Fundamentals of
PSYCHOLOGY
PERSPECTIVES AND CONNECTIONS

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FUNDAMENTALS OF PSYCHOLOGY: PERSPECTIVES AND CONNECTIONS

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This book is printed on acid-free paper.

1 2 3 4 5 6 7 8 9 LWI 21 20 19

ISBN 978-1-260-50022-6 (bound edition)
MHID 1-260-50022-5 (bound edition)

ISBN 978-1-260-30742-9 (loose-leaf edition)
MHID 1-260-30742-5 (loose-leaf edition)

Senior Portfolio Manager: *Nancy Welcher*
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Cover Image: ©*Francesco Carta fotografo/Getty Images*
Compositor: *Lumina Datamatics*

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Library of Congress Cataloging-in-Publication Data

Names: Feist, Gregory J., author. | Rosenberg, Erika L., author.
Title: Fundamentals of psychology : perspectives and connections / Gregory J. Feist, San Jose State University, Erika L. Rosenberg, University of California, Davis.
Description: 1 Edition. | Dubuque : McGraw-Hill Education, [2018]
Identifiers: LCCN 2018027210 | ISBN 9781260500226 (alk. paper)
Subjects: LCSH: Psychology.
Classification: LCC BF121 .F3198 2018 | DDC 150—dc23
LC record available at https://lccn.loc.gov/2018027210

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To our most precious collaborative work,

Jerry and Evan

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About the Authors



Courtesy of Gregory Feist

Gregory J. Feist

Gregory J. Feist is Professor of Psychology in Personality and Adult Development at San Jose State University. He has also taught at the College of William & Mary and the University of California, Davis. He received his PhD from the University of California, Berkeley, and his undergraduate degree from the University of Massachusetts–Amherst.

Dr. Feist is widely published in the psychology of creativity, the psychology of science, personality, and the development of scientific talent. One of his major goals is establishing the psychology of science as a healthy and independent study of science, along the lines of history, philosophy, and sociology of science. Toward this end, Dr. Feist has published a book titled *Psychology of Science and the Origins of the Scientific Mind* (2006, Yale University Press), which was awarded the 2007 William James Book Prize by the Division of General Psychology, American Psychological Association (APA). In addition, he is the founding president of the International Society for the Psychology of Science and Technology.

A second major focus for Dr. Feist is the identification and development of scientific talent, as seen in finalists of the Westinghouse and Intel Science Talent Search. His paper (co-authored with Frank Barron) "Predicting Creativity from Early to Late Adulthood: Intellect, Potential, and Personality" won Article of the Year for 2003 in the *Journal of Research in Personality* and *Psychology of Aesthetics, Creativity and the Arts*. His teaching efforts have been recognized by outstanding teaching awards at both UC Berkeley and UC Davis. Dr. Feist is also co-author with his late father, Jess Feist (and Tomi-Ann Roberts), of the undergraduate text *Theories of Personality*. In his spare time, Dr. Feist enjoys cycling, camping, hiking, and skiing.

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Courtesy of Evan Feist

Erika L. Rosenberg

Erika L. Rosenberg is an emotions researcher, health psychologist, and teacher of meditation. Dr. Rosenberg received her PhD in Psychology from the University of California, San Francisco, where she studied with Paul Ekman. Dr. Rosenberg served on the faculties at the University of Delaware and the College of William & Mary. Erika is a Senior Investigator at the Center for Mind and Brain at the University of California, Davis, Senior Teacher at the Center for Compassion and Altruism Research and Education (CCARE) at Stanford University, Faculty at Nyingma Institute of Tibetan Studies, in Berkeley, CA, and Founding Faculty at The Compassion Institute, a new nonprofit devoted to the promotion of compassion education worldwide.

Dr. Rosenberg is a world-renowned expert in facial expression of emotion, who trains and consults on facial measurement using the Facial Action Coding System (FACS). She teaches FACS workshops worldwide and consults on facial expression with academic, corporate, and entertainment industry clients worldwide, including digital effects and animators in major computer game and film production companies. From 2009 to 2011 she served as Scientific Consultant on the Fox TV show *Lie to Me*.

Erika's work with meditation encompasses both teaching and personal practice and spans nearly three decades. As a senior teacher at Stanford University's CCARE, she co-authored the Compassion Cultivation Training (CCT) program with Thupten Jinpa and others in 2009. In 2010, she personally presented the CCT program to His Holiness the Dalai Lama. Erika Rosenberg has taught meditation in diverse international venues such as Google Inc., Lerab Ling Monastery, Upaya Zen Center, Kripalu Yoga Center, The Telluride Institute, and Burning Man.

In addition to McGraw-Hill's *Psychology: Perspectives and Connections,* Erika is co-editor of *What the Face Reveals* (with Paul Ekman), now in press in its 3rd edition, and author of numerous scientific articles and chapters on facial expression, emotion, and meditation.

Formerly married, now amicably divorced and forever colleagues, Erika and Greg have two sons, Jerry and Evan, and live in Oakland, California.

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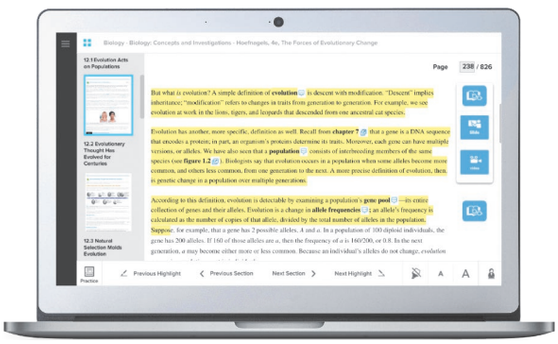
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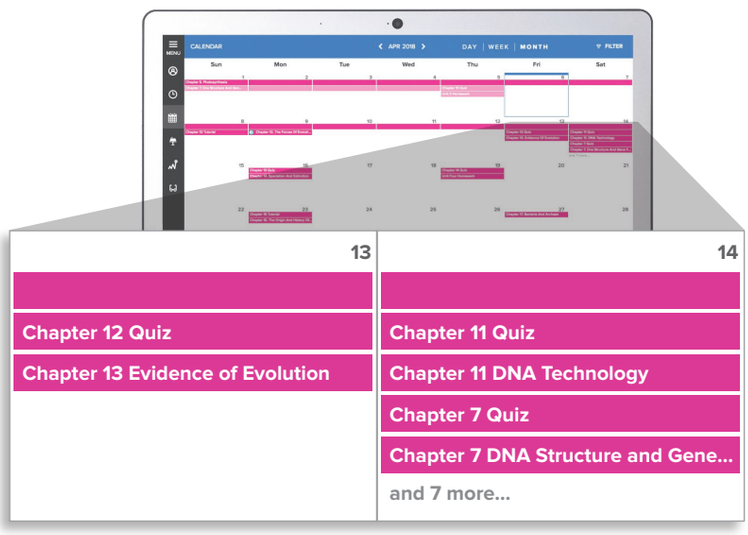
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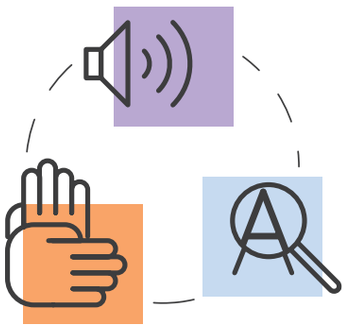
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Fundamentals of Psychology:

Those of us who teach at universities and colleges on a traditional 15-week semester system face a perpetual dilemma: Do we omit an entire chapter or two of a text to fit the readings into a 15-week semester, or do we pick and choose information to assign and discuss from within each chapter? On a 10-week quarter system, there is an even more difficult decision on what to cover. Our well-received *Psychology: Perspectives and Connections* has 16 chapters and co-author Greg, for instance, deletes one full chapter each semester to fit it into his 15-week semester.

One solution to this dilemma is to create a more concise version. Our new volume, *Fundamentals of Psychology: Perspectives and Connections*, contains all the core information from the full-length *Psychology* but condenses the most fundamental material into fewer chapters and pages. In *Fundamentals of Psychology* we maintain all the themes and concepts that made *Psychology* so successful:

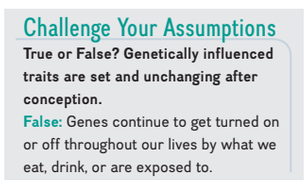
- Themes and questions in each chapter that challenge assumptions and foster critical, active reading and learning of the material; in the age of so-called "fake news," it is more important than ever that students learn to challenge assumptions and not believe everything they read, see, and think.
- An emphasis on showing the interaction and connectedness between different perspectives, especially the interplay of nature and nurture on most every aspect of thought and behavior.
- A writing style that makes crucial and current scientific findings accessible and engaging.
- Inclusion of cutting-edge and important current scientific findings in each chapter, with consistent emphasis on how technology and social media are impacting how we think, learn, feel, develop, and interact.

In addition to paring down each chapter to its most fundamental findings and concepts, we also combined two related chapters from *Psychology*. We integrated Language and Thought (Chapter 9) with Intelligence and Creativity (Chapter 10) to yield a new chapter called, "Language, Thought, and Intelligence." At 15 chapters, *Fundamentals of Psychology* fits a 15-week semester perfectly!

Fundamentals of Psychology guides students in moving beyond what may seem obvious, to reevaluating the thoughts and beliefs they bring to the course. Students will learn to challenge their assumptions, understand the elements of scientific research, and recognize that in psychology, *no one perspective tells the whole story.*

CHALLENGING ASSUMPTIONS

Questioning assumptions is the first step in thinking scientifically. While building a foundation in the concepts and principles of psychology, our goal as teachers and authors has always been to encourage students to examine their preconceptions (as well as those held by others) and understand that there is often more than one plausible explanation for a given phenomenon.



Each chapter opens with **Challenge Your Assumptions**, a list of common assumptions for students to consider.

THINKING SCIENTIFICALLY

Throughout *Fundamentals of Psychology*, we model critical thinking and offer multiple opportunities for students to practice this skill. In "Introduction to Psychology," we define the discipline, analyze major ways of thinking about the human experience, and present a framework for analyzing research and testing assumptions against real world observation.

We focus on high-interest topics including obsessive-compulsive disorder (OCD) and anxiety disorders (Treatment of Psychological Disorders) and how people of different genders and cultures experience the world (Sensing and Perceiving Our World), to emphasize how psychological science uses systematic investigation to address important questions about the human experience.

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Perspectives and Connections

Another key goal is helping students to understand the theoretical perspectives and learn to apply them in a variety of settings—hence, the presence of the term *perspectives* in the subtitle. We call attention to the influence of theoretical perspectives on advances in psychology, as well as in the different subfields of psychology. For example, we include a section comparing theoretical perspectives on intelligence (Language, Thought, and Intelligence), and we invite students to explore the influences of nature and nurture on personality development, along with the theoretical perspectives that have inspired personality researchers (Personality: The Uniqueness of the Individual). By understanding that it's possible to study behavior through different lenses, students learn to look for underlying points of view.

Fundamentals of Psychology also encourages students to consider the diverse approaches to the study of human thought and behavior. **Connection** annotations appear throughout the text, emphasizing the interrelatedness of subfields of psychology.

Connection

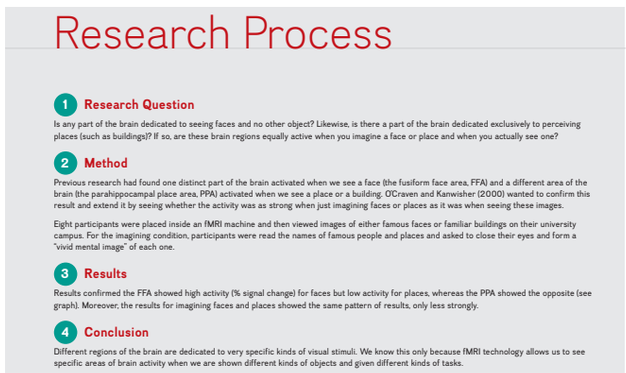
Area 25 is a region in the front of the brain; it is overly active in people with depression. A therapy known as "deep brain stimulation" can calm this area down and lead to a sudden decrease in depressed symptoms for some people.

See "Challenging Assumptions in the Treatment of Severe Depression," in the chapter "Treatment of Psychological Disorders." (p. 543)

MAKING SCIENCE ACCESSIBLE

Fundamentals of Psychology approaches the science of psychology in a straightforward, approachable manner to help students develop scientific literacy. Beginning with the question "What is science?" in the "Introduction to Psychology" chapter, we stress that psychology shares with the natural and physical sciences a way of thinking about the world that separates what we *believe* from what is *real*. A strong focus on research and the scientific method in the "Conducting Research in Psychology" chapter lays the foundation for subsequent science-based chapters on neuroscience and genetics and on sensation and perception, which are challenging topics for many students. Throughout the program, we describe classic and contemporary research in depth to familiarize students with the scientific approach to collecting and analyzing data and sharing the results to advance knowledge. Moreover, this edition reflects the latest thinking, based on current research, in all areas of psychology.

Overcoming preconceptions about the research process may be one of the biggest challenges students face in Introductory Psychology. **Research Process** features, appearing in most chapters, demystify research by providing a step-by-step visual approach to the scientific method.



Research Process

1 **Research Question**

Is any part of the brain dedicated to seeing faces and no other object? Likewise, is there a part of the brain dedicated exclusively to perceiving places (such as buildings)? If so, are these brain regions equally active when you imagine a face or place and when you actually see one?

2 **Method**

Previous research had found one distinct part of the brain activated when we see a face (the fusiform face area, FFA) and a different area of the brain (the parahippocampal place area, PPA) activated when we see a place or a building. O'Craven and Kanwisher (2000) wanted to confirm this result and extend it by seeing whether the activity was as strong when just imagining faces or places as it was when seeing these images.

Eight participants were placed inside an fMRI machine and then viewed images of either famous faces or familiar buildings on their university campus. For the imagining condition, participants were read the names of famous people and places and asked to close their eyes and form a "vivid mental image" of each one.

3 **Results**

Results confirmed the FFA showed high activity (% signal change) for faces but low activity for places, whereas the PPA showed the opposite (see graph). Moreover, the results for imagining faces and places showed the same pattern of results, only less strongly.

4 **Conclusion**

Different regions of the brain are dedicated to very specific kinds of visual stimuli. We know this only because fMRI technology allows us to see specific areas of brain activity when we are shown different kinds of objects and given different kinds of tasks.

Using the basic structure of a contemporary study to exemplify scientific thinking, we walk through the "story" of how the research was conducted. In the chapter "Sensing and Perceiving Our World," for example, this feature illustrates the methodology chosen by a researcher to answer the question, "Do people from an Eastern culture (Japan) focus more on and have better recall for objects in the background and periphery of a scene than people from a Western culture (United States)?"

Most chapters feature expanded coverage on technology and social media and how they affect thought and behavior. For example, in the "Social Behavior" chapter, we address the concept of groupthink in social media as well as the rise of "fake news" sites.

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APPLYING PSYCHOLOGY TO EVERYDAY LIFE

One of the perennially difficult tasks we face as instructors is to connect course material to students' lives and interests. In *Fundamentals of Psychology* we demonstrate the relevance of psychology in multiple ways in both the text and digital programs.

Psychology in the Real World features show how psychological research can directly affect people's lives. For instance, how musical training changes the brain ("Human Development"), and whether Internet use can become an addiction ("Psychological Disorders").

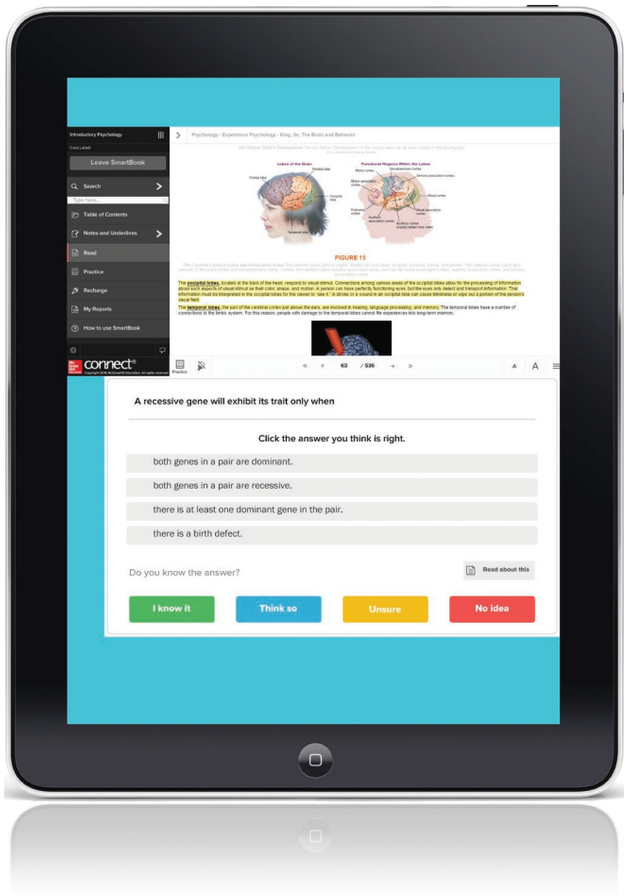
Additional examples in the text make psychological principles and concepts more concrete by connecting them to current, real-world experiences; for instance, in the chapter "Consciousness," the limits of *attention* are underscored with the example of how texting during class prevents attention to the lecture, and graphics in the chapter "Learning" use student-relevant examples of classical and operant conditioning to make these difficult concepts accessible.

