us to better understand many aspects of our world, including educational systems, economic systems, and social systems. Understanding our brain will also help us to understand our many cultural, religious, and sexual differences. In short, understanding our

brain will help us understand why we — that is, humans — are the most behaviorally diverse species.

2. *The brain is the most complex organ on Earth and is found in many groups of animals.* We study the brain to understand its place in the biological order of our planet. The importance we place on the brain extends deep into our cultures, as reflected in the many science fiction depictions of alien life, which assume that this life will include animals with brains. This chapter describes the basic function and evolution of the brain on our planet, especially the human brain.
3. *A growing list of behavioral disorders can be explained and treated as we increase our understanding of the brain.* As we have noted, more than 2000 disorders may be in some way related to brain abnormalities. As indicated in the Index of Disorders at the beginning of the book, we detail relationships between brain disorders and behavioral disorders in every chapter, especially in the Focus features. Understanding our brain helps us to understand the physical, mental, and emotional changes that occur as we develop and age, including disorders that emerge in childhood and continue to impact us throughout our lives. The better educated we are about the nature of brain and brain disorders, the better equipped we will be to develop effective treatments for these disorders.
4. *Study of the brain leads to an understanding of diversity*. The study of neuroscience gives us a more expansive understanding of the developmental complexity and individual differences, which can reduce stigma and break down social barriers that often pose

challenges for individuals with disorders. Although the field of neuroscience has not been immune to the influence of bias and prejudice, research geared toward obtaining a better understanding of brain disorders and differences has often operated ahead of social progress and is an important tool in combating stereotypes and misconceptions.

The concept of *neurodiversity,* originally developed by sociologist Judy Singer in the late 1990s, seeks to contextualize cognitive and behavioral disorders within a wider spectrum of normal variation across individuals.

5. *Study of the brain brings insights to other fields of knowledge and is a source of employment*. The field of neuroscience is becoming more diverse, as witnessed by the emergence of new areas of study, including neuropsychology, neurophilosophy, neuroeconomics, neurobiology, and neuroethics. Neuroscience is also having an impact on business, as shown by the application of neuroscience discoveries to a wide variety of industries, including medicine, drug development, data storage and analysis, and robotics. For example, deep learning, a kind of *artificial intelligence* (AI) developed from the study of brain networks, is becoming so sophisticated that scientists can create machines with truly brain-like properties.

None of us can predict how the knowledge we gain about the brain and behavior may prove useful. A former psychology major wrote to tell us that she took our course because she was unable to register in a preferred course. She felt that, although our course was interesting, it

was “biology, not psychology.” After graduating and getting a job in a social service agency, she has found — to her great delight — that understanding the links between brain and behavior is actually a source of insight into many of her clients’ disorders and the treatment options available for them.

What Is the Brain?

Brain is the Anglo-Saxon word for the tissue found within the skull. The brain, along with its vast connections with the organs of the body, is a part of the human nervous system (Figure 1-1). In subsequent sections, we will describe the relationships between the many animal species that have nervous systems and the subset of those species that have nervous systems that include some type of brain.

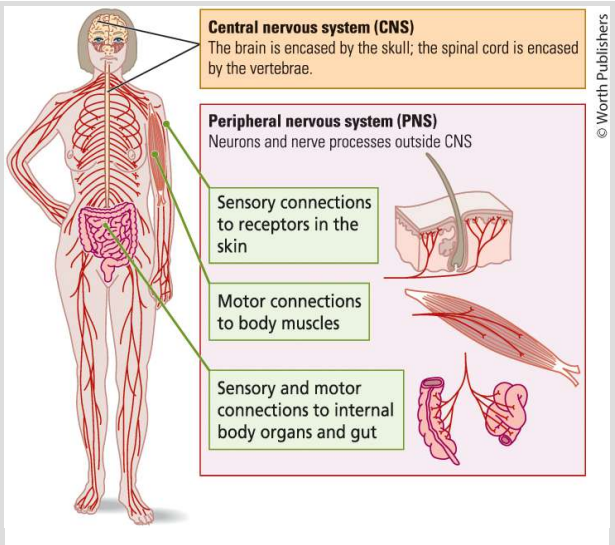


FIGURE 1-1 Major Divisions of the Human Nervous System The brain and spinal cord together make up the central nervous system. All of the nerve processes radiating

out beyond the brain and spinal cord and all of the neurons outside the CNS connect to sensory receptors, muscles, and internal body organs to form the peripheral nervous system.

