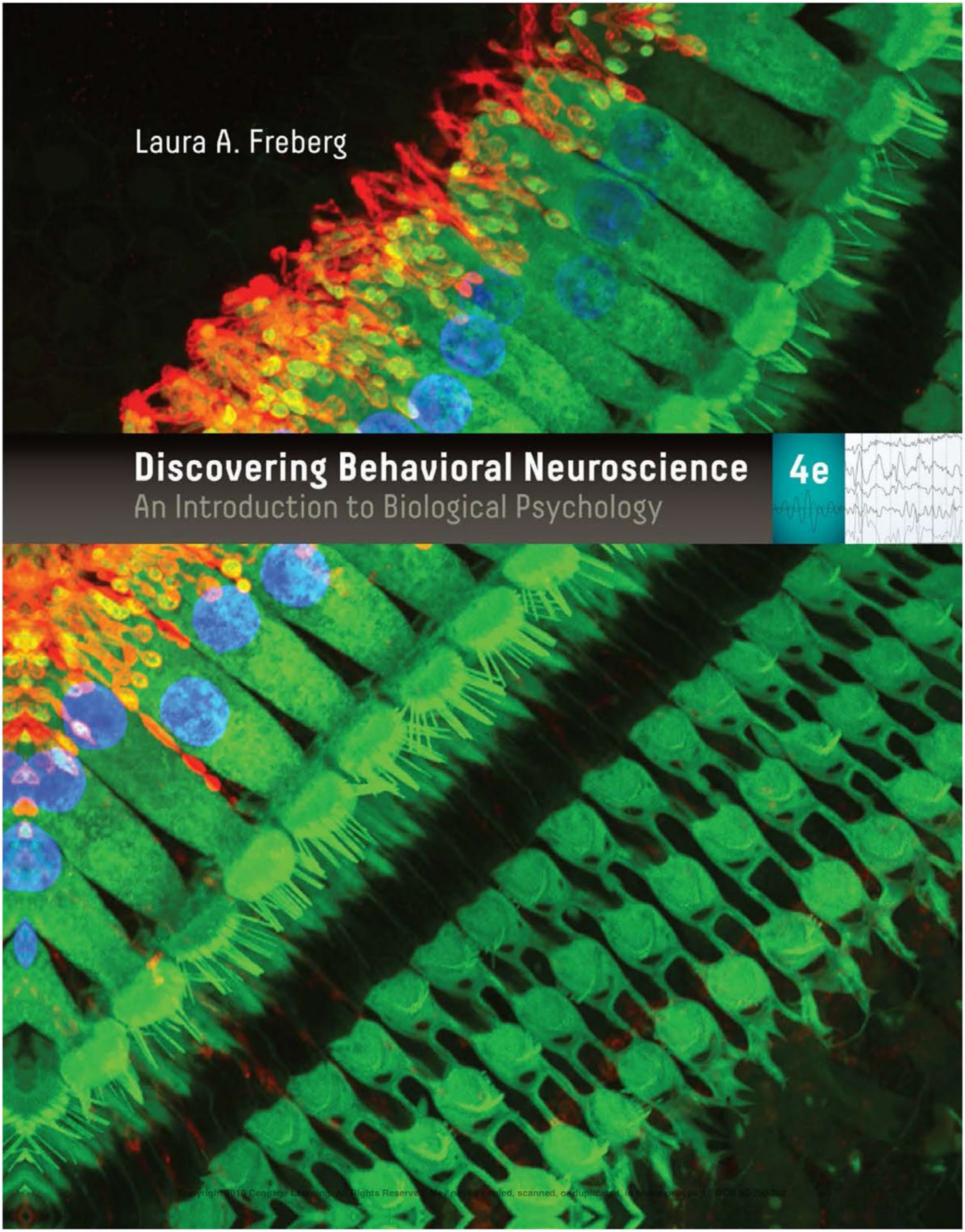

Laura A. Freberg

Discovering Behavioral Neuroscience 4e

An Introduction to Biological Psychology

Discovering Behavioral Neuroscience

AN INTRODUCTION TO BIOLOGICAL PSYCHOLOGY

Fourth Edition

Laura A. Freberg

California Polytechnic State University,
San Luis Obispo

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TO MY FAMILY
Roger, Kristin, Karen, and Karla

About the Author

Laura A. Freberg is Professor of Psychology at California Polytechnic State University, San Luis Obispo, where she teaches courses in Introductory Psychology, Biological Psychology, and Sensation and Perception. With John Cacioppo of the University of Chicago, Laura is the co-author of three editions of *Discovering Psychology: The Science of Mind* for Cengage Learning. She is also lead author on a new online Research Methods textbook.

Laura completed her undergraduate and graduate studies at UCLA, where her thinking about psychology was shaped by Eric Holman, John Garcia, O. Ivar Lovaas, Larry Butcher, Jackson Beatty, John Libeskind, Donald Novin, Frank Krasne, and F. Nowell Jones. She was privileged to study neuroanatomy with Arnold Scheibel, and she investigated the effects of psychoactive drugs on learning and memory under the direction of Murray Jarvik and Ronald Siegel in the UCLA Neuropsychiatric Institute. As a capstone to her education, Laura completed her dissertation with Robert Rescorla, then at Yale University.

Laura's teaching career began when she taught her first college course at Pasadena City College at the age of 23 while still a graduate student at UCLA. Beginning in 2011, to better understand the needs of the online education community, she also began teaching for Argosy University Online, including courses in Social Psychology, Sensation/Perception, Cognitive Psychology, Statistics, Research Methods, and Writing in Psychology. She has also redesigned her Cal Poly introductory course according to QOLT standards to be administered completely online. She has received Faculty Member of the Year recognition from Cal Poly Disabilities Resource Center three times (1991, 1994, and 2009) for her work with students with disabilities. She enjoys using technology and social media in the classroom and is a Google Glass Explorer. Laura enjoys collaborating with daughters Kristin Saling (Systems Engineering—U.S. Military Academy at West Point) and Karen Freberg (Communications—University of Louisville) on a variety of research projects in crisis management and public relations as well as in psychology. She serves as the Bylaws and Archives Committee Chair for the Society for Social Neuroscience and was recently elected President-Elect of the Western Psychological Association (WPA).

In her spare time, Laura enjoys family time with her husband, Roger, their youngest daughter Karla, who has autism spectrum disorder, and an active menagerie including an Australian shepherd, two cats, and three parakeets. She usually writes while consuming vast quantities of Gevalia coffee and listening to the Rolling Stones (which might be apparent in the book's writing style), and she has been known to enjoy college football, Harley Davidsons, episodes of *Game of Thrones* that do not feature weddings, and *Sherlock*. Her ringtone is from Nintendo's *Legend of Zelda*.

Brief Contents

About the Cover

If you are familiar with the first three editions of this textbook, you know that we like to pick colorful visuals that portray the biology behind the behavior. For this fourth edition, we selected an image of the Organ of Corti in the inner ear produced by Sonja Pyott of the Univeristy of Groningen using a technique known as confocal microscopy. Confocal microscopy produces superior resolution compared to conventional, wide-field microscopes. This stunning image was awarded fourth place in the annual Olympus BioScapes International Digital Imaging Competition in 2007. The green structures are the hair cells of the cochlea (see Chapter 7), and the nuclei of the inner hair cells appear in blue. Neurons making contact with the hair cells appear red.