A PERSONALIZED EXPERIENCE THAT LEADS TO IMPROVED LEARNING AND RESULTS

How many students think they know everything about introductory psychology, but struggle on the first exam?

Students study more effectively with Connect and SmartBook.

- SmartBook helps students study more efficiently by highlighting where in the chapter to focus, asking review questions, and pointing students to resources until they understand.
- Connect's assignments help students contextualize what they've learned through application, so they can better understand the material and think critically.
- Connect will create a personalized study path customized to individual student needs.
- Connect reports deliver information regarding performance, study behavior, and effort. So instructors can quickly identify students who are having issues, or focus on material that the class hasn't mastered.



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THE POWER OF DATA

Fundamentals of Psychology harnesses the power of data to improve the instructor and student experiences.

Step 1. Over the course of three years, data points showing concepts that caused students the most difficulty were anonymously collected from the Connect **SmartBook** for *Psychology: Perspectives and Connections*, 3/e.

Step 2. The data from **SmartBook** was provided to the authors in the form of a **Heat Map**, which graphically illustrated "hot spots" in the text that impacted student learning.

Step 3. Greg Feist and Erika Rosenberg used the Heat Map data to refine the content and reinforce student comprehension in the new edition. Additional quiz questions and assignable activities were created for use in Connect Psychology to further support student success.

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Result: With empirically based feedback at the paragraph and even sentence level, the authors developed the new edition using precise student data to pinpoint concepts that caused students to struggle.

POWERFUL REPORTING

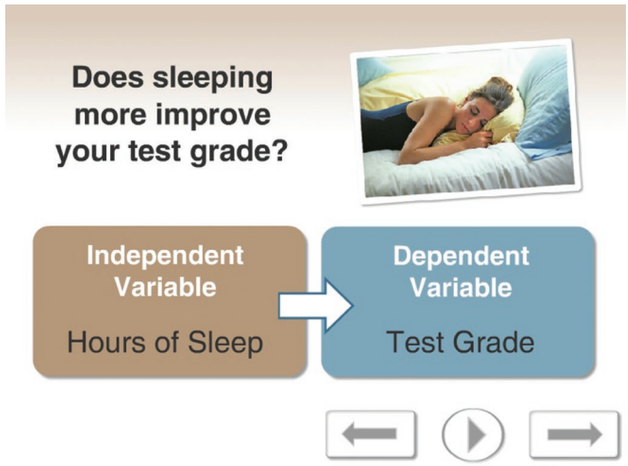
Whether a class is face-to-face, hybrid, or entirely online, McGraw-Hill Connect provides the tools needed to reduce the amount of time and energy instructors spend administering their courses. Easy-to-use course management tools allow instructors to spend less time administering and more time teaching, while reports allow students to monitor their progress and optimize their study time.

- The **At-Risk Student Report** provides instructors with one-click access to a dashboard that identifies students who are at risk of dropping out of the course due to low engagement levels.
- The **Category Analysis Report** details student performance relative to specific learning objectives and goals, including APA learning goals and outcomes and levels of Bloom's taxonomy.
- **Connect Insight** is a one-of-a-kind visual analytics dashboard—now available for both instructors and students—that provides at-a-glance information regarding student performance.
- The **LearnSmart Reports** allow instructors and students to easily monitor progress and pinpoint areas of weakness, giving each student a personalized study plan to achieve success.

STUDENT CRITICAL THINKING SKILLS

At the Apply and Analyze levels of Bloom's taxonomy, **Scientific Reasoning Activities** found in Connect offer in-depth arguments to sharpen students' critical thinking skills and prepare them to be more discerning consumers of psychology in their everyday lives. For each chapter, there are multiple sets of arguments accompanied by auto-graded assessments requiring students to think critically about claims presented as facts. These exercises can also be used in Connect as group activities or for discussion.

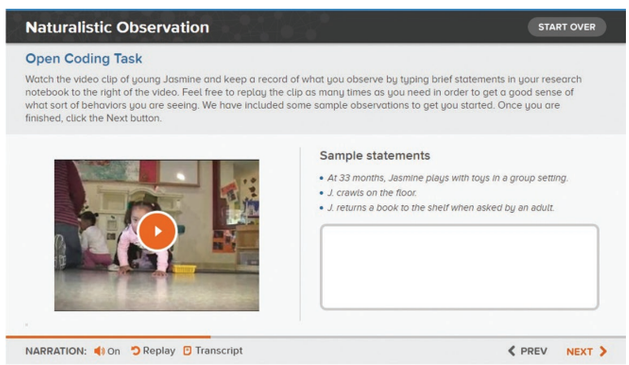
The **Power of Process**, now available in McGraw-Hill Connect, guides students through the process of critical reading, analysis, and writing. Faculty can select or upload their own content, such as journal articles, and assign analysis strategies to gain insight into students' application of the scientific method. For students, Power of Process offers a guided visual approach to exercising critical thinking strategies to apply before, during, and after reading published research. Additionally, utilizing the relevant and engaging research articles built into Power of Process, students are supported in becoming critical consumers of research.



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STUDENT ACTIVE ENGAGEMENT

Concept Clips help students comprehend some of the most difficult ideas in introductory psychology. Colorful graphics and stimulating animations describe core concepts in a step-by-step manner, engaging students and aiding in retention. Concept Clips can be used as a presentation tool in the classroom or for student assessment. Concept Clips are embedded in the eBook to offer an alternative presentation of these challenging topics.



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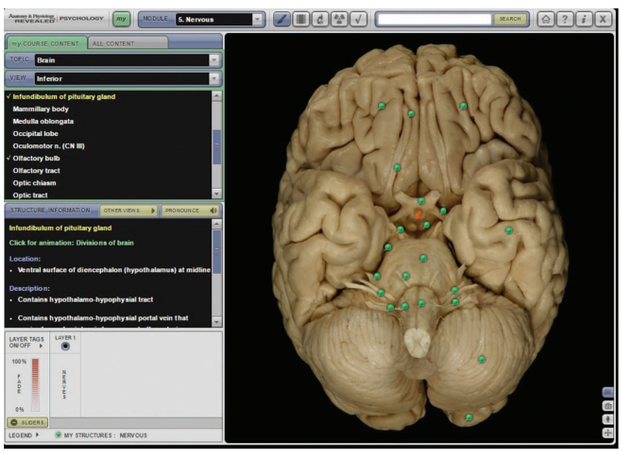
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Interactivities, assignable through Connect, engage students with content through experiential activities. Activities include: Perspectives in Psychology; Correlations; Neurons; The Brain and Drugs; The Stages of Sleep; Levels of Processing; Maslow's Hierarchy of Needs; Naturalistic Observation; Observational Learning; Defense Mechanisms; Stereotypes and Prejudice; Heuristics; Personality Assessment; and First Impressions and Attraction.

Through the connection of psychology to students' own lives, concepts become more relevant and understandable. Powered by McGraw-Hill Education's Connect Psychology, **NewsFlash exercises** tie current news stories to key psychological principles and learning objectives. After interacting with a contemporary news story, students are assessed on their ability to make the link between real life and research findings.

Psychology at Work videos, assignable and assessable within McGraw-Hill Connect, highlight nine careers in which knowledge of psychology is beneficial in the workplace. Each video introduces a person at work, who specifies how knowledge gained from taking introductory psychology in college is applied to the work environment.

Anatomy and Physiology REVEALED® for Psychology McGraw-Hill Education presents an interactive tool that encourages the exploration of biological structures related to psychology. **Lab Activity** assignments in Connect walk students through virtual nervous system and cell dissection experiences, including views of CT scans, x-ray imaging and histology, and include illustrated animations that link anatomy to the biology of behavior.



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Touring the Brain and Touring the Senses offer detailed digital overlays of key structures. These tours provide students with practice in grasping key biological structures and processes that are essential to an appreciation of the role of science in psychology and success in the course.

SUPPORTING INSTRUCTORS WITH TECHNOLOGY

With McGraw-Hill Education, you can develop and tailor the course you want to teach.

Campus Use a different learning management system. **McGraw-Hill Campus** (www.mhcampus.com) provides faculty with true single sign-on access to all of McGraw-Hill's course content, digital tools, and other high-quality learning resources from any learning management system. McGraw-Hill Campus includes access to McGraw-Hill's entire content library, including eBooks, assessment tools, presentation slides, and multimedia content, among other resources, providing faculty open, unlimited access to prepare for class, create tests/quizzes, develop lecture material, integrate interactive content, and more.

Tegrity With **Tegrity**, you can capture lessons and lectures in a searchable format and use them in traditional, hybrid, "flipped classes," and online courses. With Tegrity's personalized learning features, you can make study time efficient. Its ability to affordably scale brings this benefit to every student on campus. Patented search technology and real-time learning management system (LMS) integrations make Tegrity the market-leading solution and service.

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McGraw-Hill Education's Connect offers comprehensive service, support, and training throughout every phase of your implementation. If you're looking for some guidance on how to use Connect, or want to learn tips and tricks from super users, you can find tutorials as you work. Our Digital Faculty Consultants and Student Ambassadors offer insight into how to achieve the results you want with Connect.

INTEGRATION WITH YOUR LEARNING MANAGEMENT SYSTEM

McGraw-Hill integrates your digital products from McGraw-Hill Education with your school LMS for quick and easy access to best-in-class content and learning tools. Build an effective digital course, enroll students with ease, and discover how powerful digital teaching can be.

Available with Connect, integration is a pairing between an institution's learning management system (LMS) and Connect at the assignment level. It shares assignment information, grades, and calendar items from Connect into the LMS automatically, creating an easy to manage course for instructors and simple navigation for students. Our assignment-level integration is available with **Blackboard Learn**, **Canvas by Instructure**, and **Brightspace by D2L**, giving you access to registration, attendance, assignments, grades, and course resources in real time, in one location.

INSTRUCTOR SUPPLEMENTS

Instructor's Manual The instructor's manual provides a wide variety of tools and resources for presenting the course, including learning objectives, and ideas for lectures and discussions.

Test Bank By increasing the rigor of the test bank development process, McGraw-Hill Education has raised the bar for student assessment. A coordinated team of subject-matter experts methodically vetted each question and set of possible answers for accuracy, clarity, effectiveness, and accessibility; each question has been annotated for level of difficulty, Bloom's taxonomy, APA learning outcomes, and corresponding coverage in the text. Organized by chapter, the questions are designed to test factual, conceptual, and applied understanding. All test questions are available within TestGen™ software and as Word documents.

PowerPoint Presentations The PowerPoint presentations, available in a dynamic lecture-ready format and a WCAG-compliant version, highlight the key points of the chapter and include supporting visuals. All of the slides can be modified to meet individual needs.

Image Gallery The Image Gallery features the complete set of downloadable figures and tables from the text. These can be easily embedded by instructors into their own PowerPoint slides.



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Acknowledgments

As usual, this project could not have been undertaken and completed without the dedicated and professional staff at McGraw-Hill Education. Nancy Welcher as portfolio manager for psychology, spearheaded and went to bat for this project and had faith in it and us from the outset; our product developer, Sara Gordus, provided invaluable feedback and helped keep the project on track. Dawn Groundwater, lead product developer, was also instrumental in overseeing the project and provided us with the "big picture" perspective. Sandy Wille was so very helpful in assisting with the technical aspects of seeing this book go into and through production. A.J. Laferrera has been an untiring marketing manager for *Psychology: Perspectives and Connections* and will continue to add his professional commitment to *Fundamentals of Psychology*.

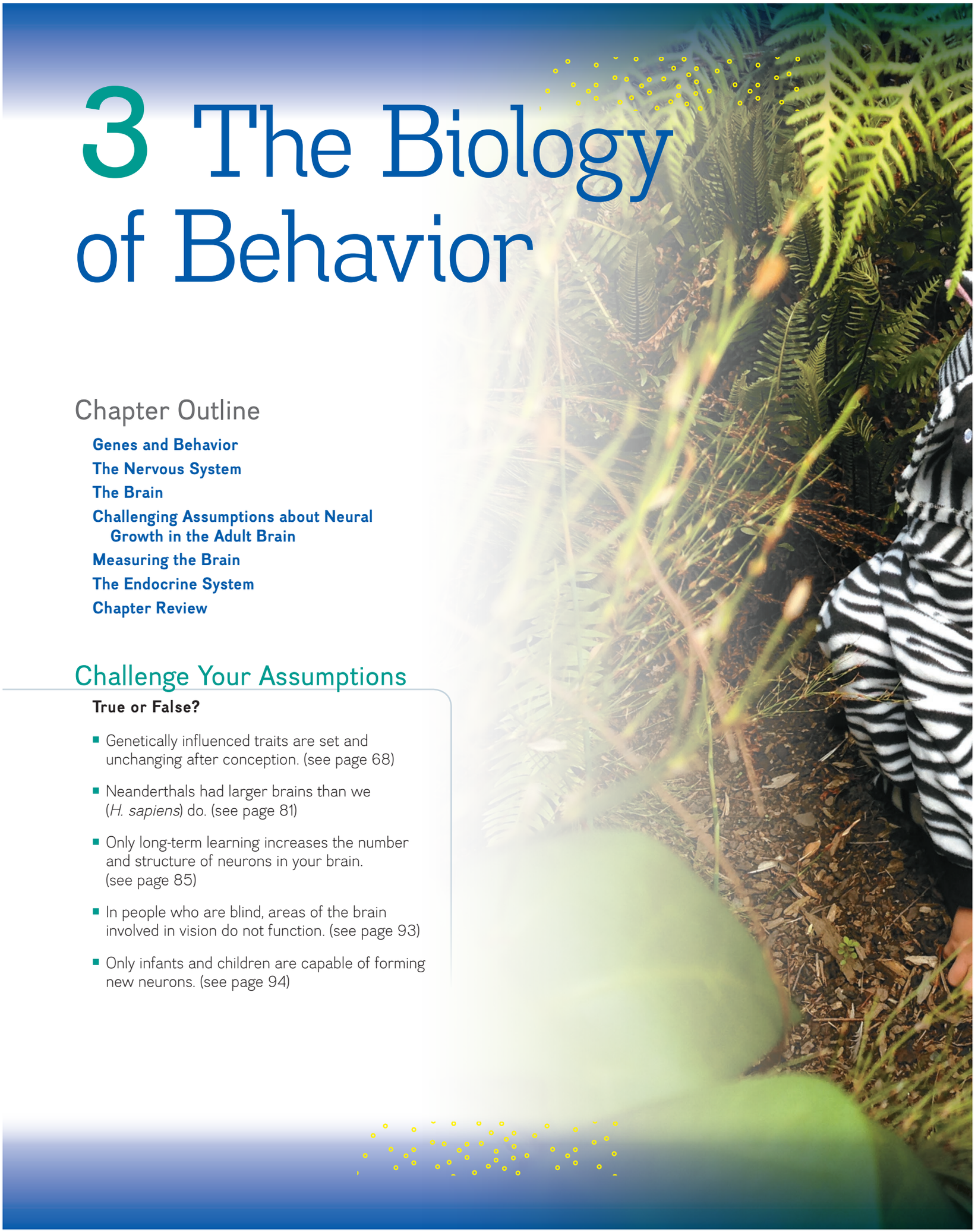
Greg would also like to give heartfelt thanks to his students each semester whose fresh eyes and minds renew his excitement in how important and fascinating the study of human thought and behavior really is. A semester never goes by where he is not inspired to include something new in his approach to teaching based on ideas and questions from students.

Erika would like to thank Greg for his forever partnership and never-ending professionalism, their children for their patience, and the staff at McGraw-Hill for their belief in our message and this project. She is eternally grateful to Stanley Marshall for his constant reminder to "be here now," Paul Ekman for a lifetime of mentorship, and Bica Coffeehouse for supporting her writing with exceptional macchiato and good cheer!

Finally, although no longer married, Erika and Greg have carried forth their deep and long-term connection in writing this book and are grateful to each other for this solid and deep relationship that will always be more than just professional. Most importantly, we each want to give personal and heartfelt thanks to what will forever be our best collaborative work—our sons Jerry and Evan!

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3 The Biology of Behavior



Chapter Outline

Genes and Behavior
The Nervous System
The Brain
Challenging Assumptions about Neural Growth in the Adult Brain
Measuring the Brain
The Endocrine System
Chapter Review

Challenge Your Assumptions

True or False?

- Genetically influenced traits are set and unchanging after conception. (see page 68)
- Neanderthals had larger brains than we (*H. sapiens*) do. (see page 81)
- Only long-term learning increases the number and structure of neurons in your brain. (see page 85)
- In people who are blind, areas of the brain involved in vision do not function. (see page 93)
- Only infants and children are capable of forming new neurons. (see page 94)

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See the painting in Figure 1. It is pleasing, colorful, and nicely done. It features realistic color, perspective, and shadowing. It seems, perhaps, not extraordinary—except by virtue of its maker. He cannot see at all.

Born blind to an impoverished family in Turkey, Esref Armagan started drawing at a young age; later he began painting with oils and acrylics. Armagan has been actively painting for over 35 years. His work strikes us not only for its beauty but also for how it depicts objects in a way that a sighted person would see them. How can someone who has never seen anything in his life create beautiful paintings that depict realistic images? It seems as if his brain is doing something that his eyes cannot.