The human nervous system is composed of cells, as is the rest of the body. Just over half of these nervous system cells (86 billion of them) are called **neurons**. Neurons are specialized in that they interconnect with each other and with the muscles and organs of the body and are involved with information processing. The other half of the nervous system cells (85 billion) are called **glial cells**, and they support the function of the neurons. These two cell types are described in detail in Chapter 2.

Through interconnections, neurons send electrical and chemical signals to communicate with one another, with sensory receptors in the skin, with muscles, and with internal body organs. Most of the interconnections between the brain and body are made through the spinal cord, a tube of nervous tissue encased in our vertebrae. The spinal cord, in turn, sends nerve fibers out to our muscles and internal body organs and receives fibers from sensory receptors on many parts of our body.

Together, the brain and spinal cord make up the **central nervous system (CNS)**, the part of our nervous system encased in bone. The CNS is called *central* because it is both the nervous system's physical

core and the core structure that mediates behavior. All the processes that radiate out beyond the brain and spinal cord constitute the **peripheral nervous system (PNS)**.

The human brain comprises many structures, but we will focus on two major divisions here. The **cerebrum (forebrain)**, shown in **Figure 1-2A**, has two nearly symmetrical halves, called **hemispheres**, one on the left and one on the right. The forebrain features a large number of structures, but the most prominent in the human brain is the neocortex. The **neocortex** ("new cortex"), often *cortex* for short (*cortex* means "bark" in Latin), is the crinkly tissue covering most of the rest of the brain. The cortex is proposed to be responsible for our conscious behavior.

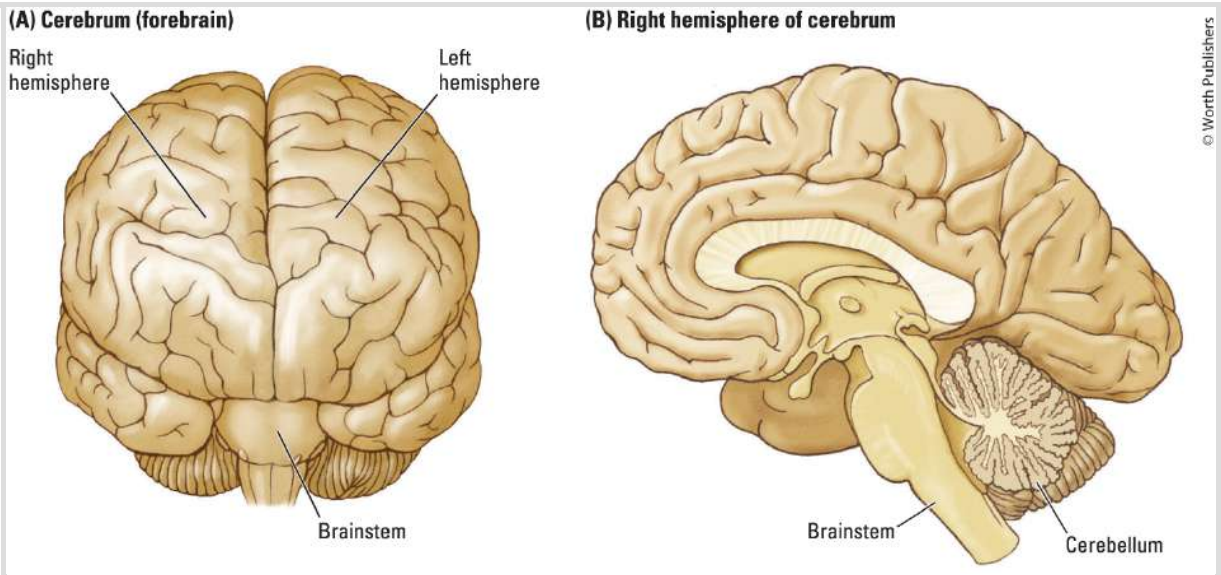


FIGURE 1-2 The Human Brain (A) Shown head-on, as oriented within the human skull, are the nearly symmetrical left and right hemispheres of the cerebrum. **(B)** A cut through the middle of the brain from back to front reveals the right hemispheres of the cerebrum and cerebellum and the right side of the brainstem. The spinal cord (not shown) emerges from the base of the brainstem.