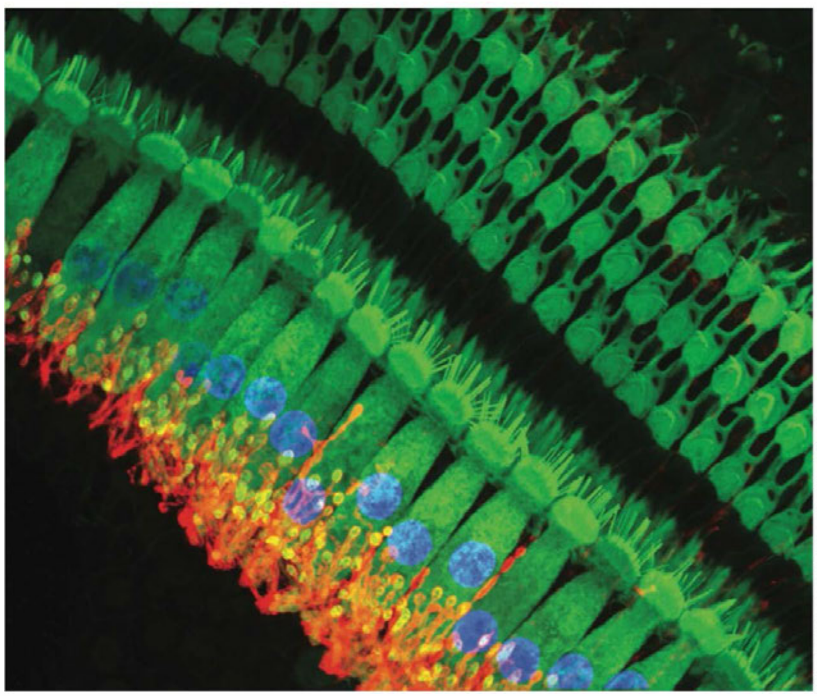

Photo by Dr. Sonja Pyott, University of North Carolina

Contents

Preface

> "[I]n teaching, you must simply work your pupil into such a state of interest in what you are going to teach him that every other object of attention is banished from his mind; then reveal it to him so impressively that he will remember the occasion to his dying day; and finally fill him with devouring curiosity to know what the steps in connection with the subject are."
>
> —William James (1899, p. 10)

James's goals for the classroom instructor might seem lofty to some, but many of us who teach neuroscience have enjoyed the peak experience of seeing students "turn on" to the material in just the way James describes.

This is an exciting time to be a neuroscientist. Every day, science newsfeeds announce some new and dramatic breakthroughs in our knowledge about the nervous system and the human mind. Important questions raised in the past now have definitive answers. In 1890, James commented that "blood very likely may rush to each region of the cortex according as it is most active, but of this we know nothing" (vol. 1, p. 99). With today's technology, it is safe to say we now know much more than "nothing" about this phenomenon James described.

Much has changed in the field of neuroscience since our first edition of this textbook in 2006. More than half of the four-year universities in the United States now offer bachelor's degrees in neuroscience, and most offer at least a minor in the discipline. Neuroscience reflects a general academic trend of the twenty-first century, in which the walls separating specializations are giving way to new, transdisciplinary research teams, courses, and educational programs. In recognition of these changes, we modified the title of the third edition of this textbook from *Discovering Biological Psychology* to *Discovering Behavioral Neuroscience: An Introduction to Biological Psychology*. This change was welcomed by our faculty and student audiences. A greater emphasis on the neurosciences in general is also achieved by renaming some chapter titles. Psychology still provides a foundation for the study of behavioral neuroscience, as without the ability to ask the right questions about behavior and mental processes, all of the technology on the planet wouldn't do us much good. Our current behavioral neuroscience students, however, are just as likely to be preparing for careers in the health professions, biomedical engineering, or even scientific journalism as they are in psychology.

A major reflection of the transdisciplinary approach exemplified by the neurosciences is the inclusion of psychology and behavioral neuroscience content in the revised edition of the Medical College Admission Test (MCAT) beginning in 2015. One hundred years ago, the leading killers of humans were infectious diseases. Today's top killers—heart disease, diabetes, and cancer—have far stronger relationships with behavior, not only in their causes but also in their treatments. A simple five-minute conversation with a health professional about the need to quit smoking is sufficient to lead to abstention for one year by2 percent of patients (Law & Tang, 1995). This might not sound like much, but given the 20 percent or so of American adults who smoke and the billions of dollars their health care and lost productivity represent, the stakes are high. Imagine what could be accomplished by health care providers who have a deep understanding of learning, motivation, and social influences on behavior. In response to these and similar trends, the current edition of the textbook explores relevant applications to students pursuing fields of study other than psychology whenever these are relevant.

This fourth edition continues and expands on the goals of the previous three:

- To provide challenging, current content in a student-friendly, accessible form.
- To stimulate critical thinking about neuroscience by presenting controversial and cutting-edge material.
- To promote active student engagement and excitement about the neurosciences.
- To integrate across chapters rather than treating them as stand-alone modules; to encourage students to see the connections among the topics. For example, connections are made between glutamate as a chemical messenger, its role in learning, the effects of psychoactive drugs on glutamate, its role in psychosis, and its importance to the causes and treatments of stroke and epilepsy.

Pedagogical Features

We realize that a course in behavioral neuroscience can be challenging for many students, particularly those who are underprepared for science courses. To make the process of mastering behavioral neuroscience concepts easier, we have included the following features:

- **Accessible Writing Style** Many textbooks are classified by "level," but it is my opinion that the most complex topics can be mastered by students across a wide range of preparation if the writing style is clear. Students and instructors from the community college through the top R1 universities have kindly complimented me on the accessible writing style used in this textbook. The textbook is also widely adopted in non-English-speaking countries, which suggests that the writing style is manageable for those for whom English is not a first language.
- **Clear, Large, Carefully Labeled Illustrations** Our medical-quality anatomical illustrations help students visualize the structures and processes discussed in each part of the textbook. Behavioral neuroscience is similar to geography in its highly visual nature, and both fields require more visual aids than most other courses. The illustrations in the textbook are augmented by a set of online animations that help the student grasp processes over time, such as the propagation of action potentials down the length of an axon.
- **Learning Objectives and Chapter Outlines** Each chapter begins with a concise set of learning objectives designed to tap into higher levels of Bloom's taxonomy, as well as an outline of the chapter's content. These features assist students in planning their learning and in becoming familiar with main terms and concepts to be covered.
- **Margin Glossaries** We regularly provide margin definitions for many difficult terms. Unlike many textbooks, we do not restrict margin definitions to key terms only. In the electronic forms of the book, these take the form of pop-up definitions, with which students are familiar from their online searching experience.
- **Key Terms** We provide a concise list of key terms to help students focus their learning. Behavioral neuroscience can often seem more like a foreign language course than a science course, and students benefit from guidance regarding which terms should be prioritized.
- **Interim Summaries** Each chapter features two to three interim summaries where students can catch their breath and check their mastery of the material before proceeding. These summaries feature summary points keyed to the learning objectives listed at the beginning of each chapter as well as review questions. Most interim summaries also include a helpful table that pulls together key concepts from the previous section in one convenient place.
- **Chapter Integration** To emphasize how the material fits together and to promote elaborative rehearsal, we make references to other chapters relevant to the topic at hand.