You can experience how this is possible at the Tactile Dome, part of the Exploratorium in San Francisco. Once there, you enter a room full of common, recognizable objects, such as a cheese grater, an egg carton, and a sieve. You look at them and feel them.

Then you proceed through a pitch-black tunnel. As you find your way through it by touch, you feel the common objects you saw earlier. When you reach the end, you are prompted to think back and remember your way through the tunnel. Surprisingly, the memory of what you encountered along the path in the dark with your hands is visual! Your brain has taken a tactile experience and unwittingly converted it into a visual memory. How?

The Tactile Dome and the skills of Esref Armagan both suggest that our experience of the world is not a direct representation of what is out there. The brain can change our experiences—give us visual memories for tactile experiences. The brain is both fixed and flexible in how it acts. While most of us use the rear portion of our brains to process visual information, Esref Armagan uses that area when he paints by the feel of his hands.



©Images & Stories/Alamy Stock Photo

FIGURE **1**

PAINTING BY ESREF ARMAGAN, A BLIND PAINTER. Besides being beautiful to look at, Armagan's vivid, realistic paintings and drawings challenge conventional thinking about the brain and its ability to adapt and overcome limitations imposed on it.

Can you think of how Armagan is able to paint with color, shadow, and perspective, even though he has never seen any of these?

In this chapter and the next, we will explore what is known about how the brain works, supports behavior, and is transformed by experience. Our main task in this chapter is to introduce the biological systems that are most relevant to a basic understanding of psychology. We will explore the workings of the nervous system, the relationship between behavior and chemicals called hormones, and the role of heredity and evolution in shaping the brain and behavior. Throughout this chapter we will highlight the ways that biological and environmental forces constantly interact and influence who we are, what we do, and how we feel. We will also see how biological systems involved in thought and behavior—genes, brain structures, brain cells, and so on—are open to ongoing modification from the environment (LaFreniere & MacDonald, 2013; Ottersen, 2010).

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GENES AND BEHAVIOR

We seldom have trouble accepting the idea that heredity is responsible for outward family resemblances, such as the shape of the nose and face, height, and the color of hair and skin. But when it comes to behavior, many of us are uncomfortable with the idea that heredity might strongly influence what we think and do. Research has revealed that heredity strongly shapes our behavior and experience, although it does not operate in a simple, deterministic way.

Before we can explore how our hereditary material and behavior are linked, we must first determine the structures and mechanisms involved in heredity. Your genetic material is composed mainly of **DNA (deoxyribonucleic acid)** and is passed down in the form of chromosomes from both your mother and your father. A **chromosome** is a very long thread of DNA wrapped around proteins to hold it all together. You inherit 23 chromosomes from one parent and 23 chromosomes from the other parent such that you end up with 23 *pairs* of chromosomes (46 individual chromosomes) in every cell of your body. Together, the total amount of your unique DNA is referred to as your **genome**. Each person's unique and incomparable genome is called his or her **genotype**.

DNA (deoxyribonucleic acid)
A large molecule that contains genes.

chromosome
A coiled-up thread of DNA.

genome
All the genetic information in DNA.

genotype
The entire genetic makeup of an organism.

In our genome we carry our entire ancestral history (Pickrell & Reich, 2014; Tucci & Akey, 2016). Recently companies have developed the technology to commercially analyze anyone's genome and tell them which geographical regions of the world their ancestors came from. For instance, a report might show that someone has an ancestry makeup that is 29% Asian Native American, 22% European, and 3% sub-Saharan African, when in fact, all the person ever knew about was her Asian Native American ancestry. Our genetic makeup is more complex than we often believe, and is yet another example of the interaction between nature (genes) and nurture (geography and place).

But our unique genotype that each of us is born with is not the end point but the starting point of gene expression. What form a gene takes and how it gets expressed in observable characteristics is known as the **phenotype**. As we see at the end of this section, there are many ways in which our genes get turned on or off from our experience, many after the genome is established.

phenotype
An organism's observed characteristics.

Within your genome, some information codes for the production of proteins. That is what **genes** do—they are the segments of DNA that code for protein synthesis, and are therefore the functional segment of DNA. In fact, the vast majority of DNA (98%) is not genetic because it does not code for proteins (Zimmer, 2015). It's not "junk" as some biologists used to say because it does other things, but it does not code for proteins. The proteins that are coded from genes in turn make up most chemicals and structures in the body (see Figure 2). As a result, genes have a profound control over physical characteristics, such as height or hair color, by directing the synthesis of proteins. In addition, there are genes that code for proteins responsible for making up your brain and the chemicals it needs to make you feel happy or sad. Thus, genes play an important role in shaping how you think and feel.

genes
Small segments of DNA that contain information for producing proteins.

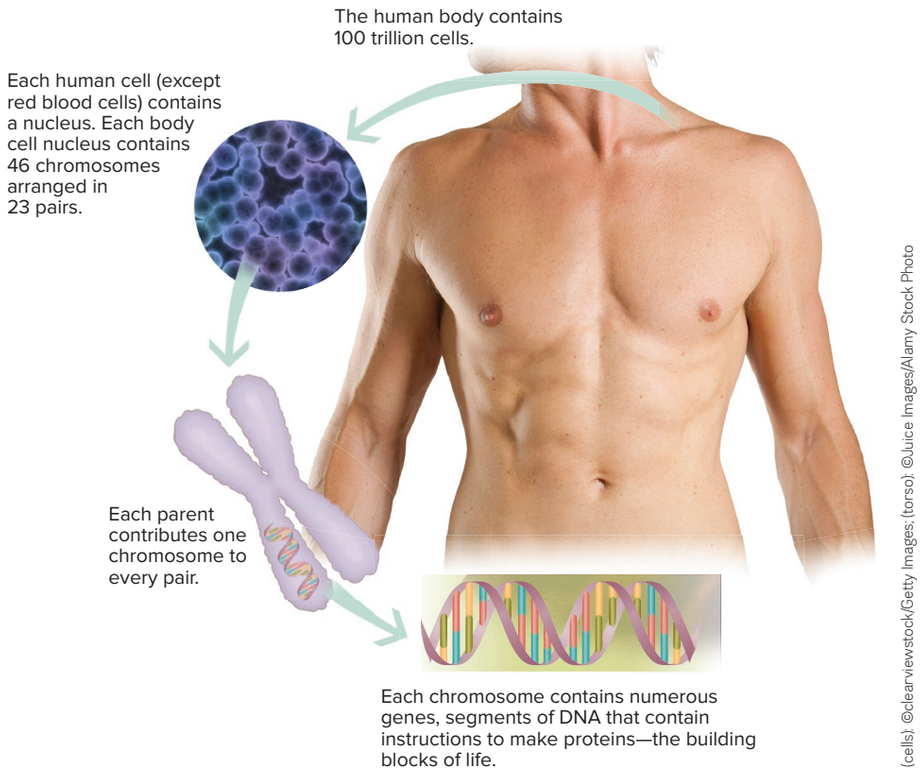
Most traits, such as height, weight, intelligence, and personality, are the result of many dozens or even hundreds of genes and these are known as **polygenic** traits. Any characteristic that cannot be placed in a small number of categories and ranges from a little to a lot is polygenic (Clark & Grunstein, 2000; Plomin et al., 2013). All psychological and almost all physical traits in humans are polygenic (Ebstein, 2006; Plomin et al., 2013). By contrast, traits that have a one-to-one connection to a gene are known as **monogenic** traits. Humans have very few traits that result from a single gene.

polygenic
The process by which many genes interact to create a single characteristic.

monogenic
The hereditary passing on of traits determined by a single gene.

Lactose tolerance/intolerance is one of the few examples of a monogenic trait in humans. Everyone can metabolize lactose (digest milk) as an infant, but

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(cells): ©clearviewstock/Getty Images; (torso): ©Juice Images/Alamy Stock Photo

FIGURE **2**
DNA, CHROMOSOMES, AND THE HUMAN CELL. Every cell in the human body contains the same genetic material distributed in 23 pairs of chromosomes.

mutation
A random change in genetic sequence.

alleles
Different forms of a gene.

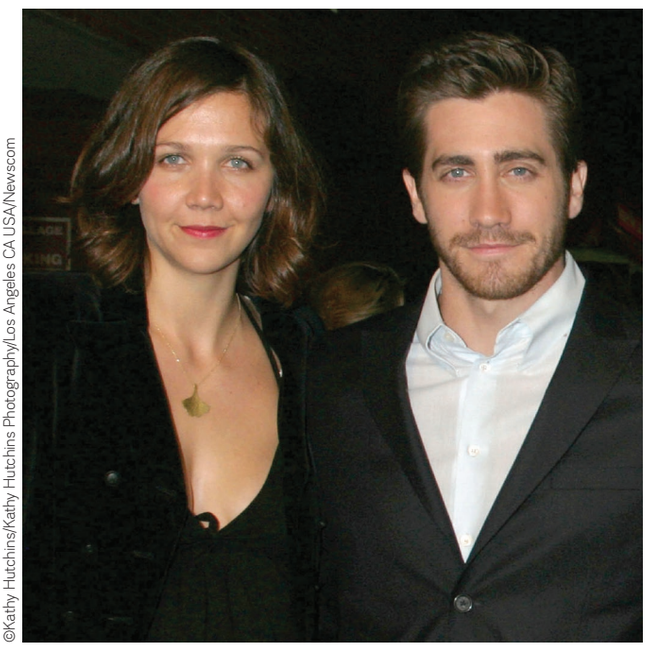
dominant alleles
Alleles that show their effect even if there is only one allele for that trait in the pair.

recessive alleles
Alleles that show their effects only when both alleles are the same.

most people lose this ability with age, because the activity of lactase (the protein that breaks down lactose) decreases. Some humans, however, have a change, or **mutation**, in their genetic sequence that allows lactase activity to persist into adulthood, so they can eat and drink dairy products without getting an upset stomach. This means that some people have one form of the gene, which allows lactase persistence (they are lactose tolerant), and some people have another form, which results in lactase nonpersistence (they are lactose intolerant). These different forms of a gene are known as **alleles** (Clark & Grunstein, 2000; Starr & Taggart, 2004), one of which you inherit from your mother and the other from your father.

If you receive alleles for lactose tolerance from both your mother and your father, then you will digest dairy products easily into adulthood.

However, what happens if you inherit one lactose tolerant gene and one lactose intolerant gene from your parents? The lactase persistent or tolerant allele is dominant over the intolerant one. **Dominant alleles** show their effect even if there is only one copy of that allele in the pair. So if you have one of each kind of allele (tolerant and intolerant) chances are you will still be able to digest some dairy products. Alternatively, **recessive alleles** show their effects only when both alleles are the same. Consequently, a person will be lactose intolerant only if he or she receives a lactase persistent allele from each parent.



©Kathy Hutchins/Kathy Hutchins Photography/Los Angeles CA USA/Newscom

Actors (and siblings) Maggie and Jake Gyllenhaal inherited their blue eyes from their parents. Blue eyes are a recessive trait, which means that each parent must possess at least one allele for blue eyes.

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Principles of Behavioral Genetics

To understand how heredity affects behavior, psychologists turn to the science of **behavioral genetics** (Fuller & Thompson, 1960; Plomin et al., 2013). There are three principles of behavioral genetics that are especially relevant to psychology:

behavioral genetics
The scientific study of the role of heredity in behavior.

1. The relationship between specific genes and behavior is complex, usually with many genes involved in each trait.
2. By studying twins and adoptees, as well as genetic markers, behavioral geneticists may disentangle the contributions of heredity (nature) and environment (nurture) that influence behavior.
3. The environment influences how and when genes affect behavior.

The Connection between Genes and Behavior Is Complex The connection between genes and behavior is complex. To understand how genes influence behavior, we must abandon the notion of simple causation (Rutter, 2006). Genes seldom make behaviors a certainty. For example, no single gene causes anxiety. Both genetic and environmental factors make anxiety more likely to trouble some people than others.

In a few cases, having a specific gene guarantees an outcome—such as the incurable neuromuscular disease called Huntington's—but these outcomes are primarily physical, not behavioral. Typically, a specific gene plays only a small part in creating a given behavior, which is precisely what happens in polygenic traits. For example, there is wide variation in intelligence because numerous genes contribute to it. Other examples of polygenic traits are skin color, mental disorders, personality traits (such as whether a person is likely to be adventurous), height, and weight (Clark & Grunstein, 2000; Ebstein, 2006; Evans et al., 2007). Environmental events such as smoking during pregnancy, early childhood experiences, stress or trauma, and enriched environments all interact with genes to make specific behaviors more or less likely.

Connection

Genetic influence accounts for about 50% of the differences in performance on intelligence tests, leaving about the same amount to be explained by nongenetic influences.

See "The Nature and Nurture of Human Intelligence," in the chapter "Language, Thought, and Intelligence." (p. 333)

The Relative Effects of Genes and Environment Can Be Teased Apart The extent to which a characteristic is influenced by genetics is known as **heritability**. The second principle of behavioral genetics is that teasing apart and identifying genetic and environmental influences on behavior can be done but requires special techniques. Recall from the chapter "Conducting Research in Psychology" that researchers use two different research methods to study the relative effects of nature and nurture (heritability), namely twin-adoption studies and gene-by-environment studies.

heritability
The extent to which a characteristic is influenced by genetics.

Twin-adoption studies take advantage of the fact that genetic similarity ranges from 0% (strangers) to 100% (identical twins) and environmental similarity ranges from a little (different families) to a lot (same families). Genetic influence or heritability is strongest when twins—who have high genetic similarity—are still very much alike on traits even when they are raised by different families. Environmental influence is strongest when adopted siblings—who have no genetic similarity—are still very much alike on traits when they are raised by the same family.

Gene-by-environment studies do not use twins but rather examine whether genes that vary in people are correlated with a particular trait. An example of this kind of research is seen from the findings that people with certain genetic markers are more likely to be depressed, anxious, or hyperactive than people without those markers (Moffitt, Caspi, & Rutter, 2005; Thapar, Langley, & Asherson, 2007).

The Environment Can Change Gene Expression: Epigenetics The third—and, in many ways, the most important—principle of behavioral genetics is a relatively new one, epigenetics. **Epigenetics** is the study of changes in the way genes are expressed—that is, are activated (turned "on") or deactivated

epigenetics
The study of changes in the way genes are turned on or off without a change in the sequence of DNA.

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The field of study known as epigenetics examines how experience can turn genes on or off.

What implications does this have for what we eat, drink, and are exposed to?

(turned "off")—without changing the sequence of DNA (Meaney, 2010; Plomin et al., 2013). Some substances that we eat, drink, or get exposed to result in molecules attaching to certain base pairs of genes. By doing so these tags turn off or on the gene expression process. Put differently, epigenetics involves heritable changes to DNA that are independent of the genetic sequence yet influence its expression. This means that experience (nurture) shapes our nature.

The food we eat, the drugs we take, and our exposure to certain chemicals in the environment, among other things, can have epigenetic consequences. Contrary to what many people think, genes are not destiny. They are simply the starting point for biological structures. Many things—including experience—can turn genes on or off. Epigenetic effects have been demonstrated in a host of psychological traits—including attention deficit hyperactivity disorder (ADHD), aggression, dementia, obesity, and anxiety, just to name a few (Cropley et al., 2016; Curley et al., 2011; Mill & Petronis, 2008; Sweatt, 2010).

What is even more amazing is that these environmentally produced tags can be inherited—passed on from parent to offspring. In other words, genetics is not the only way inheritance works. It also works via epigenetics (Meaney, 2010; Zimmer-Gembeck & Collins, 2008). An activated gene in your grandparent that gets turned off environmentally in one of your parents can be inherited by you as a deactivated gene. This secondary form of inheritance via epigenetics is sometimes referred to as *soft inheritance* to contrast it with traditional genetically based inheritance (Graff & Mansury, 2008). The term soft inheritance is another example of how nature and nurture work side-by-side.

Epigenetics offers one explanation for why identical twins—whose genomes are 100% alike—end up being not completely identical on numerous traits. For instance, they do not have identical fingerprints and sometimes not even the same gender identity (see the chapter "Human Development"). Recent longitudinal research shows that differences in epigenetic tags in identical twins already exist in early to middle childhood and that these differences can be related to personality differences in twins (Kaminsky et al., 2008; Wong et al., 2010). In short, although identical twins share 100% of their genotype, their phenotype—or their observed characteristics—may be subtly (even strikingly) different because different epigenetic tags are turning different genes on or off. Genes are not destiny.

Challenge Your Assumptions

True or False? Genetically influenced traits are set and unchanging after conception.

False: Genes continue to get turned on or off throughout our lives by what we eat, drink, or are exposed to.

Connection

Identical twins are often nearly identical in thought and behavior, but for epigenetic reasons this is not always so, as is clear in a case of identical twins, born male, but one of whom identified as female.

See the chapter opening for the chapter "Human Development." (p. 138)

Quick Quiz 1: Genes and Behavior

1. Genes occur in pairs, or alternate forms of each other, called
   a. chromosomes.
   b. alleles.
   c. base pairs.
   d. ribosomes.
2. Why are twin-adoption studies powerful ways to untangle the effects of genes and the environment on thought and behavior?
   a. They allow both genetic and environmental similarity to be compared and contrasted.
   b. Twins share genes.
   c. They allow for understanding epigenetic influences.
   d. They allow researchers to experimentally manipulate genetic and environmental similarity.
3. Nurturing behavior in rats can produce calmer, less stressed offspring because genes that are involved in stress reactions are turned off. This is an example of
   a. epigenetics.
   b. genetic engineering.
   c. recessive genes.
   d. dominant genes.