The cortex enfolds the **brainstem** (Figure 1-2B), the set of structures responsible for most of our unconscious behavior. The dominant part of the human brainstem, the **cerebellum**, is specialized for learning and coordinating our movements. Although the forebrain and brainstem are associated with different general functions, they cannot manage these functions without each other. Thus, as will be discussed in later chapters, our conscious and unconscious behaviors are inextricably intertwined.

Chapter 2 describes the brain's functional anatomy.

So far, we have focused on the major components of the brain and nervous system, but there is more to the story. For his graduate research, our colleague Harvey chose to study the electrical activity of the brain in paralyzed animals. He speculated that it might be possible for a brain to live on in a bottle after the body died, and to continue functioning without receiving sensory information from the body or controlling bodily movements. He expected that his research would eventually allow a bottled brain to communicate with others who could read its electrical signals.

Harvey clearly proposed to preserve not just the brain but the *self*—consciousness, those processes such as language and memory that give us self-awareness and allowed us to interact with others. This

meaning of *brain* refers to something other than the organ found inside the skull. It is what we intend when we describe a person who is clever as being "a brain" or when we speak of the computer that guides a spacecraft as being the vessel's brain. The term *brain,* then, signifies both the organ itself and the fact that this organ produces behavior.

To return to Harvey's experiment, the effect of placing even the entire CNS in a bottle would be to separate it from the PNS and, therefore, from the sensations and movements the PNS mediates. Could the brain remain awake and conscious without sensory information and without the ability to move? This question is relevant to theories of behavior as well as to many fascinating experiments and observations that have presented us with information relevant to this question.

One theory, called **embodied behavior**, proposes that our thoughts and our movements are inseparable (Conca et al., 2021). For example, we understand one another not only by listening to words but also by observing gestures and other body language. We think not only with silent language but also with overt gestures and body language. According to this view, the brain, as an intelligent entity, cannot be divorced from the body's activities.

In the 1920s, Edmond Jacobson proposed that even when motionless, we still make subliminal movements related to our thoughts. The muscles of the larynx subliminally (imperceptibly) move when we think in words, for instance, and we make subliminal eye movements

when we imagine or visualize some action or a person, place, or thing. Jacobson had participants practice "total" relaxation and later asked them what the experience was like. They reported a condition of mental emptiness, as if the brain had gone blank (Jacobson, 1932).

Woodburn Heron took Jacobson's investigations a step further when, in 1957, he conducted experiments on sensory deprivation, a form of torture used in the Korean War (1950–1953). He asked, How does the brain cope without sensory input? Heron examined the effects of *sensory deprivation*, including feedback from movement, by having student volunteers lie on a bed in a bare, soundproof room and remain completely still. Padded tubes covered their arms so that they had no sense of touch, and translucent goggles cut off their vision. The participants reported that the experience was unpleasant, not just because of the social isolation but also because they lost their focus. Some even hallucinated, as if their brain were somehow trying to create the sensory experiences that they suddenly lacked. Most asked to be released from the study before it ended.

Evidence from people who have suffered nervous system injuries further illustrates the importance of understanding the relationship between overt behavior and consciousness. When Martin Pistorius was 12 years old, his health began to deteriorate. He lapsed into a coma, a condition in which he seemed completely unconscious. His parents placed Martin in a nursing home, where over a number of years he remained completely paralyzed.

Martin's condition persisted until, when he was 25, a nurse noticed him making some small facial movements. He seemed to be trying to communicate. Martin was not unconscious, but rather was suffering from **locked-in syndrome** — a condition in which a person is conscious but unable to move. With rehabilitation, he made excellent progress toward recovering movement in his head and arms. Using a voice synthesizer, he was eventually able to communicate verbally, and even gave a TED talk in 2015. He is married, has a child, and works as a Web developer. His 2011 book *Ghost Boy* describes his frustration and helplessness during years of enduring unrecognized locked-in syndrome. Pistorius's story shows that consciousness can persist in the absence of most overt movement.