- **Chapter Review** At the end of each chapter, the student will find some thought questions that can also serve as essay or discussion prompts. The Chapter Reviews also include the list of key terms.
- **Practice Tests** In the electronic version of the textbook (see the description of MindTap), practice tests will be available for each main heading with a comprehensive practice test at the end of each chapter.

Additional Features

Students have told me that the narrative of the textbook is "packed" and that skimming paragraphs is usually a recipe for disaster, as each sentence "counts." In defense, I respond that we have so much to say and so little room to say it in that there is little space for "fluff." At the same time, psychological science shows that spaced learning is superior to massed learning, so it is a good idea to provide regular breaks in the narrative to allow students to catch their breath and digest what they have read. We like to think of these breaks as cool stepping-stones in the flow of lava.

One type of break that we used in the previous editions and continue here in the fourth is the use of interim summaries that include section summary points and review questions. Most also feature tables that pull together chunks of material in a way that makes it easy to learn. Any complex field like the neurosciences entails a bit of simple, rote memorization to form a foundation for later analysis and critical thinking. The more quickly we can bring students up to speed on the basics, the faster we can move on to higher levels of discussion. Chapter summaries include thought questions designed to push students to think more actively and deeply about what they have read.

In addition to the interim and chapter summaries, each chapter includes four types of features. We recognize that "boxing" material often encourages students to overlook content unless expressly instructed to read the boxes, but we trust instructors to use these in ways consistent with their personal style. Obviously, we hope that the content is sufficiently engaging that students will read the material regardless of "what's on the test."

- **Thinking Ethically** features introduce controversial, contemporary questions that require the students to use the information in the chapter in critical ways. Our students will graduate to become community leaders, and they need to be able to think ethically about future cultural choices related to the neurosciences. For example, this feature in Chapter 1 follows a discussion of brain imaging technology with questions about the potential use of brain imaging as a "lie detection" technology.
- **Connecting to Research** features highlight either classic or very contemporary single studies in behavioral neuroscience. This provides students with a "soft" segue into the scholarly literature, which might otherwise seem somewhat intimidating. The feature emphasizes the type of critical thinking and creativity required to advance science. For example, this feature in Chapter 2 describes the recent paradigm-shifting discovery about the links between the brain and the immune system.
- **Behavioral Neuroscience Goes to Work** features expose students to some of the many real-world career paths that relate to behavioral neuroscience. In my experience, many students are unaware of a number of these options. They love the material but have no idea how they can meld this passion with their need to find employment. In this feature in Chapter 5, we describe the role of the genetics counselor, whose insights will be increasingly important as the public obtains more information about personal genotypes. As a bridge between biological sciences and the counseling professions, this career has become increasingly popular with my students. At least a dozen who are now enrolled or who have completed genetics counseling master's degrees attribute their career choice to my "selling" this concept in class.

- **Building Better Health** features provide an additional opportunity for students to think critically about behavioral neuroscience in the context of real-world health problems. How does your mindset regarding food (healthy versus indulgent) affect your satiety? Why are microglia important for our understanding of autism spectrum disorder? Will legalization of marijuana influence attitudes and prevalence of use?

New Content for the Fourth Edition

This new edition contains hundreds of new citations to reflect the advances in the field that have occurred since the previous edition went to press. Textbook authors are often challenged by colleagues with questions about "why do you need a new edition?" In behavioral neuroscience, this question is easy to answer: we have so much new, exciting research to share.

Illustrations have also been updated to reflect the new content. Because space is so precious, illustrations are viewed as "teachable moments" that expand on or further explain the narrative rather than redundant, "pretty" placeholders. We are especially proud of our medical-quality anatomical illustrations, which have been the source of much positive feedback through the previous editions.

Space does not permit me to provide an exhaustive list of the updates, but here are some of the chapter-by-chapter highlights:

Chapter 1 What Is Behavioral Neuroscience?

- Expanded discussion of microscopic methods, including flourescent microscopy
- Added description of optical imaging
- Updated and expanded discussion of optogenetics
- Added section on genetic screens

Chapter 2 Functional Neuroanatomy and the Evolution of the Nervous System

- Added discussion of work by Louveau et al. (2015) demonstrating connectivity between the brain and the immune system
- Expanded discussion of the cingulate cortex, amygdala, and periaqueductal gray
- Refreshed Connecting to Research feature with a detailed explanation of Louveau et al. (2015) and connections between the immune system and the brain
- Refreshed Building Better Health feature with a discussion of epidural stimulation and standing/walking in patients with spinal damage

Chapter 3 Neurophysiology: The Structure and Function of the Cells of the Nervous System

- Added section on ependymal cells
- Added discussion of exosomes
- Updated and expanded discussion of microglia
- Expanded discussion of gap junctions
- Distinguished between wiring transmission and volume transmission
- Refreshed Building Better Health feature with a discussion of microglia and autism spectrum disorder

Chapter 4 Psychopharmacology

- Updated discussion of neurotransmitter, neuromodulator, and neurohormone terms
- Updated discussion of cocaine and amphetamine methods of action
- Expanded discussion of opioids
- Added discussion of hallucinogen persisting perception disorder (HPPD)
- Refreshed Building Better Health feature with discussion of the implications of legalization on attitudes toward and the prevalence of use of marijuana

Chapter 5 Genetics and the Development of the Human Brain

- Added discussion of partial dominance and codominance
- Added discussion of gene silencing to section on epigenetics
- Added discussion of the Zika virus and microencephaly
- Expanded and updated discussion of brain development in childhood, adolescence, and young adulthood
- Refreshed Building Better Health feature with a discussion of nutritional cognitive neuroscience and healthy aging
- Added comprehensive summary table of milestones in prenatal nervous system development
- Added comprehensive summary table of major neurodevelopment events from birth to late adulthood

Chapter 6 Vision

- Expanded and clarified discussion of visual receptive fields, including additional illustration
- Updated discussion of vision restoration
- Added discussion of "The Dress" to section on color constancy

Chapter 7 Nonvisual Sensation and Perception

- Added section on synaesthesia
- Updated and expanded discussion of loudness perception
- Added discussion of the McGurk effect
- Added discussion of the effects of using profanity to the experience of pain
- Expanded discussion of the connections between olfaction and dementia

Chapter 8 Movement

- Added discussion of M lines and tropomyosin
- Expanded discussion of motor units
- Added discussion of direct and indirect systems linking the thalamus, basal ganglia, and cerebral cortex
- Updated discussion of amyotrophic lateral sclerosis (ALS)
- Added discussion of CRISPR to Thinking Ethically feature on Gene Doping for Strength

Chapter 9 Homeostasis, Motivation, and Reward

- Moved topic of reward from Chapter 14 to better reflect its role in motivated behavior
- Added discussion of drive and incentive approaches to motivation
- Streamlined discussions of temperature, thirst, and hunger
- Updated discussion of obesity
- Introduced distinction between liking and wanting to organize discussion of reward pathways
- Expanded and updated discussion of the neurochemistry of reward