Answers can be found at the end of the chapter.

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THE NERVOUS SYSTEM

The human genome contains an estimated up to 30,000 genes (National Human Genome Research Institute, 2010). At least half of these genes code for proteins in the brain, where they play a central role in seeing, hearing, thinking, memory, learning, movement, and all other behavior. The brain mediates all of our experiences and orchestrates our responses to those experiences.

The nervous system controls all the actions and automatic processes of the body. Ultimately, everything we experience and do results from the activity of nerve cells, which are organized in a net of circuits far more complex than any electrical system you could imagine.

Organization of the Nervous System

The human nervous system has two main parts and several components, as depicted in Figure 3. It is divided into the **central nervous system (CNS)**, which includes the brain and spinal cord, and the **peripheral nervous system (PNS)**, which consists of all the other nerve cells in the body. The peripheral nervous system includes the somatic nervous system and the autonomic nervous system. The **somatic nervous system** serves the skeletal muscles of the body: It sends messages out to the skeletal muscles from the CNS and transmits sensory information back to the CNS from the skeletal muscles. The **autonomic nervous system (ANS)** serves the involuntary systems of the body, such as the internal organs and glands.

Autonomic means "self-governing," and to a large extent the structures served by the autonomic nervous system control bodily processes over which we have little conscious control, such as changes in heart rate and blood pressure. The ANS has two main branches: the **sympathetic nervous system** and the

central nervous system (CNS)
The part of the nervous system that comprises the brain and spinal cord.

peripheral nervous system
The part of the nervous system that comprises all the nerve cells in the body outside the central nervous system.

somatic nervous system
Nerve cells of the peripheral nervous system that serve the skeletal muscles. Somatic nerves transmit from the central nervous system (CNS) to the skeletal muscles and sensory information from the skeletal muscles back to the CNS.

autonomic nervous system (ANS)
All the nerves of the peripheral nervous system that serve involuntary systems of the body, such as the internal organs and glands.

sympathetic nervous system
The branch of the autonomic nervous system that activates bodily systems in times of emergency.

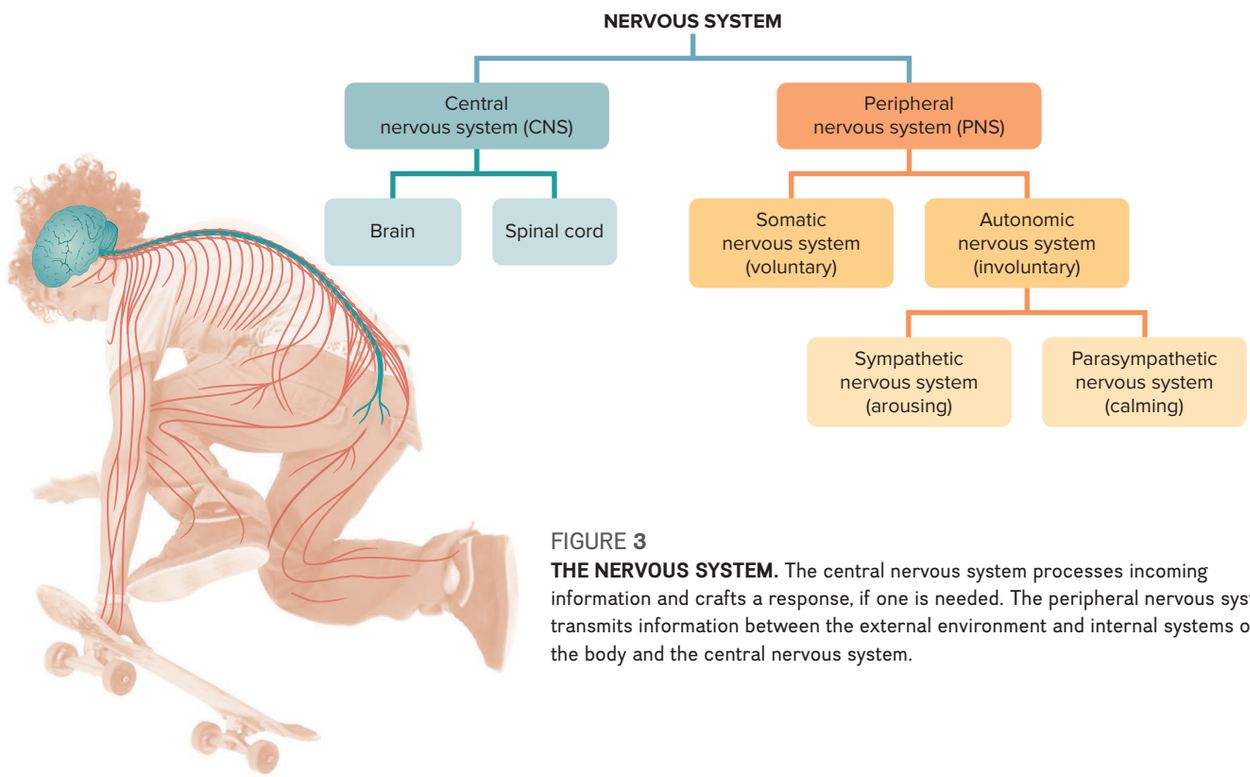


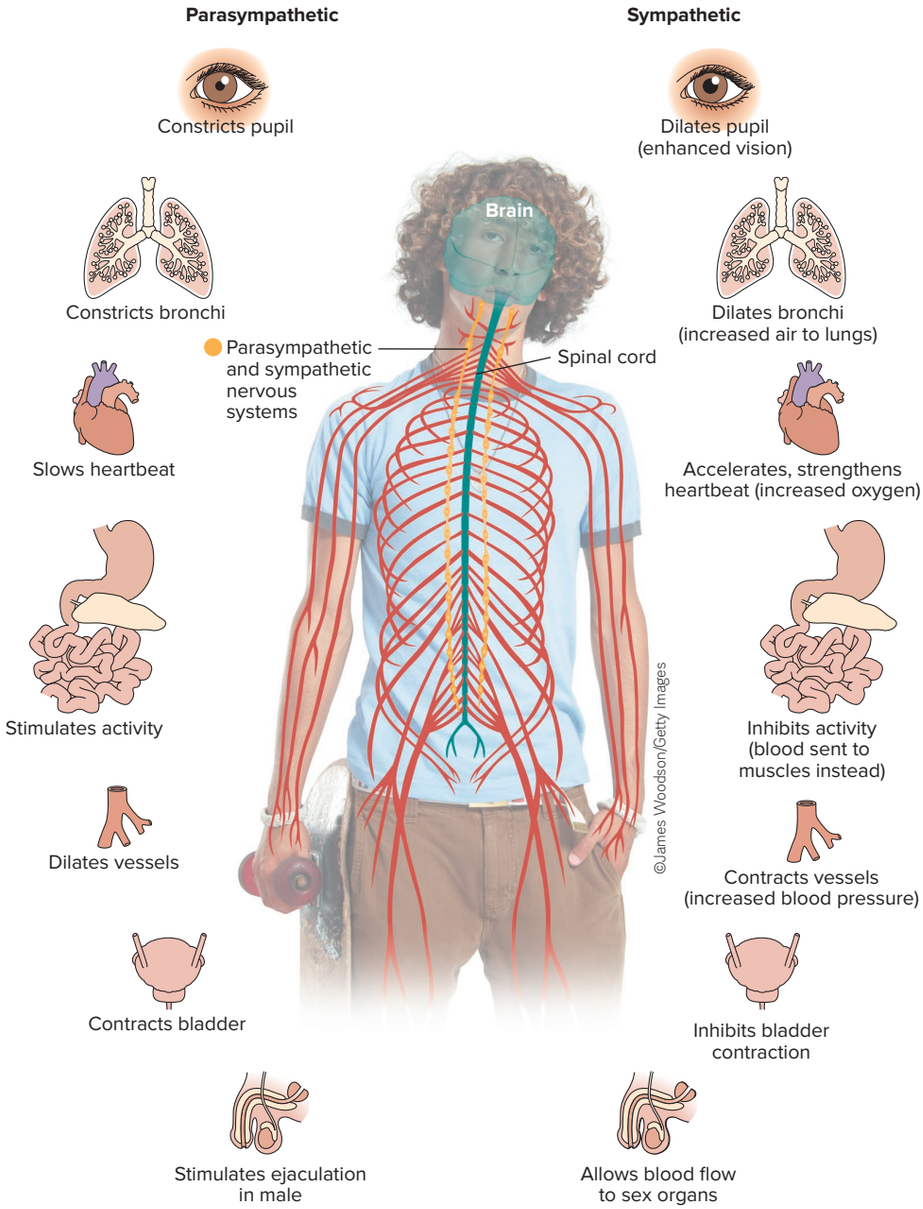
FIGURE **3**
THE NERVOUS SYSTEM. The central nervous system processes incoming information and crafts a response, if one is needed. The peripheral nervous system transmits information between the external environment and internal systems of the body and the central nervous system.

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parasympathetic nervous system
The branch of the autonomic nervous system that usually relaxes or returns the body to a less active, restful state.

parasympathetic nervous system. The nerves of both of these systems control muscles in organs such as the stomach, small intestine, and bladder and in glands such as the sweat glands. The sympathetic nervous system activates bodily systems in times of emergency by increasing the heart rate, dilating the pupils of the eyes, or inhibiting digestion. It is responsible for what the physiologist Walter Cannon (1939) labeled the *fight-or-flight response*. The function of the parasympathetic nervous system is largely one of relaxation, returning the body to a less active, restful state. All of the systems that are aroused by the sympathetic nervous system are relaxed by the parasympathetic nervous system (see Figure 4).

FIGURE **4**
THE SYMPATHETIC AND PARASYMPATHETIC NERVOUS SYSTEMS. The sympathetic nervous system prepares the body for action, whereas the parasympathetic nervous system returns it to a relaxed and resting state.



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Because of its effects on these various bodily systems, the ANS produces many of the physical sensations we experience during emotional arousal, such as a racing heart or sweaty palms.

The Cells of the Nervous System: Glial Cells and Neurons

Without a nervous system, we would have no sensory experiences—no seeing, hearing, touching, tasting, smelling, or feeling. We would also have no thoughts, memories, or emotions. Everything we sense or do is accomplished by means of nerve cells.

The central nervous system is made up of two types of cells: glial cells and neurons. *Glia* is the Greek word for "glue." Indeed **glial cells** serve the primary function of holding the CNS together. For years their primary functions were thought to be structural support for the CNS and the removal of cellular debris (Kandel, 2000b). We now know that glial cells also play an important role in communication between neurons, produce the material that insulates neurons (myelin), aid cell metabolism, help form the blood–brain barrier, play a key role in the control of breathing, regulate neuronal transmission, and may play an important role in neural regeneration repair after brain injury (Ballanyi, Panaitescu, & Ruangkittisakul, 2010; Benner et al., 2013; Charsar, Urban, & Lepore, 2016; Eroglu & Barres, 2010; Li & Chen, 2016; Verkhratsky, Rodrıguez, & Parpura, 2012). Glial cell abnormalities may also play a role in the development of schizophrenia (Bernstein et al., 2015).

glial cells
Central nervous system cells that provide structural support, promote efficient communication between neurons, and serve as scavengers, removing cellular debris.

Neurons are the cells that process and transmit information throughout the nervous system. Within the brain, neurons receive, integrate, and generate messages. By most estimates, there are more than 10 billion neurons in the human brain. Each neuron has approximately 10,000 connections to other neurons, making for trillions of neural connections in the human brain (Hyman, 2005; Nauta & Feirtag, 1979). Thus, it is understandable why some scientists consider the human brain to be one of the most complex structures in the known universe. Over the last 125 years, three major principles of neuroscience have emerged concerning the neuron and how it communicates with other neurons (Kandel, 2006):

neurons
The cells that process and transmit information in the nervous system.

1. Neurons are the building blocks of the nervous system. All the major structures of the brain are composed of neurons.
2. Information travels within a neuron in the form of an electrical signal by action potentials.
3. Information is transmitted between neurons by means of chemicals called **neurotransmitters**.

neurotransmitters
Chemicals that transmit information between neurons.

Let's explore each of these principles to better understand the mechanisms of brain function and behavior.

The Structure and Types of Neurons Whereas most cells in the body have a round shape, neurons are spidery, with long branches and projections. Neurons are so small that they cannot be seen with the naked eye; only a strong microscope can magnify them enough to be viewed and described. In the late 1800s, the Spanish anatomist Santiago Ramón y Cajal deciphered the precise nature and structure of nerve cells, which he named neurons. It was Ramón y Cajal who identified the three major parts of the neuron: cell body, dendrites, and axon.

As in other cells, the cell body, or **soma**, of the neuron contains a *nucleus* and other components needed for cell maintenance and function (see Figure 5). The genes that direct neural change and growth lie within the nucleus itself. Extending from one side of the soma is a long projection called an **axon**, which

soma
The cell body of the neuron.

axon
A long projection that extends from a neuron's soma; it transmits electrical impulses toward the adjacent neuron and stimulates the release of neurotransmitters.

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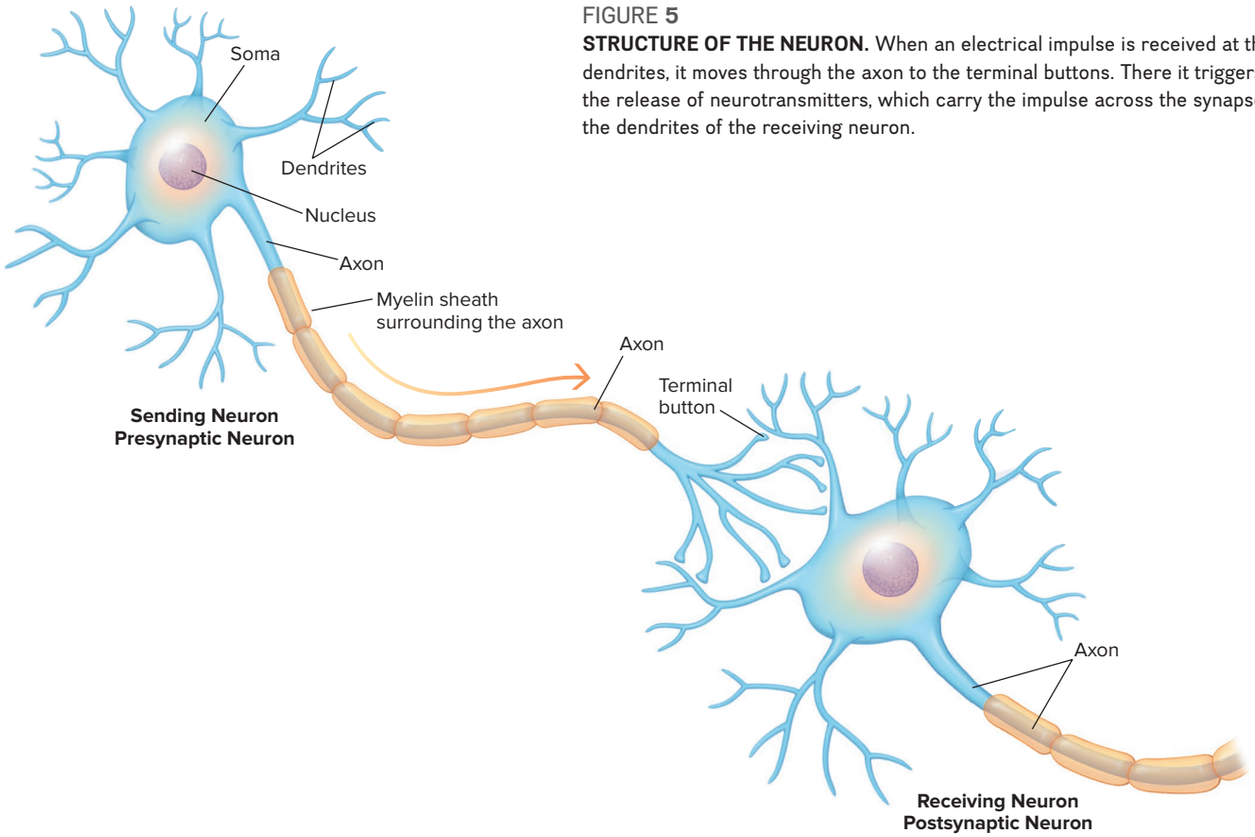


FIGURE **5**

STRUCTURE OF THE NEURON. When an electrical impulse is received at the dendrites, it moves through the axon to the terminal buttons. There it triggers the release of neurotransmitters, which carry the impulse across the synapse to the dendrites of the receiving neuron.

dendrites
Fingerlike projections from a neuron's soma that receive incoming messages from other neurons.

myelin sheath
The fatty substance wrapped around some axons, which insulates the axon, making the nerve impulse travel more efficiently.

synapse
The junction between an axon and the adjacent neuron, where information is transmitted from one neuron to another.

terminal button
A little knob at the end of the axon that contains tiny sacs of neurotransmitters.

sensory neurons
Nerve cells that receive incoming sensory information from the sense organs (eye, ear, skin, tongue, nose).

motor neurons
Nerve cells that carry commands for movement from the brain to the muscles of the body.