Martin Pistorius

Another case study offers further insight into the importance of arousal, or being awake, for consciousness. The patient, a 38-year-old man with brainstem damage, had lingered in a **minimally conscious state (MCS)** for more than 6 years after an assault. He was occasionally able to follow simple commands and to communicate with single words. He could make a few movements but could not feed himself despite 2 years of inpatient rehabilitation and 4 years in a nursing home.

Nicholas Schiff and his colleagues (Edlow et al., 2021) reasoned that if they could stimulate the remaining brainstem in this patient by administering a small electrical current, they could improve his level of wakefulness and so enhance his behavioral abilities. As part of a **clinical trial** (a consensual experiment directed toward developing a treatment), they implanted thin wire electrodes in the patient's brainstem so they could administer a small electrical current.

Through these electrodes, which are visible in the X-ray image shown in **Figure 1-3**, the investigators applied electrical stimulation for 12 hours each day — a procedure called **deep brain stimulation (DBS)**. The researchers observed dramatic improvements in the patient's arousal. For the first time since his assault, he was able to feed himself and swallow food. During brain stimulation, he could interact with his caregivers and watch television, and showed further improvement in response to rehabilitation. Clearly, wakefulness and consciousness are connected.

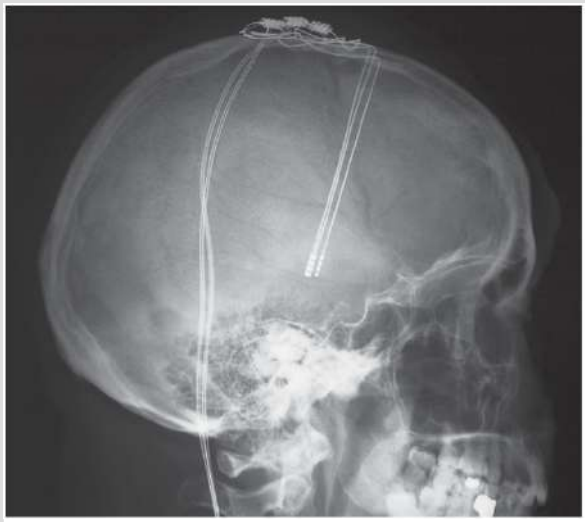


FIGURE 1-3 Deep Brain Stimulation X-ray image showing electrodes implanted in the thalamus, a structure deep in the brain near the tip of the brainstem, for DBS. DBS can treat disorders such as Parkinson disease and depression (see Section 16-3) and aid recovery from TBI (see Section 14-5).

Another remarkable line of investigation illustrates that consciousness can be present in the absence of all voluntary movement. Patients who have experienced a brain injury so severe that it places them in **persistent vegetative state (PVS)** are alive, but are unable to communicate and show no signs of any cognitive function. Adrian Owen and his colleagues asked whether by imaging the brains of some of these patients, they could assess the extent to which the patients were conscious. Using a magnetic resonance imaging (MRI) procedure that measures brain function in terms of oxygen use, Owen's group discovered that some comatose patients are conscious and can communicate when given the opportunity. (For a

discussion of Owen's experiments and their relevance to contemporary medical recommendations, see Scolding et al., 2021.)

> We refer to people who voluntarily take part in research studies as *participants* and to those who are in treatment for brain or behavioral impairments as *patients*; nonhuman animals are referred to as *subjects.*

Owen's group devised ways to communicate with these patients by using the signals in their brains' activity patterns (just as our colleague Harvey imagined could be done). When imaging the brains of control participants, Owen's group asked them to imagine hitting a tennis ball with a racket. When they did so, the researchers observed that their brain activity changed in association with the imaginary act. Next, the researchers asked the patients to imagine hitting a tennis ball. In response, some patients did exhibit activity similar to that of the control participants, showing that they understood the instructions. Owen's study demonstrated that some patients were conscious, which then allowed him to proceed with further efforts geared toward communication and rehabilitation.

> More research on TBI and other neurological disorders as well as treatments for these conditions are discussed in Sections 7-1, 14-5, and 16-3. Concussion is the topic of Clinical Focus 16-3.

Taken together, these studies reveal that the brain can be conscious to a great extent even in the absence of much overt behavior. They also show that in the absence of overt behavior, the brain can