Chapter 10 Sexual Behavior

- Added discussion of mini-puberty
- Updated discussion of Turner syndrome
- Added summary section on lessons learned from sex chromosome abnormalities
- Added discussion of the organizing roles of sex chromosome genes
- Added discussion of brain imaging and gender dysphoria
- Updated discussion of hormones and sexual interest
- Updated discussion of oxytocin and bonding
- Updated discussion of the treatment of sexual dysfunction
- Updated Building Better Health feature on antidepressant-induced sexual dysfunction

Chapter 11 Biorhythms

- Updated discussion of shift work type circadian disorders
- Expanded discussion on mechanisms of light therapy
- Updated and expanded discussion of default mode network (DMN) and its relationship to levels of consciousness
- Expanded discussion of eye movements during REM
- Updated and expanded discussion of memory consolidation and reconsolidation during sleep, including elimination and maintenance of synapses during REM
- Added section on sleep and emotion regulation

Chapter 12 Learning and Memory

- Reorganized chapter material to reflect the continuity between learning and memory
- Expanded and clarified discussion of long-term potentiation (LTP)
- Expanded discussion of working memory, including a further discussion of the role of LTP
- Expanded discussion of memory consolidation and reconsolidation, including the role of transcription factors
- Updated discussion of conditioned fear
- Updated discussion of Henry Molaison (Patient H.M.) and the relationships between the hippocampus and cortex in memory formation
- Updated the discussion of stress effects on memory

Chapter 13 Cognitive Neuroscience

- Changed chapter title to reflect the organization of topics
- Added section on decision making, including a discussion of neuroeconomics
- Updated section on the development of lateralization
- Updated section on the lateralization of emotion and music abilities
- Expanded discussion of intelligence to include genome-wide association studies
- Updated Thinking Ethically feature on performance-enhancing drugs for the mind

Chapter 14 Emotion, Reward, Aggression, and Stress

- Reordered topics to present major theories earlier in the chapter
- Added sections on emotion regulation and social cognition
- Updated and expanded discussion of detecting deception

Chapter 15 Neuropsychology

- Updated section on Alzheimer's disease
- Updated section on brain tumors
- Added information about the Zika virus
- Updated section on migraine

Chapter 16 Psychopathology

- Added discussion of the NIMH Research Domain Criterion project (RDoC)
- Updated section on autism spectrum disorder (ASD), including discussion of paternal age, default mode network differences, and microglia actions
- Clarified and updated research on saccades and schizophrenia
- Expanded discussion of the roles of dopamine and glutamate in schizophrenia
- Updated discussion of tardive dyskinesia
- Updated discussion of causes of bipolar disorder
- Introduced the hypothesis that inflammation plays a role in major depressive disorder (MDD)
- Expanded the discussion of obsessive-compulsive disorder (OCD)
- Updated the section on posttraumatic stress disorder (PTSD)
- Updated the section on antisocial personality disorder (ASPD)
- Refreshed the Building Better Health feature with a discussion of the gut microbiota and mental disorders

MindTap

MindTap® Psychology: *MindTap® for Discovering Behavioral Neuroscience: An Introduction to Biological Psychology* 4th edition is the digital learning solution that helps instructors engage and transform today's students into critical thinkers. Through paths of dynamic assignments and applications that you can personalize, real-time course analytics, and an accessible reader, MindTap helps you turn cookie cutter into cutting edge, apathy into engagement, and memorizers into higher-level thinkers.

As an instructor using MindTap you have at your fingertips the right content and unique set of tools curated specifically for your course all in an interface designed to improve workflow and save time when planning lessons and course structure. The control to build and personalize your course is all yours, focusing on the most relevant material while also lowering costs for your students. Stay connected and informed in your course through real-time student tracking that provides the opportunity to adjust the course as needed based on analytics of interactivity in the course.

Instructor Ancillaries

Online Instructor's Manual: The manual includes learning objectives, key terms, a detailed chapter outline, a chapter summary, lesson plans, discussion topics, student activities, media tools, a sample syllabus and an expanded test bank. The learning objectives are correlated with the discussion topics, student activities, and media tools.

Online PowerPoints: Helping you make your lectures more engaging while effectively reaching your visually oriented students, these handy Microsoft PowerPoint® slides outline the chapters of the main text in a classroom-ready presentation. The PowerPoint® slides are updated to reflect the content and organization of the new edition of the text.

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I view this text as a work in progress. Please take a moment to share your thoughts and suggestions with me: lfreberg@calpoly.edu. You can also find me on Facebook, on Twitter as @biopsych, and on my blog: http://www.laurafreberg.com/blog.

I am enormously grateful for the team that Cengage assembled to help make this book a reality. First, I would like to thank my professional colleagues who reviewed the many drafts of one or more of the four editions:

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I would like to give a special thank you to several colleagues. ***Skirmantis Janusonis*** of the University of California, Santa Barbara, has provided not only encouragement but also gentle suggestions for improved accuracy. Skirmantis kindly provided me with an opportunity to photograph some of his human brains (one appears in Chapter 1), and he shared an image of his fantastic dissection of the hippocampus for us to use in Chapter 2. ***Simon LeVay*** is a gifted researcher and a truly elegant writer. His careful review of the chapter on sexual behavior for the first edition is deeply appreciated. I am indebted to Simon for pointing out many important studies included in the sections on sexual orientation and gender differences in cognition. ***Marie Banich*** at the University of Colorado at Boulder provided her expert opinions on the art program, and ***Gayle Brosnan-Watters*** at Arizona Christian University contributed many helpful suggestions as a reviewer and while working with me on the third edition of the Test Bank. ***John Cacioppo*** of the University of Chicago generously shared his considerable insight into the social aspects of neuroscience. ***Konstantinos Priftis*** of the University of Padova supplied several helpful corrections to the second edition. ***Robert Matchock*** of the University of Pennsylvania, Altoona, has been a friendly voice of encouragement beginning with the first edition. The late ***Larry Butcher*** of UCLA, one of my former professors, provided valuable assistance in the fine-tuning of my cholinergic pathway image in Chapter 4. ***Rick Howe*** and the students and faculty of the psychology department at College of the Canyons in California not only took the time to meet with me to share their reactions to the first edition but fed me cookies as well.

At Cengage, Erin Schnair, product manager for psychology, has championed my text through this edition. Linda Man, my content developer for the fourth edition, was my sounding board and partner every step of the way. Ruth Sakata Corley, senior project manager, guided the production of the text and coordinated innumerable aspects of the art and text program. Photo researcher Geeta Kamath tenaciously pursued the photos that enliven the text. Vernon Boes, art director, guided our design to new heights in appeal and usability. One faculty adopter referred to the design as "Steve Jobs-esque," which we view as the ultimate compliment. I would also like to thank the many other capable and creative professionals at Cengage who contributed to this project in ways large and small over the years of its development.

Finally, I would like to thank my family for their patience and support. Roger, my husband of 45 years, read every word, helped me choose photos, and even contributed some of our original sketches when I had trouble articulating what I wanted to show. My daughters, Kristin, Karen, and Karla, frequently offered their encouragement and perspectives. My Australian shepherd, Ronnie, waited patiently by my desk until it was time to clear the mind with a walk through some beautiful San Luis Obispo scenery. I am very much indebted to all.

Laura A. Freberg

CHAPTER 1

What Is Behavioral Neuroscience?

LEARNING OBJECTIVES

LO1 Classify the subfields of neuroscience, and explain how behavioral neuroscience fits within the field.