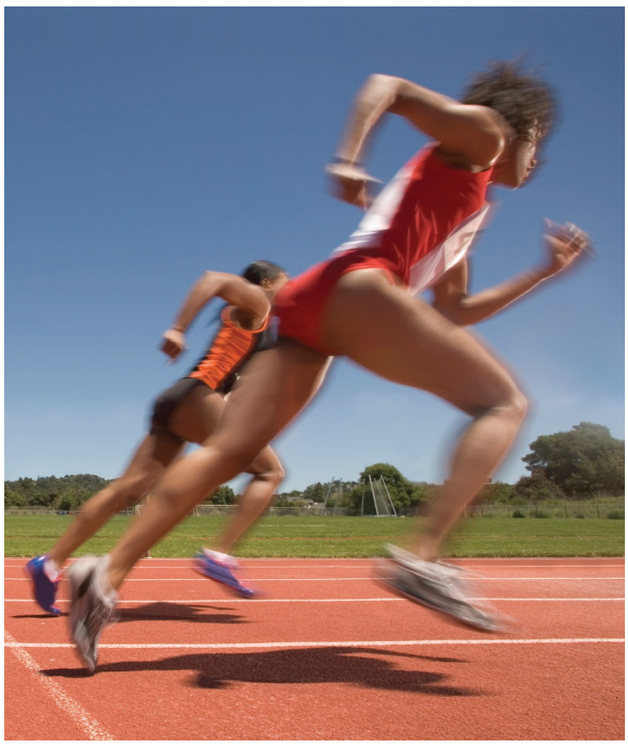
transmits electrical impulses toward the adjacent neuron. On the other side of the soma are **dendrites**, fingerlike projections that receive incoming messages from other neurons.

The axons of some neurons are wrapped in a fatty **myelin sheath**. Just like rubber around an electrical wire, the myelin sheath insulates the axon, so that the impulse travels more efficiently, strengthening the connection to adjacent neurons. The process of *myelination* is a gradual one that starts before birth, is facilitated in breast-fed babies, and continues into early adulthood (Deoni et al., 2013; Fields, 2008). The glial cells are responsible for creating the myelin that insulates axons throughout the nervous system (Simons & Nave, 2016). The junction between the axon and the adjacent neuron is known as the **synapse**. At the end of the axon, at each synapse, is a **terminal button** containing tiny sacs of neurotransmitters. When an electrical impulse reaches the terminal button, it triggers the release of neurotransmitter molecules into the gap between neurons, known as the *synaptic cleft*. The neurotransmitter carries the signal across the synaptic cleft to the next neuron.

There are three kinds of neurons: sensory neurons, motor neurons, and interneurons. **Sensory neurons** receive incoming sensory information from the sense organs (eyes, ears, skin, tongue, and nose). Any sensation you receive—anything you see, hear, touch, taste, or smell—activates sensory neurons, which take the message to the brain for processing.

Motor neurons take commands from the brain and carry them to the muscles of the body. Each time you move any muscle in your body, intentionally or not, motor neurons are at work. Researchers have identified motor neurons that are active when monkeys observe others performing an action, as well as when the monkeys undertake the same action (Rizzolatti et al., 1996). Neurons

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Sensory and motor neurons working in concert with the brain make this sprinter's elegant strides possible.

that behave this way, called **mirror neurons**, appear to play an important role in learning by observation (Lametti & Watkins, 2016). The discovery of mirror neurons has changed the way we make sense of a wide range of human experiences, including how we interpret the emotions of and feel empathy toward others.

mirror neurons
Nerve cells that are active when we observe others performing an action as well as when we are performing the same action.

Interneurons communicate only with other neurons. Most interneurons connect neurons in one part of the brain with neurons in another part. Others receive information from sensory neurons and transmit it to motor neurons for action. If you touched a sharp object, interneurons in your spinal cord would receive pain information from sensory neurons in your fingers and communicate it to motor neurons in the muscles of your arm, so that you could pull away. Interneurons are the most common kind of neuron in the brain, outnumbering sensory and motor neurons by at least 10 to 1 (Nauta & Feirtag, 1979). They play a crucial role in the inhibition of impulses between one brain region and another (Crandall & Connors, 2016). Dysfunction in these important inhibitory circuits has been implicated in disorders associated with overexcitation in the brain, such as epilepsy and schizophrenia (Marin, 2012) and may play a role in the memory deficits of Alzheimer's disease (Schmid et al., 2016).

interneurons
Neurons that communicate only with other neurons.

Connection

Mirror neurons support learning by imitation as well as empathy.

See "The Developing Infant and Child," in the chapter "Human Development," p. 145; "Imitation, Mirror Neurons, and Learning," in the chapter "Learning," p. 289; and "Prosocial Behavior," in the chapter "Social Behavior," p. 486.

Neural Communication Neural communication is a two-step process: action potential and neurotransmission.

The Action Potential The **action potential**, an electrical and chemical process, is the positively charged impulse that moves one way down an axon. This happens by virtue of changes in the neuron itself. The neuron, like all cells in the body, is surrounded by a membrane that is somewhat permeable,

action potential
The impulse of positive charge that runs down an axon.

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letting only certain particles move through it. The fluid inside and outside the cell contains electrically charged particles called **ions**. Positively charged sodium and potassium ions and negatively charged chloride ions are the most common. Channels in the membrane of the neuron allow ions to flow between the inside and outside of the cell. Some of these channels are always open. Others, called *voltage-dependent channels*, open only when certain electrical conditions are met.

ions
Chemically charged particles that predominate in bodily fluids; found both inside and outside cells.

Due to the flow of ions into and out of the neuron, there is a difference in charge inside the cell compared to outside at all times. In the resting state, there is an excess of negatively charged particles inside the axon, whereas the fluid outside the axon has a positive charge. When a neuron is at rest, the charge difference, known as a *potential*, between the inside and the outside of the axon is −70 millivolts (mV). This value is the **resting potential** of the neuronal membrane (see Figure 6a).

resting potential
The difference in electrical charge between the inside and outside of the axon when the neuron is at rest.

Neurons do not stay at rest, however. An incoming impulse—which may have been stimulated by events as different as pressure to the skin and the thought of a loved one—can temporarily change the potential. Here is how touch can stimulate a neural impulse: A message received from sense receptors in the skin or from other neurons changes the axonal membrane's permeability, especially to positively charged sodium ions. If an incoming impulse increases the positive charge inside the neuron to a certain threshold, the neuron becomes *depolarized* and fires an action potential, a surge in positive charge (see Figure 6b). The sodium channels at the top of the axon fly open, and positively charged sodium ions pour into the cell. The influx of sodium leads to a brief spike in positive charge, raising the membrane potential from −70 mV to +40 mV.

Once initiated, the action potential causes sodium channels to close and potassium voltage-dependent channels to open (see Figure 6c). As positively charged potassium ions flow out of the cell, the membrane potential returns to its resting state of −70 mV. While the neuron is returning to its resting state, it temporarily becomes supernegatively charged. During this brief period, known as the **refractory period**, the neuron cannot generate another action potential.

refractory period
The span of time, after an action potential has been generated, when the neuron is returning to its resting state and the neuron cannot generate an action potential.

We can summarize the electrical changes in the neuron from resting to action potential to refractory period and back to the resting state as follows (see Figure 6d):

1. Resting potential is −70 mV.
2. If an incoming impulse causes sufficient depolarization, voltage-dependent sodium channels open and sodium ions flood into the neuron.
3. The influx of positively charged sodium ions quickly raises the membrane potential to +40 mV. This surge in positive charge inside the cell is the action potential.
4. When the membrane potential reaches +40 mV, the sodium channels close and potassium channels open. The outward flow of positively charged potassium ions restores the negative charge inside the cell.

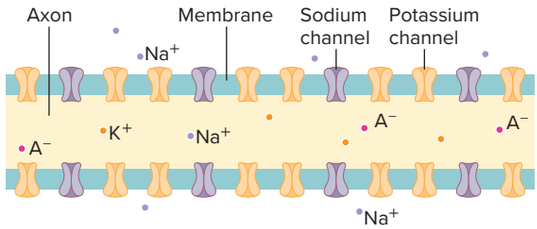
This process repeats all along the axon, as the impulse moves toward the synapse. As the action potential subsides in one area, it immediately depolarizes the next portion of membrane, causing sodium channels to open there, continuing the action potential. This process of how an impulse moves down the axon is known as *propagation*. Like a wave, the action potential travels along the axon, until it reaches the terminal buttons. In myelinated neurons, the action potential travels faster still, as depolarization occurs only at gaps in the myelin sheath and the action potential jumps from gap to gap (see Figure 5). The gaps in the myelin sheath across which the action potential jumps are known as the **nodes of Ranvier**.

node of Ranvier
The gap(s) in the myelin sheath across which the action potential jumps.

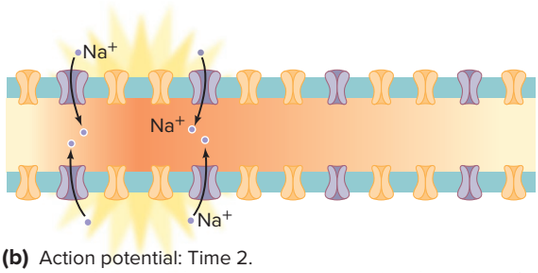
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FIGURE **6**

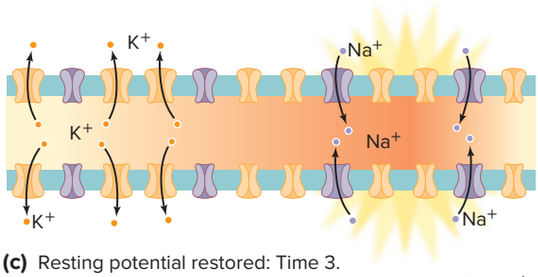
HOW NEURONS FIRE: MEMBRANES AND VOLTAGE CHANGES IN ACTION POTENTIALS



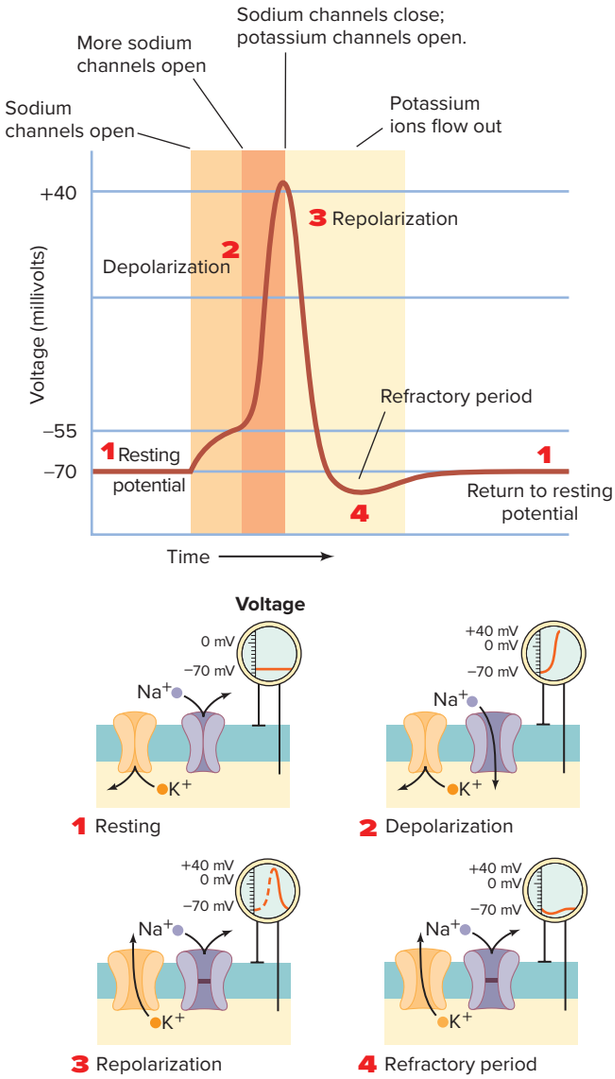
(a) Resting potential: Time 1.
In the resting neuron, the fluid outside the axon contains a higher concentration of positive ions than the inside of the axon, which contains many negatively charged anions (A–).



(b) Action potential: Time 2.
An action potential occurs in response to stimulation of the neuron. Sodium channels in the axonal membrane open, and positively charged sodium ions (NA^+) pour into the axon, temporarily raising the charge inside the axon up to +40 mV.



(c) Resting potential restored: Time 3.
As the impulse moves on down the axon, potassium (K^+) channels open, allowing more K^+ to flood out of the cell, restoring the negative resting potential (–70 mV).



(d) This graph depicts the electrical changes that occur during each stage of an action potential (resting, depolarization, repolarization, refractory period). The top portion shows changes in voltage over time as measured by direct recording from single neurons in animal research. The lower four pictures show the membrane changes that correspond to each stage. The electrical changes of an action potential occur in a few thousandths of a second. During the refractory period, no new action potential can be generated.

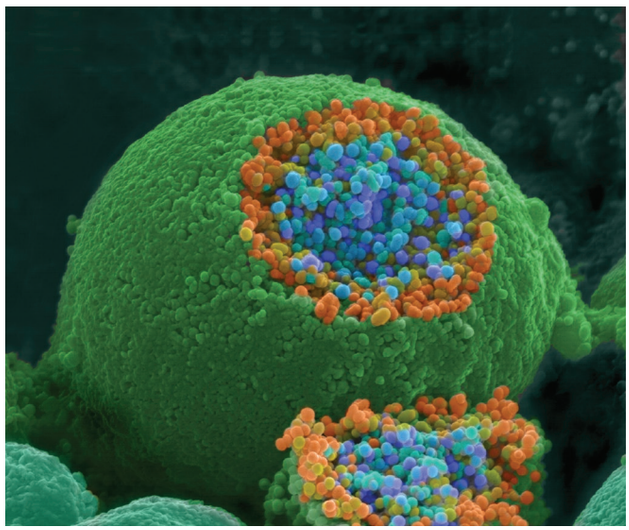


How does a neural firing (action potential) happen?

How fast are action potentials? In the 1920s, Edgar Douglas Adrian recorded individual action potentials of sensory neurons and confirmed a speed of about 100 feet per second (Kandel, 2006). Adrian's work also confirmed the existence of a threshold—a point of no return. Once the charge inside the neuron exceeds threshold (and *only* if it exceeds threshold), the action potential fires. This is known as the **all-or-none principle**; that is, either an action potential fires or it does not.

all-or-none principle
The idea that, once the threshold has been crossed, either an action potential fires or it does not.

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Source: Tina Carvalho/NIH-NIGMS

In this image taken by a scanning electron microscope, we see a terminal button that has been broken to show vesicles (colored balls). Neurotransmitters reside in the vesicles.

Neurotransmission The arrival of an action potential at the terminal buttons of a neuron triggers the second phase in neural communication—the release of neurotransmitters into the synaptic cleft to pass on the impulse to other neurons. Neurotransmitters are packaged in sacs called **synaptic vesicles** in the terminal button. When an action potential reaches the terminal button, the vesicles fuse with the cell membrane of the terminal and release neurotransmitter molecules into the synaptic cleft, where they may be taken up by receptors in the dendrites of adjacent neurons (Schwartz, 2000).

In a synapse, the neuron on the receiving end is known as the *postsynaptic* neuron. Neurotransmitters bind with receptors in the postsynaptic neuron in a lock-and-key type of arrangement (see Figure 7). There are many different types of neurotransmitters, each of which binds only with a specific receptor. For example, some receptors bind only with the neurotransmitter acetylcholine. If other neurotransmitters come in contact with acetylcholine receptors, they will not bind and no signal will be transmitted.

synaptic vesicles
Tiny sacs in the terminal buttons that contain neurotransmitters.

graded potentials
Small changes in membrane potential that by themselves are insufficient to trigger an action potential.

After a neurotransmitter binds to a receptor on the postsynaptic neuron, a series of changes occurs in that neuron's cell membrane. These small changes in membrane potential are called **graded potentials**. Unlike action potentials, these are not "all-or-none." Rather, they affect the likelihood that an action potential will occur in the receiving neuron. Some neurotransmitters, called *inhibitory* neurotransmitters, create graded potentials that decrease the likelihood of a neuron firing. In contrast, *excitatory* neurotransmitters create graded potentials that increase the likelihood of an action potential.

The excitatory potentials bring the neuron closer to threshold, while the inhibitory potentials bring it farther away from threshold. The soma in the postsynaptic neuron *integrates* the various graded potentials. If the integrated message from these graded potentials depolarizes the axon enough to cross the threshold, then an action potential will occur.

Common Neurotransmitters

Within the past century, researchers have discovered at least 100 distinct neurotransmitters and related chemical messengers and have learned what most of them do, though the exact number of neurotransmitters is unknown. Of the known neurotransmitters, those most relevant for the study of human thought and behavior are acetylcholine, dopamine, epinephrine, norepinephrine, serotonin, GABA, and glutamate (see Figure 8). Neurotransmitters are found only in the brain. They are synthesized inside the neuron for the purpose of neurotransmission.

acetylcholine (ACh)
A neurotransmitter that controls muscle movement and plays a role in mental processes such as learning, memory, attention, sleeping, and dreaming.

The neurotransmitter **acetylcholine (ACh)** is released at synapses that control muscle movement (these are known as *neuromuscular junctions*), and it is also released at synapses involved in learning, memory, attention, sleeping, and dreaming. Whether ACh excites muscles or slows them down depends on what kind of receptor receives it. Furthermore, researchers have discovered that the degenerative memory disorder called Alzheimer's disease results at least partly from a decrease in ACh activity and that ACh drug enhancers aid memory. ACh enhancers are now used to treat memory disorders, such as Alzheimer's disease, and they seem to slow the progression of memory loss (Czech & Adessi, 2004; Selkoe, 2002).

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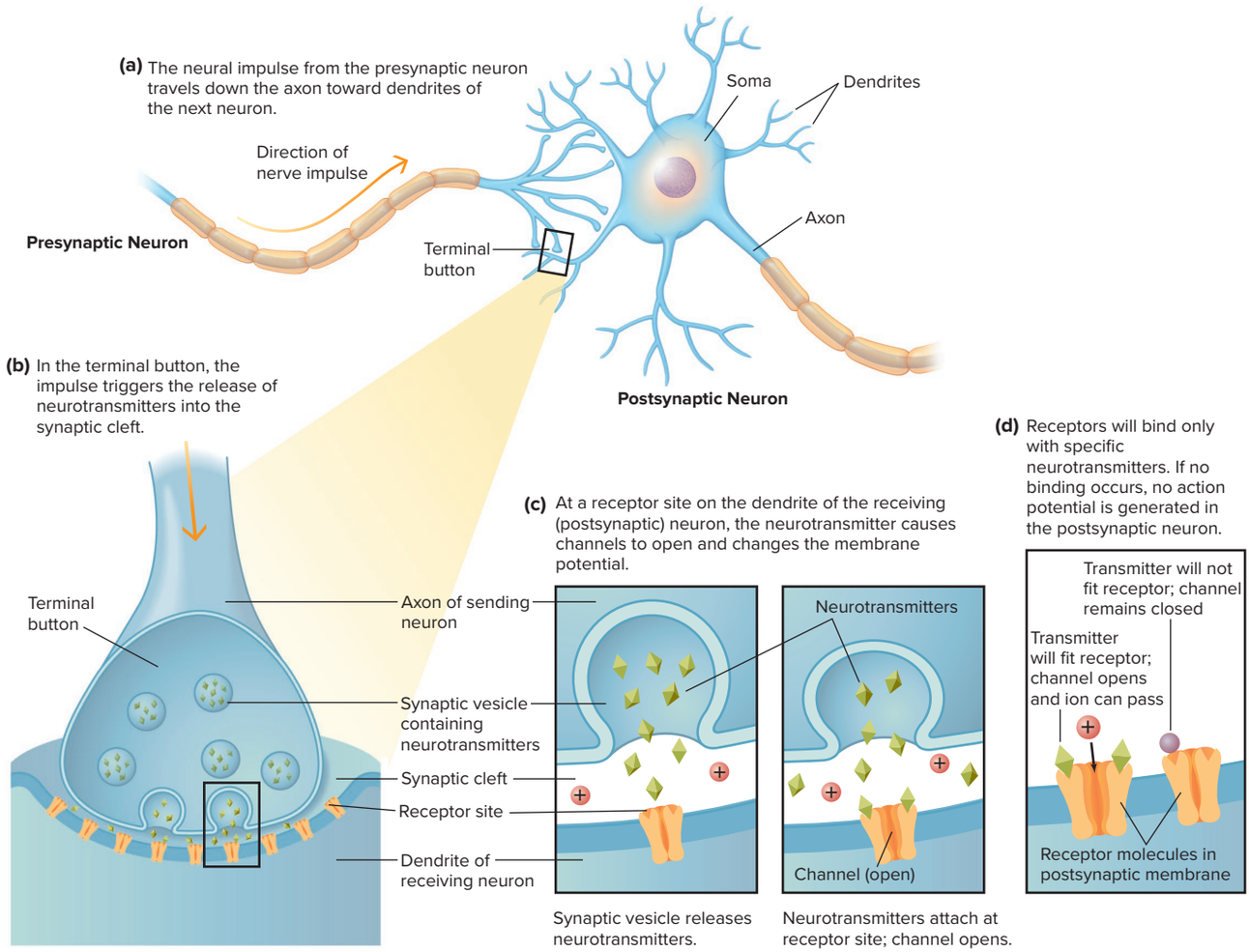
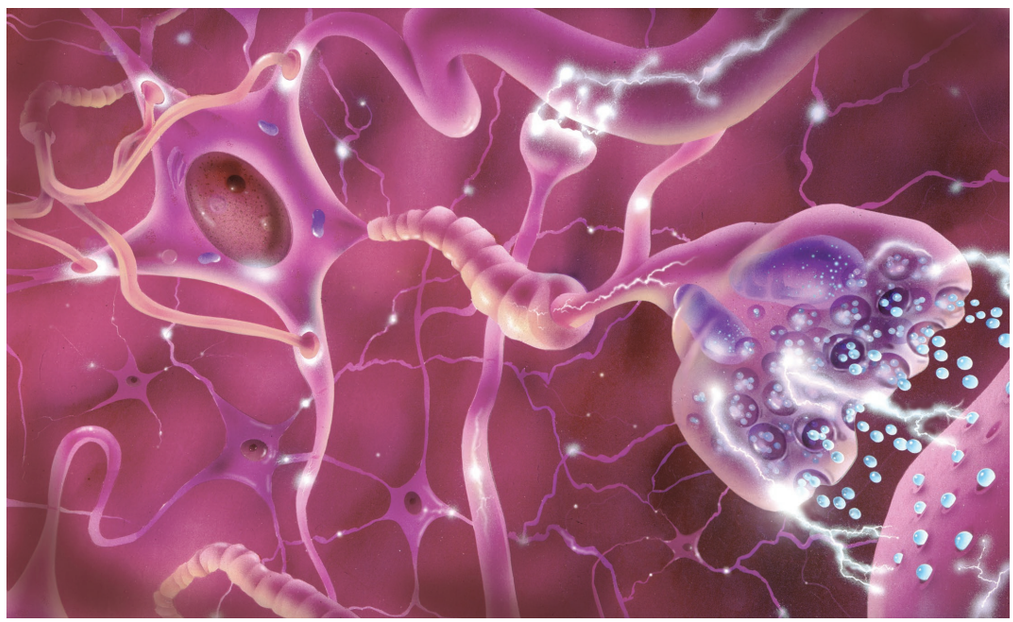


FIGURE **7**
HOW SYNAPSES AND NEUROTRANSMITTERS WORK. In (a), two neurons connect, a presynaptic neuron and a postsynaptic neuron. They do not touch, but terminal buttons in the presynaptic neuron form a synaptic cleft with the postsynaptic neuron. In (b), the synaptic cleft has been enlarged to show the synaptic vesicles that carry neurotransmitters. They release neurotransmitters into the cleft where they bind to receptor sites on the postsynaptic neuron. In (c), we see a further enlargement of the neurotransmitters being released into the synaptic cleft and binding to receptor sites in the postsynaptic neuron. In (d), each receptor site binds to only one specific kind of neurotransmitter.



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A three-dimensional artistic interpretation of neurons in the brain.

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FIGURE **8**

MAJOR NEUROTRANSMITTERS AND THEIR FUNCTIONS. Neurotransmitters can be excitatory, increasing the likelihood of an action potential, or inhibitory, decreasing the likelihood of an action potential.

Neurotransmitter	Major Function
Acetylcholine	Slows ANS activity; eating, drinking, neuromuscular junction; involved in learning, memory, sleeping, and dreaming
Dopamine	Plays an important role in arousal, mood (especially positive mood); oversupply correlates with schizophrenia; voluntary muscle control
Epinephrine	Increases ANS activity; fight-or-flight response
Norepinephrine	Affects CNS activity; plays role in increasing alertness, attention
Serotonin	Plays role in mood, sleep, eating, temperature regulation; undersupply correlates with anxiety and depression
GABA	Is the major inhibitory neurotransmitter in the brain; slows CNS function; correlates with anxiety and intoxication
Glutamate	Is the most common excitatory neurotransmitter in the brain; involved in learning and memory; may be involved in schizophrenia

dopamine
A neurotransmitter released in response to behaviors that feel good or are rewarding to the person or animal; also involved in voluntary motor control.

Dopamine is involved in voluntarily controlling your muscles and is released during feelings of pleasure or reward. Eating a good meal, doing well on an exam, having an orgasm, or drinking a glass of water when really thirsty—each of these behaviors stimulates dopamine activity in the brain (Hamer & Copeland, 1998; Kringelbach & Berridge, 2015). Because dopamine activity makes us feel good, many drug addictions involve increased dopamine activity. For instance, cocaine blocks the reuptake of dopamine into the presynaptic neuron, leaving it in the synaptic cleft for a longer period of time before it binds to receptors in the postsynaptic neuron (Bradberry, 2007). The result is a feeling of euphoria and pleasure.

epinephrine
Also known as adrenaline, a neurotransmitter that arouses bodily systems (such as increasing heart rate).

norepinephrine
A neurotransmitter that activates the sympathetic response to stress, increasing heart rate, rate of respiration, and blood pressure in support of rapid action.

Epinephrine and **norepinephrine** primarily have energizing and arousing properties. (Epinephrine was formerly called *adrenaline*, a term that is still widely used in everyday speech—"Wow! What an adrenaline rush!") Both are produced in the brain and by the adrenal glands that rest atop the kidneys. Epinephrine tends not to affect mental states, whereas norepinephrine increases mental arousal and alertness. Norepinephrine activity also leads to physical arousal—increased heart rate and blood pressure. People who suffer from ADHD have unusually low norepinephrine levels, and treatment sometimes includes drugs to increase norepinephrine levels (Barr et al., 2002).

serotonin
A neurotransmitter with wide-ranging effects; involved in dreaming and in controlling emotional states, especially anger, anxiety, and depression.

Serotonin plays a role in a wide range of behaviors, including dreaming and controlling emotional states such as anger, anxiety, and depression. People who are generally anxious and/or depressed often have low levels of serotonin (Caspi, Sugden, et al., 2003; Frokjaer et al., 2009; Kendler et al., 2005). Drugs that block the reuptake of serotonin in the synapse are used to treat anxiety and depression. It is well known that depression runs in families (Weissman et al.,

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2016). Serotonin-related genes appear to modulate family risk for depression (Bansal et al., 2016). People who are consistently angry and/or aggressive (especially males) often have abnormally low levels of serotonin as well. The administration of serotonin reduces aggressive behavior in monkeys (Suomi, 2005).

Gamma-aminobutyric acid, or GABA, is a major inhibitory neurotransmitter in the brain. Remember that inhibitory neurotransmitters tell the postsynaptic neurons *not* to fire. GABA slows CNS activity and is necessary for the regulation and control of neural activity. Without it, the central nervous system would have no "brakes" and could run out of control. One theory about epilepsy is that GABA does not function properly in people who suffer from the disorder (Laschet et al., 2007). Many drugs classified as depressants, such as alcohol, increase GABA activity in the brain and lead to relaxing yet ultimately uncoordinated states. Because GABA inhibits much of the CNS activity that keeps us conscious, alert, and able to form memories, large amounts of alcohol consumption can lead to memory lapses, blackouts, loss of consciousness, and even death (White, 2003). Stress can increase GABA and thereby increase its inhibitory effects on organs such as the large intestine, which might be one reason why some people experience diarrhea when under extreme stress (Reed et al., 2016).

GABA (gamma-aminobutyric acid)
A major inhibitory neurotransmitter in the brain that tells postsynaptic neurons not to fire; it slows CNS activity and is necessary to regulate and control neural activity.

Glutamate, the brain's major excitatory neurotransmitter, is important in learning, memory, neural processing, and brain development. More specifically, glutamate facilitates growth and change in neurons and the migration of neurons to different sites in the brain, all of which are basic processes of early brain development (Nadarajah & Parnavelas, 2002). It also amplifies some neural transmissions, so that a person can tell the difference between important and less important information. For example, is it more important to notice that a car is skidding out of control in front of you or that your shoes are still the same color they were when you put them on this morning? Glutamate boosts the signals about the car.

glutamate
A major excitatory neurotransmitter in the brain that increases the likelihood that a postsynaptic neuron will fire; important in learning, memory, neural processing, and brain development.

Summary of the Steps in Neural Transmission

We have considered the complex phenomena of action potentials and neurotransmission and described the neurotransmitters involved in human thought and behavior. Before we discuss the major structures of the brain, let's take time to summarize the process of neural communication.

- The information in neural transmission always travels in one direction in the neuron—from the dendrites to the soma to the axon to the synapses. This process begins with information received from the sense organs or other neurons, which generate a nerve impulse.
- The dendrites receive a message from other neurons. That message, in the form of an electrical and chemical impulse, is then integrated in the soma.
- If the excitatory messages pass the threshold intensity, an action potential will occur, sending the nerve impulse down the axon. If the inhibitory messages win out, the likelihood that the postsynaptic neuron will fire goes down.
- The nerve impulse, known as the action potential, travels down the axon, jumping from one space in the axon's myelin sheath to the next, because channels are opening and closing in the axon's membrane. Ions, mostly sodium and potassium, pass in and out of the membrane.
- This impulse of opening and closing channels travels like a wave down the length of the axon, where the electrical charge stimulates the release of neurotransmitter molecules in the cell's synapses and terminal buttons.

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- The neurotransmitters are released into the space between neurons, known as the synaptic cleft. Neurotransmitters released by the presynaptic neuron then bind with receptors in the membrane of the postsynaptic neuron.
- This binding of neurotransmitter to receptor creates electrical changes in the postsynaptic neuron's cell membrane, at its dendrites. Some neurotransmitters tend to be excitatory and increase the likelihood of an action potential. Others tend to be inhibitory and decrease the likelihood of an action potential.
- The transmission process is repeated in postsynaptic neurons, which now become presynaptic neurons.

Quick Quiz 2: The Nervous System

1. Which branch of the nervous system is responsible for the fight-or-flight response?
   a. parasympathetic nervous system
   b. somatic nervous system
   c. sympathetic nervous system
   d. central nervous system
2. The fingerlike projections on neurons that receive input from other neurons are called
   a. dendrites.
   b. nuclei.
   c. axons.
   d. terminal buttons.
3. What property of the neuron is most directly responsible for the changes that lead up to an action potential?
   a. sodium ions outside the cell
   b. its permeable membrane
   c. chloride ions inside the cell
   d. the flux of potassium ions
4. What is the most common excitatory neurotransmitter in the brain?
   a. GABA
   b. serotonin
   c. glutamate
   d. acetylcholine

Answers can be found at the end of the chapter.

THE BRAIN

The brain is a collection of neurons and glial cells that controls all the major functions of the body; produces thoughts, emotions, and behavior; and makes us human. This jellylike mass at the top of the spine has been mapped and described in astonishing detail. Here we consider the evolution of the brain, look at key brain regions, and explore what is currently known about their specialized functions. At this point, the picture is still far from complete, and neuroscientists continue to piece it together.

Evolution of the Human Brain

Evolution provides a fundamental example of how biology and environment interact. The human brain has been shaped, via natural selection, by the world in which humans have lived. It is worth noting that brains do not fossilize to allow a present-day analysis, but the skulls that hold them do. By looking at the size and shape of skulls from all animals and over very long time periods, scientists can glean something about how and when human brains evolved. The evolution of the human brain is a fascinating story. Although the details lie well beyond the scope of this book, we can consider a general outline of brain evolution (Dunbar, 2001; Jerison, 2000; Klein, 1999; Striedter, 2005).

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Neanderthals had larger but less complex brains than modern humans do.

Can you think of how this is the case—that is, what makes a brain complex?

The first primates lived around 55 million years ago—10 million years after the dinosaurs went extinct (Jerison, 2000; Zhang et al., 2008). Compared to other mammals, birds, reptiles, and fish, primates have relatively large amounts of brain cortex, allowing more complex thinking and problem solving. The earliest ancestors of humans appeared in Africa about 6 million years ago. One of our closest evolutionary relatives, the Neanderthals (*Homo neanderthalensis*), lived from about 350,000 to 28,000 years ago, when they were replaced by our species (*Homo sapiens*). Neanderthals had brains slightly larger, on average, than those of modern humans (see Figure 9).

Challenge Your Assumptions

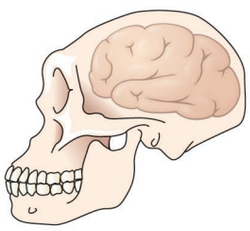
True or False? Neanderthals had larger brains than we (*H. sapiens*) do.

True: Average Neanderthal brain volume was slightly greater than ours (1,450 cc to 1,300 cc).

Overview of Brain Regions

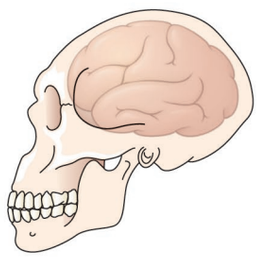
In evolutionary terms, then, the human brain is the result of a few hundred million years of natural selection. The three major regions of the brain, in order from

***Australopithecus* (4 million years ago)**



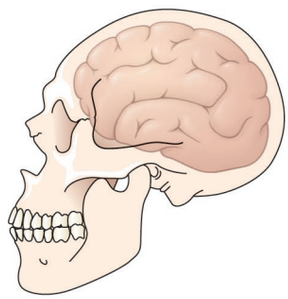
The brain capacity ranges from 450 to 650 cubic centimeters (cc).