LO2 Interpret the significance of the major historical highlights in the study of the nervous system.

LO3 Differentiate the brain imaging technologies, including CT, PET, SPECT, MRI, fMRI, and DTI.

LO4 Assess the use of microscopic, recording, stimulation, optogenetic, lesion, and biochemical methods in behavioral neuroscience.

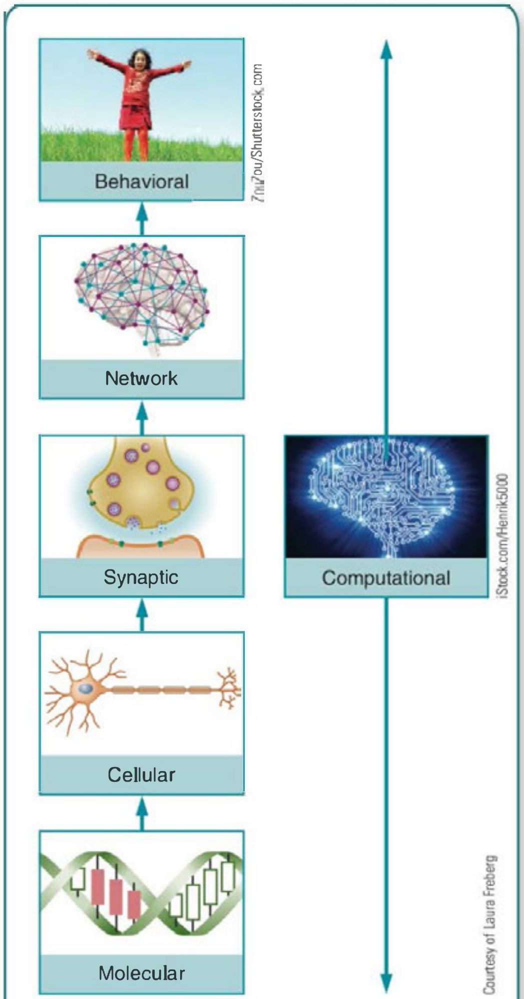
LO5 Analyze the relative strengths and weaknesses of twin studies, adoption studies, and genetic screens for understanding behavior.

LO6 Evaluate the ethical standards used to protect human and animal research participants.

CHAPTER OUTLINE

Neuroscience as an Interdisciplinary Field

Neuroscience is the scientific study of the brain and nervous system, in health and in disease (UCLA, 2008). Neuroscientists strive to understand the functions of the brain and nervous system across a number of levels of analysis, using molecular, cellular, synaptic, network, computational, and behavioral approaches (see ● Figure 1.1). You might think of this field as analogous to Google Earth. We can zoom in to see the tiniest detail and then zoom back out again to see the "big picture."



● **Figure 1.1 The Neurosciences: Building from Molecule to Behavior**

Beginning at the most microscopic level, the molecular neuroscientist explores the nervous system at the level of the molecules that serve as its building blocks. We will cover their work in our chapters on neural cell physiology (Chapter 3), psychopharmacology (Chapter 4), and genetics (Chapter 5). Starting with DNA and RNA and the proteins resulting from gene expression, the molecular neuroscientist attempts to understand the chemicals that build the system and make neural functioning possible.

Zooming out just a bit from the molecular level of analysis, we find the cellular neuroscientist hard at work outlining the structure, physiological properties, and functions of single cells found within the nervous system. These isolated cells would be of no use unless they could forge connections, which they do at junctions we call synapses. Synaptic neuroscience examines the strength and flexibility of neural connections, which underlie complex processes such as learning and memory.

Beyond the single synapse, we find that interconnected neurons form pathways or networks. In contemporary neuroscience, we are seeing a move away from the idea that "this structure engages in this function" to ideas that more accurately reflect neural networks that have been identified. We are more likely to say that "this structure participates in a network connecting these other structures to engage in this type of processing."

Zooming out perhaps to the most global point of view, we find **behavioral neuroscience,** also known as **biological psychology,** which is the primary focus of this textbook. Behavioral neuroscientists use all of the previous levels of analysis, from the molecular up through the network, in their efforts to understand the biological correlates of behavior. The relationship between biology and behavior is reciprocal—biology can impact our behavior, and behavior, including your cognitions and emotions, impacts biology. The experiment described in the Connecting to Research feature illustrates this reciprocal relationship. The way you think about what you're eating can influence your physical reaction to the food.

Like the neurosciences in general, behavioral neuroscience looks at the activity of the nervous system in health and in cases of illness, injury, and psychological disorder. Subspecialties within behavioral neuroscience include cognitive neuroscience, or the study of the biological correlates of information processing, learning and memory, decision making, and reasoning. We investigate these topics in depth in chapters on sensation and perception (Chapters 6 and 7), learning and memory (Chapter 12), and cognition (Chapter 13). Social neuroscience, covered in Chapter 14, explores the interactions between the nervous system and our human social environment and behavior.

Computational neuroscience runs parallel to the types of neuroscience described so far, but it draws from computer science, electrical engineering, mathematics, and physics to produce models of the nervous system from the molecular up through the behavioral levels of analysis. The predictions from these computational models can

neuroscience The scientific study of the brain and nervous system in health and in disease.

behavioral neuroscience/biological psychology The study of the biological foundations of behavior, emotions, and mental processes.

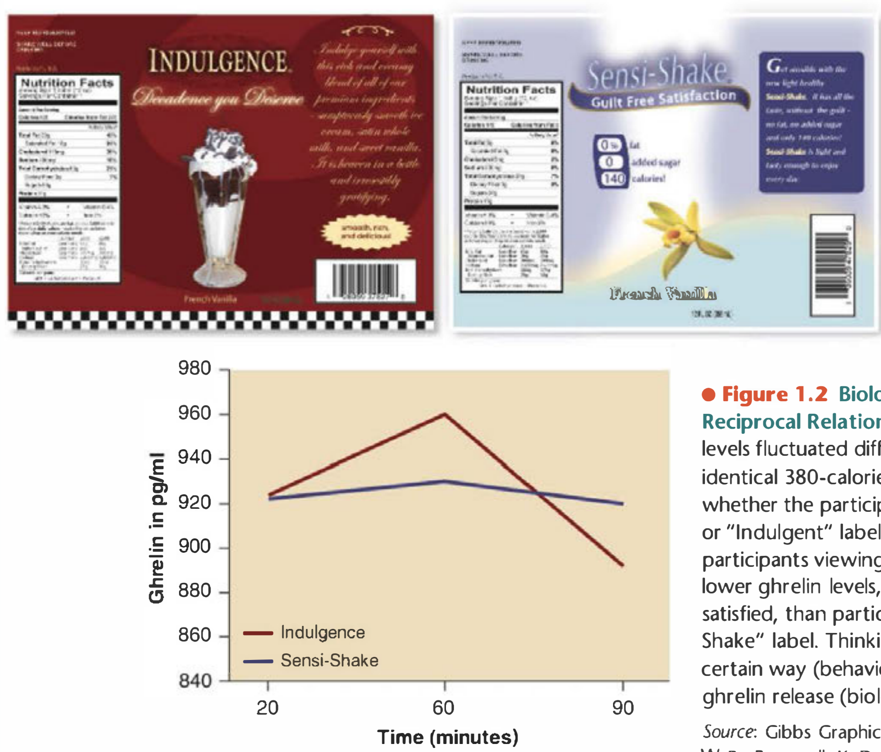
Connecting to **Research**

THINKING ABOUT YOUR FOOD AS HEALTHY OR INDULGENT AFFECTS YOUR PHYSICAL REACTIONS TO EATING

One of the key aspects of behavioral neuroscience that we introduce in this chapter is the reciprocal nature of the relationship between biology and behavior. Most of us are quite familiar and comfortable with the idea that our biology can influence our behavior, but the influence of behavior on biology is perhaps less obvious. A clever study by Alia Crum and her colleagues (2011) provides a compelling illustration of the reciprocal influences of biology and behavior by exploring factors that lead to hunger and feelings of fullness or satiety.

When you haven't eaten for a while, you release a gut hormone called ghrelin that tells your brain that you're hungry (see Chapter 9). Once you eat something, the release of ghrelin is suppressed, and you no longer feel hungry. So your biology (how much ghrelin is released) initiates behavior (feeling hungry or feeling satisfied). So far, so good.

At the same time, the way you think about eating can affect your body's responses to food. Simply telling research participants that their 380-calorie milkshake was either "sensible" or "indulgent" produced big differences in the amount of ghrelin released (Crum, Corbin, Brownell, & Salovey, 2011) (see ● Figure 1.2). After consuming the "sensible" shake, ghrelin levels didn't change much, which means that the participants still felt hungry and unsatisfied. After consuming the "indulgent" shake, ghrelin levels dropped significantly and the participants felt more satisfied. In other words, thinking about the shake as sensible or indulgent (behavior) had a remarkable impact on biology (large or small ghrelin release). There are no guarantees that praising your healthy salad as indulgent will help you stick to your diet, but it can't hurt to try!



Courtesy of Alia Crum and Gibbs Graphics

● **Figure 1.2 Biology and Behavior Form Reciprocal Relationships** Participants' ghrelin levels fluctuated differently after drinking an identical 380-calorie milkshake depending on whether the participant viewed a "Sensi-Shake" or "Indulgent" label at Minute 20. By Minute 90, participants viewing the "Indulgent" label had lower ghrelin levels, associated with feeling satisfied, than participants viewing the "Sensi-Shake" label. Thinking about the milkshake a certain way (behavior) had a dramatic effect on ghrelin release (biology).

Source: Gibbs Graphics, Crum, A. J., Corbin, W. R., Brownell, K. D., & Salovey, P. (2011). Mind over milkshakes: Mindsets, not just nutrients, determine ghrelin response. *Health Psychology, 30*(4), 424–429.

then be tested against living systems, forming a cooperative symbiosis with researchers in other areas of neuroscience. One of the practical applications of computational neuroscience is the use of neural decoding, or using neural activity to estimate what the brain is doing, in the development of sophisticated prosthetic devices. The devices can use neural activity to figure out the brain's intentions to move in certain ways or perceive certain types of input as touch.

These different levels of analysis complement each other rather than compete with one another. Because of the diversity of skills needed to pursue each of these approaches, neuroscience is an essentially interdisciplinary field of study, reaching across traditional academic departments of biology, chemistry, psychology, medicine, mathematics, physics, engineering, and computer science.

The need for better understanding of the nervous system has never been greater. The Society for Neuroscience (2012) reported that neurological illnesses impact one out of six Americans annually at a cost of more than $500 billion for treatment, which does not include the cost of disability. Delaying the onset of Alzheimer's disease on an average of five years would save the United States $50 billion in annual health care costs. Connections between biology and behavior are not just relevant to neurological disease, but they inform our understanding of health in general. Compared to 100 years ago, when most people died from infectious diseases, today's killers (cancer, diabetes, heart disease) are tightly linked to behavior. Reflecting recognition of the role of behavior in illness, the standardized Medical College Admission Test (MCAT) for medical school applicants now contains a significant number of questions about psychology and behavioral neuroscience.

Illness is only part of the human equation. We also need to understand how the nervous system responds in typical ways to promote well-being, including better relationships, better parenting, better child development, and better thinking and learning. Through improved understanding of the nervous system and its interactions with behavior, scientists and practitioners will be more thoroughly prepared to tackle the significant challenges to health and well-being faced by contemporary world populations.

Behavioral Neuroscience GOES TO WORK

WHAT CAN I DO WITH A DEGREE IN NEUROSCIENCE?

One of the pleasures of teaching courses in behavioral neuroscience occurs when a student suddenly falls in love with the field. "This is for me," the student might say, but the question that usually follows is, "But how can I make a living doing this?" The answers to this question are as diverse as the field. Because neuroscience is so broad, opportunities can be found down many different paths.

Like many other fields, neuroscience has more opportunities for people with more education. Many practicing neuroscientists have medical degrees, PhDs, or even both. This does not mean that jobs are unavailable for students with undergraduate degrees, however. Students with undergraduate degrees can be employed as research assistants in pharmaceutical firms, universities, and government agencies. Some neuroscience graduates work in substance abuse counseling or in mental health facilities. Neuroscience is used in some unexpected places as well. A growing trend in advertising agencies is to use brain imaging and other technologies to gauge public reactions to advertising. Web and application designers use eye-tracking technology to evaluate the user experience (UX), such as whether a person "sees" and processes the important features of a webpage and has a good time while doing so.

The ongoing burst in neuroscience technologies is likely to continue to shape the field, and additional opportunities are likely to emerge. In the meantime, any student interested in neuroscience would benefit from gaining the best possible skills in general science, research methods, mathematics, and statistics.

Historical Highlights in Neuroscience

The history of neuroscience parallels the development of tools for studying the nervous system. Early thinkers made progress in spite of limited scientific methods and technologies.

Ancient Milestones in Understanding the Nervous System

Our earliest ancestors apparently had at least a rudimentary understanding about the brain's essential role in maintaining life. Archaeological evidence of brain surgery suggests that as long as 7,000 years ago, people tried to cure others by drilling holes in the skull, a process known as trephining or trepanation (see ● Figure 1.3). Because some skulls have been located that show evidence of healing following the drilling procedure, we can assume that the patient lived through the procedure and that this was not a postmortem ritual. What is less clear is the intent of such surgeries. Possibly, these early surgeons hoped to release demons or relieve feelings of pressure (Clower & Finger, 2001).

The *Edwin Smith Surgical Papyrus* represents the oldest known medical writing in history yet features many sophisticated observations (Breasted, 1930). The Egyptian author of the *Papyrus* clearly understood that paralysis and lack of sensation in the body resulted from nervous system damage. Cases of nervous system damage were usually classified as "an ailment not to be treated," indicating the author's understanding of the relatively permanent damage involved.

Building on the knowledge taken from ancient Egypt, the Greek scholars of the fourth century BCE proposed that the brain was the organ of sensation. Hippocrates (460–379 BCE) correctly identified epilepsy as originating in the brain, although the most obvious outward signs of the disorder were muscular convulsions (see Chapter 15). Galen (130–200 CE), a Greek physician serving the Roman Empire, made careful dissections of animals (and we suspect of the mortally wounded gladiators in his care as well). Galen believed erroneously that the ventricles played an important role in transmitting messages to and from the brain, an error that influenced thinking about the nervous system for another 1,500 years (Aronson, 2007).