***Homo erectus* (1.6 million to 100,000 years ago)**



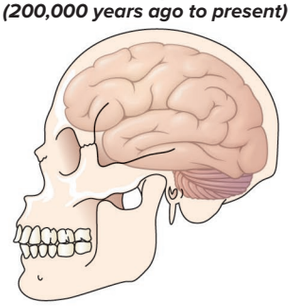
Further development of skull and jaw are evident and brain capacity is 900 cc.

***Homo neanderthalensis* (350,000 to 28,000 years ago)**



The human skull has now taken shape: The skull case has elongated to hold a complex brain of 1,450 cc.

***Homo sapiens* (200,000 years ago to present)**



The deeply convoluted brain reflects growth in areas concerned with higher mental processes (1,300 cc).

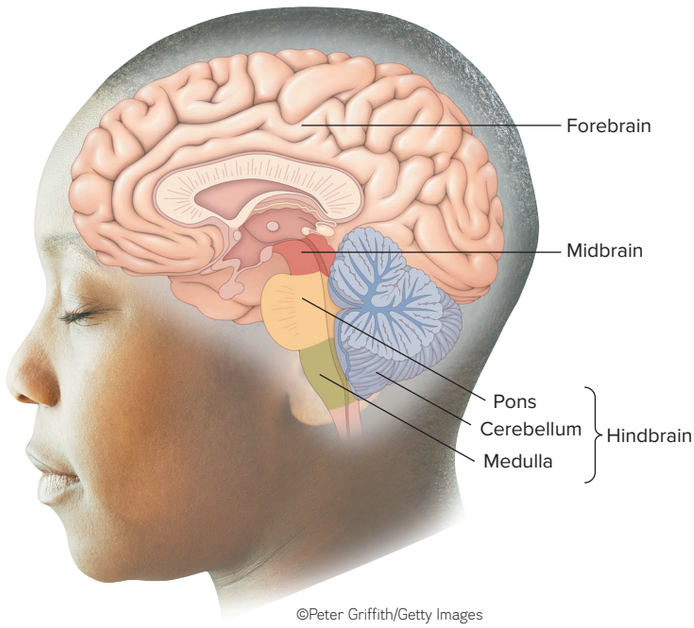
FIGURE **9**

EVOLUTION OF THE HUMAN BRAIN OVER THE LAST 4 MILLION YEARS. An early form of prehuman, *Australopithecus*, had a brain about one-third the size of the modern human (*H. sapiens*) brain. In general, the overall brain size has grown over the course of 4 million years. But note that Neanderthal's brain was slightly larger than ours. Just as important as overall size for modern human thought and behavior is the relative enlargement of the frontal lobe area. This can be seen in the less-sloped forehead of modern humans compared to their earlier ancestors.

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FIGURE **10**

THREE MAIN BRAIN STRUCTURES: HINDBRAIN, MIDBRAIN, AND FOREBRAIN. The hindbrain regulates breathing, heart rate, arousal, and other basic survival functions. The midbrain controls eye muscles, processes auditory and visual information, and initiates voluntary movement. The forebrain controls cognitive, sensory, and motor function and regulates temperature, reproductive function, eating, sleeping, and emotions.

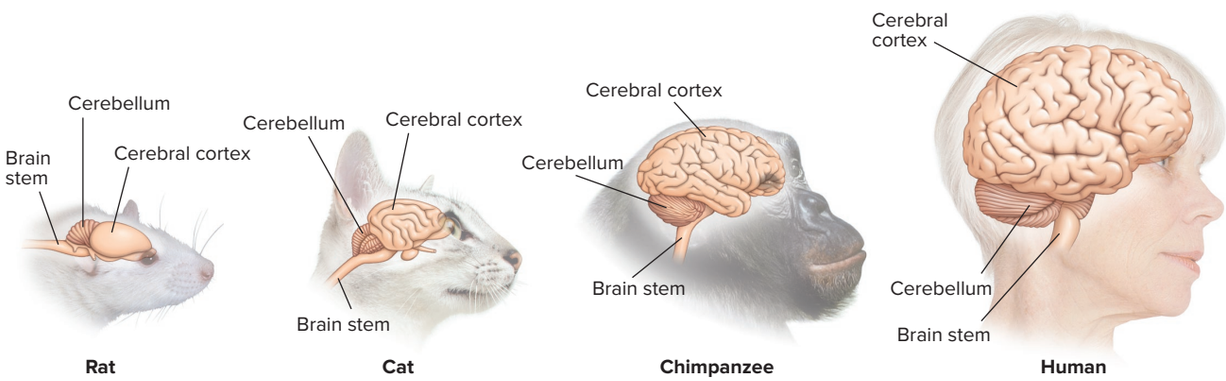


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earliest to develop to newest, are the hindbrain, the midbrain, and the forebrain (see Figure 10). By comparing the relative size of each region in distinct kinds of animals that vary in evolutionary age (see Figure 11), we gain an appreciation of how these regions evolved. When we compare brains from these different groups, we see an increase in size of the forebrain in humans and other primates (Jerison, 2000).

FIGURE **11**

THE BRAIN STRUCTURE OF MAMMALS. Mammals have many of the same brain structures, but of different relative sizes. Notice how much larger the cerebral cortex is in humans than in chimpanzees, cats, and rats. Also notice the increase in brain folds in primates.



What are the main differences you notice in these brains?

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Hindbrain The oldest brain region is the hindbrain, the region directly connected to the spinal cord. Hindbrain structures regulate breathing, heart rate, arousal, and other basic functions of survival. There are three main parts of the hindbrain: the medulla, the pons, and the cerebellum.

Extending directly from the spinal cord, the **medulla** regulates breathing, heart rate, and blood pressure. It is also involved in various kinds of involuntary, reflexive responses such as coughing, swallowing, sneezing, and vomiting. **Reflexes** are inborn, involuntary behaviors that are elicited by very specific stimuli (Anokhin, 2013).

The **pons** serves as a bridge between lower brain regions and higher midbrain and forebrain activity, thereby playing an important role in regulating many of the same automatic functions as the medulla as well as body movement, including facial expressions (Müri, 2016). For instance, information about body movement and various sensations is relayed from the cortex via the pons to the cerebellum.



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Swallowing is one of a number of involuntary behaviors controlled by the medulla.

The **cerebellum**, or "little brain," contains more neurons than any other single part of the brain. It is responsible for body movement, balance, coordination, and fine-motor skills such as typing and piano playing. The cerebellum is also important in cognitive activities such as learning and language, and abnormalities in the cerebellum may be linked to cognitive as well as motor abnormalities (Amaral, 2000; Salman & Tsai, 2016; Stroodley & Schmahmann, 2009).

Midbrain The next brain region to evolve after the hindbrain was the smallest of the three major areas, the midbrain. Different parts of the midbrain control the eye muscles, process auditory and visual information, and initiate voluntary movement of the body. People with Parkinson's disease have problems with midbrain functioning, due to the loss of neurons that use dopamine there, and so they shake uncontrollably (Vogt Weisenhorn, Giesert, & Wurst, 2016). The midbrain, the medulla, and the pons together are sometimes referred to as the *brain stem*.

A network of nerves called the **reticular formation** runs through both the hindbrain and the midbrain (*reticular* means "netlike"). The reticular formation plays a key role in wakefulness. Among the first neuroscientists to study the reticular formation were Giuseppe Moruzzi and Horace Magoun. In a classic study, Moruzzi and Magoun electrically stimulated the reticular formation of a sleeping cat, and it immediately awoke. When they *lesioned*, or damaged, its connection to higher brain systems, the cat went into a deep coma, from which it never recovered. No kind of pinching or loud noises would arouse the cat (Moruzzi & Magoun, 1949). To this day, the reticular formation is still considered a major player in the maintenance of wakefulness (Koch et al., 2016).

Forebrain The last major region to evolve was the largest part of the human brain, the forebrain. It consists of the cerebrum and numerous other structures, including the thalamus and the limbic system. Collectively, the structures of the forebrain control cognitive, sensory, and motor function and regulate temperature, reproductive functions, eating, sleeping, and the display of emotions. Most forebrain structures are *bilateral*; that is, there are two of them, one on each side of the brain.

From the bottom up, the first forebrain structure is the **thalamus**, which receives input from the ears, eyes, skin, or taste buds and relays sensory information to the part of the cerebral cortex most responsible for processing that specific kind of sensory information. For this reason, the thalamus is often called

medulla
A hindbrain structure that extends directly from the spinal cord; regulates breathing, heart rate, and blood pressure.

reflexes
Inborn and involuntary behaviors—such as coughing, swallowing, sneezing, or vomiting—that are elicited by very specific stimuli.

pons
A hindbrain structure that serves as a bridge between lower brain regions and higher midbrain and forebrain activity.

cerebellum
A hindbrain structure involved in body movement, balance, coordination, fine-tuning motor skills, and cognitive activities such as learning and language.

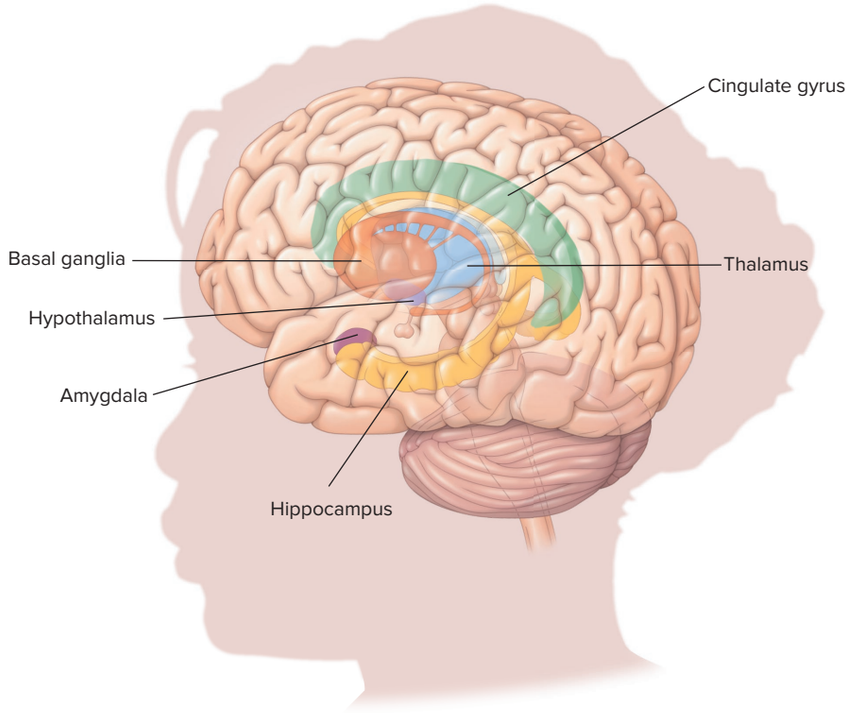
reticular formation
A network of nerve fibers that runs up through both the hindbrain and the midbrain; it is crucial to waking up and falling asleep.

thalamus
A forebrain structure that receives information from the senses and relays it to the cerebral cortex for processing.

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FIGURE **12**

THE LIMBIC SYSTEM. The limbic system controls motivation and emotion. It includes the basal ganglia, hypothalamus, amygdala, hippocampus, thalamus, and cingulate gyrus.





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How does this picture make you feel? The structures of the limbic system play a key part in emotion and motivation.

Can you think of certain kinds of drives and emotions that result from activation of the limbic system?

a sensory relay station. Olfaction (the sense of smell) is unique in this case. It has a thalamic relay, but unlike the other senses, it has direct connections to the memory and emotional processing areas of the brain in the limbic system as well (see below), which is one of the reasons why smells can trigger powerful emotional memories very quickly (Courtiol & Wilson, 2016).

The Limbic System In the middle of the brain, directly around the thalamus, lies a set of structures, traditionally referred to as a group. The **limbic system** (see Figure 12) is a group of forebrain structures that share important functions in emotion, memory, and motivation, including the hypothalamus, amygdala, hippocampus, and the cingulate gyrus. There is some debate as to whether these structures work together as a system. Some neuroscientists suggest either that the term *limbic system* should be abandoned altogether or that we should speak of limbic systems or networks instead (Rolls, 2015).

limbic system
A connection group of forebrain structures (hypothalamus, amygdala, hippocampus, and cingulate gyrus) that share important functions in emotion memory and motivation and regulate autonomic and endocrine function.

The structure directly below the thalamus is the hypothalamus (hypo means "below"). The **hypothalamus** regulates almost all of our major drives and motives, including hunger, thirst, temperature, and sexual behavior. It also controls the pituitary gland, which is responsible for producing and controlling the hormones our bodies produce. Researchers in the 1940s discovered the hypothalamus's role in eating: Lesioning one part of it produced overeating and obesity in animals, whereas lesioning another part of the hypothalamus led to undereating (Kupferman, Kandel, & Iversen, 2000). In particular, pathways from the hindbrain send crucial information to the hypothalamus about energy needs, which helps the hypothalamus regulate food intake (Utoyama et al., 2016). The hypothalamus is also involved in sexual arousal (Brunetti et al., 2008; Karama et al., 2002).

hypothalamus
A limbic structure; the master regulator of almost all major drives and motives we have, such as hunger, thirst, temperature, and sexual behavior; also controls the pituitary gland.

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Wrapped around the thalamus is the **hippocampus**, which plays a vital role in learning and memory. Sensory information from the sense organs goes to the hippocampus. If these events are important enough, they are processed in the hippocampus and eventually established as lasting memories.

As we will see throughout this text, learning and memory change the brain. The brain structure most open to such change is the hippocampus. To get a feel for the kind of research that demonstrates this capacity, let's look at research conducted with taxicab drivers in London. Why study taxi drivers? Their work requires a tremendous amount of spatial and geographic knowledge, and they have to pass a difficult driving test (Maguire, Woollett, & Spiers, 2006). They must know where all the streets are relative to other streets. Neuroscientists examined images of the hippocampus and found that the hippocampi of taxi drivers were larger than that of other drivers. Moreover, the stress and frequency of driving did not account for these hippocampal size differences. Compared to bus drivers, taxi drivers had larger hippocampi (Maguire et al., 2006). Why? Bus drivers drive the same route every day, so they need to learn much less about the spatial layout of the city than taxi drivers. As this study suggests, learning changes the brain.

hippocampus
A limbic structure that wraps itself around the thalamus; plays a vital role in learning and memory.

Connection

The various appetites of the hypothalamus play a big role in motivating behavior.

See the chapter, "Motivation and Emotion." (p. 346)

The **amygdala** is a small, almond-shaped structure directly in front of the hippocampus. Anatomically, the amygdala connects with many other areas of the brain, including the structures involved in emotion and memory: the hypothalamus, which controls the autonomic nervous system; the hippocampus, which plays a crucial role in memory; the thalamus, which contains neurons that receive information from the sense organs; and the cerebral cortex. By virtue of its prime location, the amygdala plays a key role in determining the emotional significance of stimuli, especially when they evoke fear (Öhman, 2002; Phelps & LeDoux, 2005), as well as the processing of facial expressions of emotion (Wu et al., 2016).

amygdala
A small, almond-shaped structure located directly in front of the hippocampus; has connections with many important brain regions and is important for processing emotional information, especially that related to fear.

Challenge Your Assumptions

True or False? Only long-term learning increases the number and structure of neurons in your brain.

True: Whenever we learn and retain information long term, neurons in our brains actually grow and change. The same does not happen with short-term learning that is soon forgotten.

Studies in animals and humans show how important the amygdala is to emotions, especially fear. Electrical stimulation of the amygdala in cats makes them arch their backs in an angry-defensive manner, a response suggesting that anger and aggression involve the amygdala. Moreover, when aggressive monkeys had this region of the brain surgically lesioned, they became tame and nonaggressive. They also became fearless; for instance, rather than fleeing from snakes, they approached them (Klüver & Bucy, 1939; Meunier & Bachevalier, 2002). Similarly, in cases of disease, injury, or surgery to the human amygdala, people often lose their aggressive tendencies.



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One of the special functions of the amygdala is to recognize situations for which fear is an appropriate response.

What would happen if humans were not able to experience fear?

The **cingulate gyrus** is a beltlike structure in the middle of the brain. Portions of the cingulate gyrus, in particular the front part, play an important role in attention and cognitive control (Botvinick, Cohen, & Carter, 2004). When people are first trying to figure out a difficult problem and preparing to solve it, parts of the cingulate gyrus are activated (Kounios et al., 2006; Qiu et al., 2010). In contrast, this area seems to malfunction in people with schizophrenia, who have major difficulties in focusing their attention (Carter et al., 1997).

cingulate gyrus
A beltlike structure in the middle of the brain; plays an important role in attention and cognitive control.