Mary Martin/Science Source/Photo Researchers, Inc

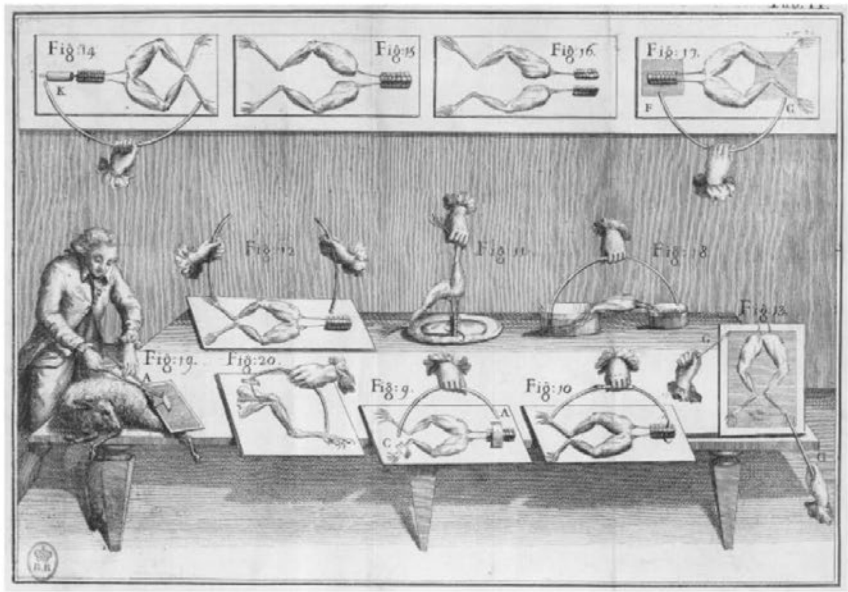
● **Figure 1.3 Prehistoric Brain Surgery** As far back in history as 7,000 years ago, people used trepanation (trephining), or the drilling of holes in the skull, perhaps to cure "afflictions" such as demonic possession. Regrowth around some of the holes indicates that at least some of the patients survived the procedure. More recently, trephining has resurfaced as a DIY (do it yourself) process, possibly as a type of self-injurious behavior.

The Dawn of Scientific Reasoning

The French philosopher René Descartes (1596–1650) argued in favor of **mind-body dualism.** For Descartes and other dualists, the mind is neither physical nor accessible to study through the natural sciences. In contrast, the modern neurosciences are based on **monism** rather than dualism. The monism perspective proposes that the mind is the result of activity in the brain, which can be studied scientifically. Descartes's ideas were very influential, and even today some people struggle with the idea that factors such as personality, memory, and logic simply represent the activity of neurons in the brain. Later in the chapter, our discussion of research ethics presents another legacy of Descartes's ideas. Because many shared his view of animals as mechanical, not sentient, beings, experiments were carried out on animals that seem barbaric to many

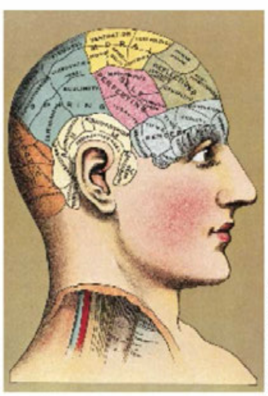
mind-body dualism A philosophical perspective put forward by René Descartes in which the body is mechanistic, whereas the mind is separate and nonphysical.

monism A philosophical perspective characteristic of the neurosciences in which the mind is viewed as the product of activity in the brain.



Time Life Pictures/Getty Images

● **Figure 1.4 Luigi Galvani Demonstrated a Role for Electricity in Neural Communication** This engraving illustrates the basement laboratory of Luigi Galvani, where his experiments with frogs not only helped establish understanding of the electrical nature of neural communication, but also inspired Mary Shelley to write *Frankenstein.*



© Bettmann/CORBIS

● **Figure 1.5 Phrenology Bust** Franz Josef Gall and his followers used maps like this one to identify traits located under different parts of the skull. Bumps on the skull were believed to indicate that the underlying trait had been "exercised." Although Gall's system was an example of very bad science, the underlying principle that functions could be localized in the brain turned out to be valuable.

phrenology The misguided effort to correlate character traits with bumps in the skull.

modern thinkers. In 1865, Claude Bernard (1813–1878) wrote that "the science of life is a superb and dazzlingly lighted hall which may be reached only by passing through a long and ghastly kitchen" (p. 15).

Between 1500 and 1800, scientists made considerable progress in describing the structure and function of the nervous system (see ●Figure 1.4). The invention of the light microscope by Anton van Leeuwenhoek in 1674 opened up a whole new level of analysis. Work by Luigi Galvani and Emil du Bois-Reymond established electricity as the mode of communication used by the nervous system. British physiologist Charles Bell (1774–1842) and French physiologist François Magendie (1783–1855) demonstrated that information traveled in one direction, not two, within sensory and motor nerves.

Modern Neuroscience Begins

As late as the beginning of the twentieth century, many scientists, including Italian researcher Camillo Golgi, continued to support the concept of the nervous system as a vast, interconnected network of continuous fibers. Others, including the Spanish anatomist Santiago Ramón y Cajal, argued that the nervous system was composed of an array of separate, independent cells. Cajal's concept is known as the Neuron Doctrine. Golgi and Cajal shared the Nobel Prize for their work in 1906. Ironically, Cajal used a stain invented by Golgi to prove that Golgi was incorrect.

The road to our current understanding of the nervous system has not been without its odd turns and dead ends. The notion that specific body functions are controlled by certain areas of the brain, called localization of function, began with an idea proposed by Franz Josef Gall (1758–1828) and elaborated by Johann Gasper Spurzheim (1776–1832). These otherwise respectable scientists proposed a "science" of **phrenology** that maintained that the structure of people's skulls could be correlated with their individual personality characteristics and abilities. A phrenologist could "read" a person's character by comparing the bumps on his or her skull to a bust showing the supposed location of each trait (see ●Figure 1.5). Although misguided, Gall and Spurzheim's work did move us away from the metaphysical, nonlocalized view of the brain that had persisted from the time of Descartes. Instead, Gall and Spurzheim proposed a more modern view of the brain as the organ of the mind, composed of interconnected, cooperative, yet relatively independent functional units.

Further evidence in support of localization of function in the brain began to accumulate. In the mid-1800s, a French physician named Paul Broca correlated the damage he observed in patients with their behavior and concluded that language functions were localized in the brain (see Chapter 13). Incidentally, it was also Broca who brought the practice of trepanation, described earlier in this chapter, to the attention of the scientific community (Clower & Finger, 2001). In 1870, Gustav Theodor Fritsch (1838–1927) and Eduard Hitzig (1838–1907) described how electrically stimulating the cortex of a rabbit and a dog produced movement on the opposite side of the body. Localization of function in the brain became a generally accepted concept.

Further evidence of the mind's physical, nonmystical nature was provided by physiologists and psychophysicists (see Chapters 6 and 7). Hermann von Helmholtz (1821–1894) demonstrated that the mind had a physical basis by asking participants to push a button as soon as they felt a touch. The participants reacted faster when their thigh was touched than when their toe was touched because the more distant signal from the toe would take more time to reach the brain.

The founding of modern neuroscience has often been attributed to the British neurologist John Hughlings Jackson (1835–1911). Hughlings Jackson proposed that the nervous system was organized as a hierarchy, with simpler processing carried out by lower levels and more sophisticated processing carried out by higher levels, such as the cerebral cortex. For example, we normally inhibit aggressive behaviors, associated with activity in lower levels of the brain, by engaging our higher cortical executive functions. When a person consumes alcohol, however, the cortical inhibition might fail, leaving the lower parts of the brain to initiate a bar fight. We meet Hughlings Jackson again in Chapter 15, in which his contributions to the understanding of epilepsy will be discussed.

Progress in the neurosciences over the past 100 years accelerated rapidly as new methods became available for studying the nervous system. Charles Sherrington not only coined the term *synapse* (defined as the point of communication between two neurons) but also conducted extensive research on reflexes and the motor systems of the brain (see Chapter 8). Otto Loewi demonstrated chemical signaling at the synapse (see Chapter 3), using an elegant research design that he claims came to him while asleep. Sir John Eccles, Bernard Katz, Andrew Huxley, and Alan Hodgkin furthered our understanding of neural communication. You will meet many more contemporary neuroscientists as you read the remainder of this text. The ranks of neuroscientists continue to grow, with membership in the Society for Neuroscience expanding from 500 members in 1969 to approximately 38,000 members in 90 countries as of 2016 (Society for Neuroscience [SfN], 2016).

INTERIM SUMMARY 1.1

Highlights in the Neuroscience Timeline

Historical Period	Significant Highlights and Contributions
Ca. 3000 BCE	• Egyptians discard brain during mummification process; however, published case studies indicate accurate observations of neural disorders.
Ca. 400 BCE–200 CE	• Hippocrates recognizes that epilepsy is a brain disease. • Galen makes accurate observations from dissection; however, he believed erroneously that fluids transmitted messages.

(continued)

Historical Period	Significant Highlights and Contributions
1600–1800	• René Descartes suggests mind-body dualism. • Anton van Leeuwenhoek invents the light microscope. • Galvani and du Bois-Reymond discover that electricity transmits messages in the nervous system.
1800–1900	• Bell and Magendie determine that neurons communicate in one direction and that sensation and movement are controlled by separate pathways. • Gall and Spurzheim make inaccurate claims about phrenology, but their notion of localization of function in the nervous system is accurate. • Paul Broca discovers localization of speech production. • Fritsch and Hitzig identify localization of motor function in the cerebral cortex.
1900–Present	• Ramón y Cajal declares that the nervous system is composed of separate cells; he shares the 1906 Nobel Prize with Camillo Golgi. • John Hughlings Jackson explains brain functions as a hierarchy, with more complicated functions carried out by higher levels of the brain. • Otto Loewi demonstrates chemical signaling at the synapse. • Charles Sherrington coins the term *synapse*; he wins the Nobel Prize in 1932. • Sir John Eccles, Andrew Huxley, and Alan Hodgkin share the 1963 Nobel Prize for their work in advancing our understanding of the way neurons communicate. • Bernard Katz receives the 1970 Nobel Prize for his work on chemical transmission at the synapse. • Society for Neuroscience counts about 38,000 members in 2016.

Summary Points

1. Neuroscience is the field that explores the structures, functions, and development of the nervous system in illness and in health. Behavioral neuroscience is the branch of the neurosciences that studies the correlations between the structures and functions of nervous system and behavior. **(L01)**
2. Although some periods of enlightenment regarding the relationship between the nervous system and behavior emerged among the Egyptians and Greeks, the major advances in behavioral neuroscience have been relatively modern and recent. **(L02)**
3. Highlights in the neuroscience timeline include discoveries regarding the electrical and chemical nature of neural communication, the control of sensation and motor functions by separate nerves, the role of single cells as building blocks for the nervous system, and the localization of functions in the brain. **(L02)**

Review Questions

1. How would you describe the goals and methods of the interdisciplinary field of neuroscience?
2. What historical discoveries contributed to our modern understanding of the brain and behavior? Which concepts actually led us in the wrong direction?

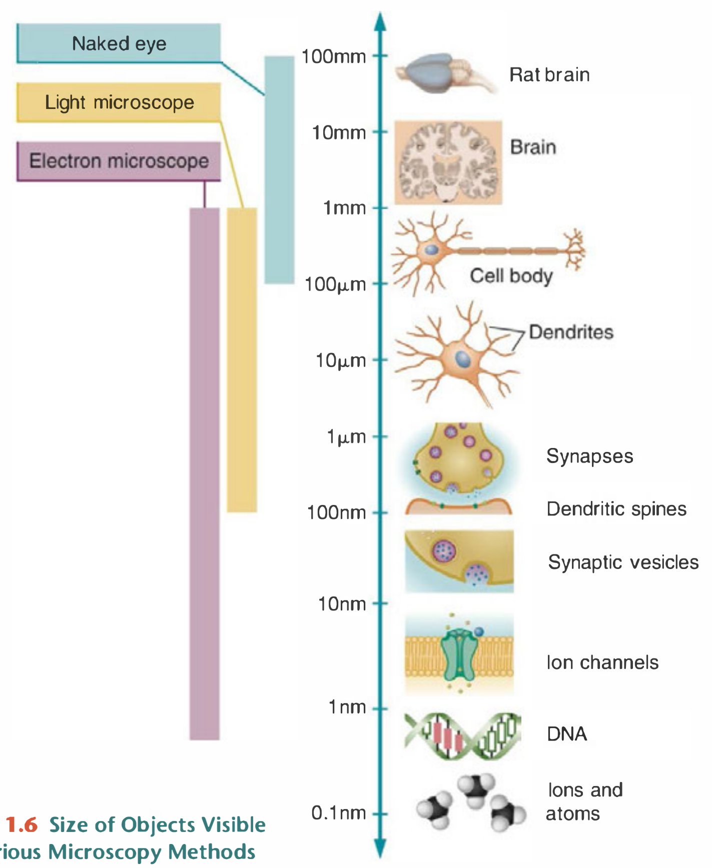
Behavioral Neuroscience Research Methods

The methods described in this section have helped neuroscientists discover the structure, connections, and functions of the nervous system and its components. From the level of single molecules to the operation of large parts of the nervous system, we now have the ability to make detailed observations that would likely astonish the early pioneers of neuroscience. The choice of methods depends very much on the goals and research questions of the neuroscientist. Each method has its shares of strengths and weaknesses, but the use of multiple methods to answer a single research question can compensate for any gaps in a particular method.

Microscopic Methods

Microscopic, or histological, methods provide means for observing the structure, organization, and connections of individual cells. The first investigation of nerve tissue under a microscope was conducted by Anton van Leeuwenhoek in 1674. However, due to the technical challenges of viewing structures as small and complex as those found in the nervous system, most of the advances in microscopy occurred following the development of stronger, clearer lenses during the 1800s.

The naked eye can perceive objects that are at least 0.2 mm in size. To see anything smaller requires magnification (see ● Figure 1.6). Magnification alone does not guarantee a clear image, however, as you probably have noticed when you've zoomed in on an image on your computer. You just get the same blurry image with bigger pixels. Our



● **Figure 1.6** Size of Objects Visible Using Various Microscopy Methods

histology The study of cells and tissues at the microscopic level.