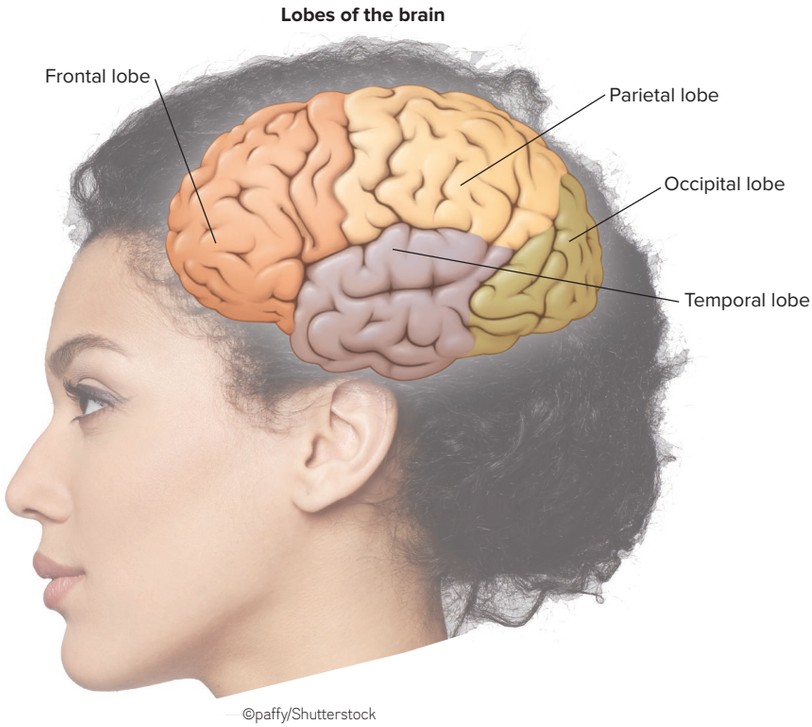
The **basal ganglia** are a collection of structures surrounding the thalamus; they are involved in voluntary motor control. Several movement-related neurological disorders, including Parkinson's disease and Huntington's disease, affect the functioning of neurons in this region. Individuals who have these disorders suffer from jerky, often uncontrollable movements.

basal ganglia
A collection of structures surrounding the thalamus; involved in voluntary motor control.

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FIGURE **13**

FOUR LOBES OF THE CEREBRAL CORTEX. Each of the four lobes has a counterpart on the opposite side of the brain. Most important for thinking, planning, and integrating the brain's activity are the frontal lobes. The parietal lobes integrate the sensation and perception of touch. Visual information is processed in the occipital lobes, whereas hearing is processed in the temporal lobes.



cerebrum
Each of the large halves of the brain; covered with convolutions, or folds.

cerebral cortex
The thin outer layer of the cerebrum, in which much of human thought, planning, perception, and consciousness takes place.

The Cerebrum and Cerebral Cortex

The uppermost portion of the brain, the **cerebrum**, is folded into convolutions and divided into two large hemispheres. When most of us think about the human brain, we typically envision the outer layer, with all of its convolutions. This outer layer is called the **cerebral cortex**. The cortex is only about one-tenth to one-fifth of an inch thick, yet it is in this very thin layer of brain that much of human thought, planning, perception, and consciousness takes place. In short, it is the site of all brain activity that makes us most human.

The cerebrum is composed of four large areas called *lobes*, each of which carries out distinct functions. These lobes are bilateral, which means they are located on both the left and right sides of the brain. The four lobes are the frontal, temporal, parietal, and occipital (see Figure 13). The *frontal lobes*, in the front of the brain, make up one-third of the area of the cerebral cortex. One important region of the frontal lobe, descending from the top of the head toward the center of the brain, is the *primary motor cortex*. One of the earliest discoveries about the brain's frontal lobes involved the motor cortex. In the 1860s, while caring for wounded soldiers, the German physiologist Eduard Hitzig noticed that touching the surface of a specific side of the brain caused a soldier's body to twitch on the opposite side.

The frontal lobe carries out many important functions, including attention, holding things in mind while we solve problems, planning, abstract thinking, control of impulses, creativity, and social awareness (Miller & Cummings, 1999; Stuss & Knight, 2002). The frontal lobes are more interconnected with other brain regions than any other part of the brain and therefore are able to integrate much brain activity. This integration allows for insight and creative problem solving (Fuster, 1999). For example, connections between the frontal lobes and the hippocampus and temporal lobe facilitate tasks involving language and memory, respectively. More than any other part of the brain, the frontal lobes are what make humans human. They are also the "youngest" brain systems to evolve and the last to fully develop in individuals. The frontal lobes continue to develop until the early 20s. Children and teenagers act more impulsively than adults partially because their frontal lobes are not fully developed.

Probably the most famous story in neuroscience comes from the first case study of frontal lobe involvement in impulse control and personality (Macmillan, 2000). In September 1848, a 25-year-old railroad foreman, Phineas Gage, was laying railroad ties. While hammering a tamping iron (an iron bar), Gage accidentally ignited gun powder used to lay the track, and it exploded. The iron bar shot upward, entered Gage's left cheek, and exited through the top of his skull after passing through his frontal lobe (see Figure 14). The iron bar was traveling so fast

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that it moved cleanly through Gage's head and landed 25 feet away. Miraculously, not only did Gage survive, but he never even lost consciousness!

Although not mortally wounded, Gage suffered immediate and obvious changes to his personality. Before the accident, he had been a mild-mannered but clever businessman. After the accident, he was stubborn, impulsive, and argumentative, and at times he said offensive things. Gage's accident was one of the first documented cases of marked personality change following an injury to the frontal lobes, suggesting that these areas play a key role in regulating social behavior.

The *parietal lobes*, which make up the top and rear sections of the brain, are important in the sensation and perception of touch. The frontmost portion of the parietal lobes is the **somatosensory cortex**. When different parts of the body are touched, different parts of this strip of cortex are activated—whether fingertips, limbs, or the genitalia. The somatosensory cortex lies directly behind the *motor cortex* of the frontal lobe, which controls the voluntary movement of the body. In fact, these two regions are "twins." The areas of the motor and somatosensory cortexes that govern specific parts of the body are parallel to and directly next to each other (see Figure 15). For example, the part of the motor cortex involved in moving the lips is directly opposite the region of the sensory cortex where we sense that our lips are being touched. Notice from Figure 15—which shows that the more sensitive portions of the body appear bigger—that touch sensation at the fingertips is much more sensitive than that hip, for example. Brain representation

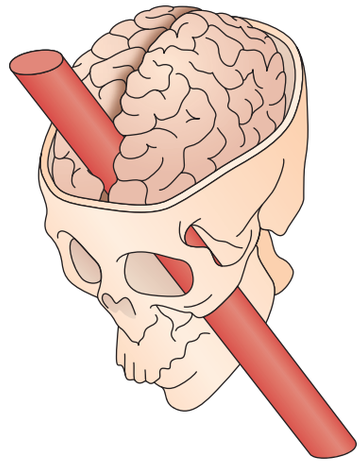


FIGURE **14**
PHINEAS GAGE'S ACCIDENT. Miraculously, Gage survived, but his personality changed dramatically as a result of the injury to his frontal lobe.

From what you have learned about the frontal lobes, can you predict what effects the accident had on Gage's personality?

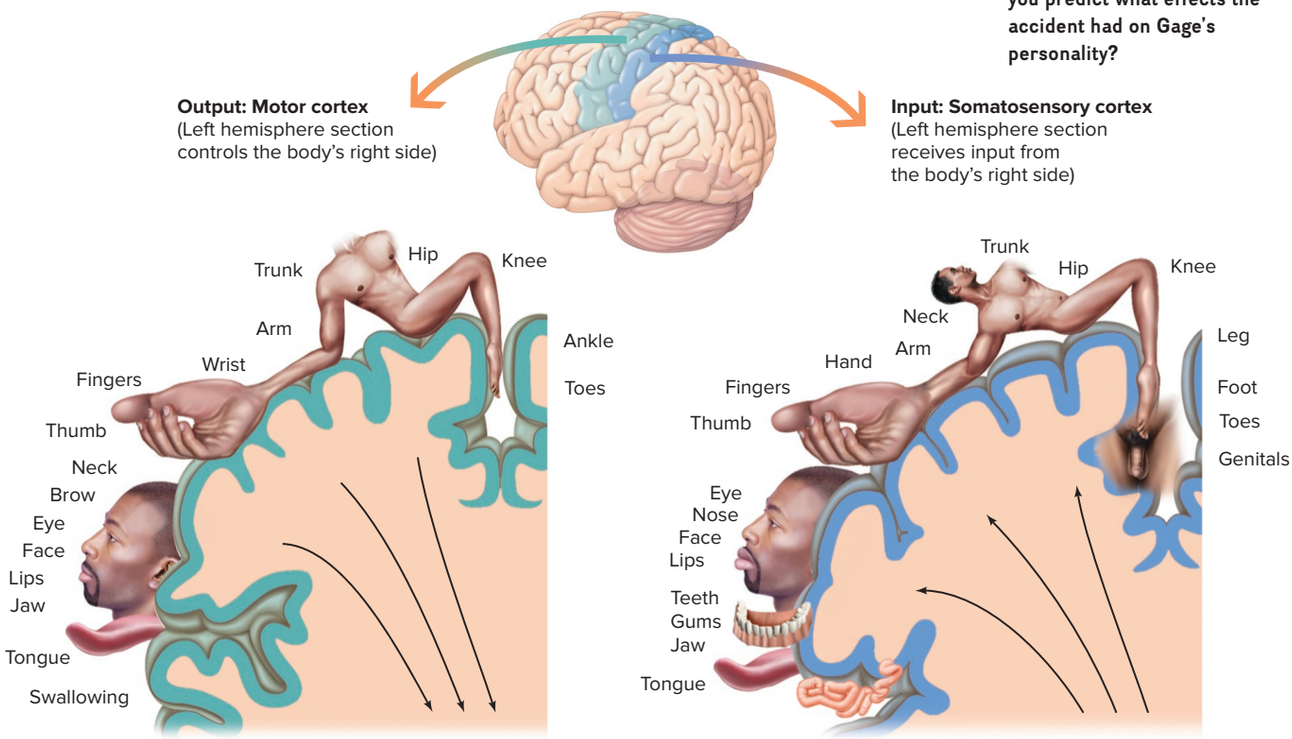


FIGURE **15**
MOTOR AND SOMATOSENSORY CORTEXES OF THE BRAIN. Note that the regions of the motor and somatosensory cortexes are "twins." The face, lips, or toes, for example, activate the same areas of both cortexes. The arrows going down into the lower brain region represent motor neurons, and the arrows coming up into the somatosensory cortex correspond to sensory neurons.

Can you think of why the distorted size differences are shown in various body parts?

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somatosensory cortex
A strip of the parietal lobe involved in the processing and perception of sensory information from the body, especially temperature, touch, pressure, and pain.

of sensation from the sex organs is a bit more complicated, however, as sexual stimulation involves more than just touch. Neural signals from the motor cortex can communicate with computers to control robotic arms or artificial limbs, as explained in "Psychology in the Real World."

The *temporal lobes* lie directly below the frontal and parietal lobes and right behind the ears. The temporal lobes have many different functions, but the main one is hearing. The temporal lobes house the *auditory cortex*, where sound information arrives from the thalamus for processing. Here, we "hear" our mother's voice, a symphony, an approaching car, or any other sound. The temporal lobes also house and connect with the hippocampus and amygdala and, so, are also involved in memory and emotion (Ventura-Bort et al., 2016).

The *occipital lobes* occupy the rear of the brain. The optic nerve travels from the eye to the thalamus and then to the occipital lobes—specifically, to the *primary visual cortex*. Visual information is processed in the visual cortex, where we "see" and "imagine." Neuroscientists have discovered that different neurons in the visual cortex are activated when we see horizontal lines, diagonal lines, and vertical lines. In other words, individual neurons are specialized for the many different aspects of vision, including shape, color, shadow, light, and orientation (Wurtz & Kandel, 2000a).

insula
A small structure inside the cerebrum that plays an important role in the perception of bodily sensations, emotional states, empathy, and addictive behavior.

The **insula** is a small structure deep inside the cerebrum, in the area that separates the temporal lobe from the parietal lobe. The insula is active in the perception of bodily sensations, emotional states, empathy, and addictive behavior (Damasio, 2000; Naqvi et al., 2007). It communicates with structures of the limbic system and higher brain areas involved in decision making. The insula also plays a key role in our awareness of our bodies as our own (Tsakiris et al., 2007). The insula may play a key role impulsive behavior and may be crucial for understanding the compulsions underlying many addictions (Belin-Rauscent et al., 2016).

Cerebral Hemispheres The human cerebrum is divided into two equal *hemispheres*. Although they look similar, the hemispheres differ in shape, size, and function. In general terms, the left hemisphere processes information in a more focused and analytic manner, whereas the right hemisphere integrates information in a more holistic, or broader, manner (Beeman & Bowden, 2000; Beever & Chiarello, 2009). Insights and solutions to problems are more likely to occur in the right hemisphere.

corpus callosum
Nerve fibers that connect the two hemispheres of the brain.

The hemispheres do not operate independently, however. The **corpus callosum**, the thick band of nerve fibers connecting the two hemispheres, provides a channel for extensive communication between the hemispheres in both logical and creative tasks.

Perhaps the best-known and biggest functional difference between the cerebral hemispheres is in language. Speech and language comprehension involve two separate regions in the left hemisphere. The French physician Paul Broca is credited with being the first "neuropsychologist." He deserves this title because his work in the early 1860s demonstrated for the first time that specific parts of the brain control particular behaviors (Kandel, 2006). Broca was the first to test the predictions of a fellow physiologist, Ernest Auburtin, who diagnosed a "softening of the anterior lobes" in a patient who understood but could not produce speech (Kolb & Whishaw, 2003, p. 11). He had a type of **aphasia**, a deficit in the ability to speak or comprehend language. Broca had a similar patient who shortly thereafter died, at which time Broca performed an autopsy and confirmed Auburtin's conjecture. He found that a cyst had damaged a small region in the left frontal lobe. Broca went on to discover similar damage in eight other aphasia patients (Pinker, 1994). These clinical findings have been confirmed by modern brain imaging techniques: People with aphasia often have damage or lesions in the same region of the left frontal lobe. This region, responsible for the ability to

aphasia
A deficit in the ability to speak or comprehend language.

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Psychology in the Real World

Neuroprosthetics: Thought Control of Artificial Limbs

Think about how incredible it is that we can use our thoughts to control voluntary movement. You might think, *I want to scratch my nose*, and then instantaneously lift your arm and move a finger to scratch your nose. When injury or disease destroys connections between the CNS and the skeletal muscles, a person's intention to move a limb—say, to pick up a coffee cup—cannot reach the muscles needed to lift the cup. Thoughts cannot lead to action. Similarly, the limbs cannot send information about felt touch, temperature, or pressure back to the brain.

Attempts to reconnect brain and limb lie at the center of *neuroprosthetics*, a field in which the brain, computing, and robotics come together to help people who no longer have functional limbs (Eapen, Murphy, & Cifu, 2016). People can learn to control movements of an artificial limb (or a *prosthetic*) with only their thoughts. How? Neural activity is recorded from key areas of the brain, and then action potentials are converted into digital signals, which then can be used to control a prosthetic or paralyzed limb (Hargrove et al., 2013). Thoughts are converted to action, whereby a robotic arm can then execute the neural instructions of "lift the arm."



©Chip Somodevilla/Getty Images

An artificial arm created by the Applied Physics Laboratory at Johns Hopkins University. The wearer or user of this limb can control the action of the arm with his thoughts, as well as feel sensations with the limb, thanks to an interface between electrodes implanted in his brain and sensors in the limb. These developments in prosthetics are a major area of work in neurotechnology.

What would be needed so that thoughts can control an artificial limb? First, one would need to know which neurons in the motor cortex control intentional movement. Such mapping of individual neurons can be done in a surgical lab setting. Studies on monkeys, in which electrodes were placed on specific areas of the motor cortex, have helped map the motor cortex of the monkey brain, mapping both muscle control and action patterns in the brain (Graziano, 2016) and helped monkeys learn to control artificial limbs with thoughts (Foley, 2016). In laboratory studies, paralyzed patients can use their intentional thoughts toward movement to control a robotic arm, which may prove to be a help for quality of life if these changes can move out into their daily lives (Davis et al., 2016; Hochberg et al., 2012).

In one of the key studies in neuroprosthetics, researchers implanted electrodes deep into the brains of two monkeys to record signals from neurons in the motor cortex. They used nerve-blocking drugs to temporarily paralyze the animals' arms. Then they wanted to see whether they could use a brain-machine interface to have these neural signals stimulate muscles in the monkeys. In spite of almost completely paralyzed wrists, the monkeys were able to use this cortically controlled system to control the contraction of four forearm muscles (Pohlmeyer et al., 2009).

Work in neuroprosthetics has taken off, with an emphasis on perfecting the relationship between brain and limb (Davis et al., 2016). Though the challenge is even greater with weight-bearing limbs like the legs, the connections between the robotic legs and the body's own muscle activity (near amputation site, for example) offer great promise for lower limb amputees as well (Bercich et al., 2016). The future is now.

produce speech, is commonly referred to as **Broca's area** (see Figure 16), and this type of aphasia is known as Broca's aphasia.

About 20 years after Broca found the area of the brain now named for him, a German physiologist, Carl Wernicke, discovered that damage to another region of the left hemisphere creates a different language problem. This area of the left temporal lobe, now called **Wernicke's area**, is responsible for speech comprehension. Wernicke's aphasia, in contrast to Broca's aphasia, results in fluent, grammatical streams of speech that lacks meaning. A patient with this disorder who was asked why he was in the hospital responded, "Boy, I'm sweating. I'm awfully nervous, you know, once in awhile I get caught up, I can't mention the tarripoi,

Broca's area
The area in the left frontal lobe responsible for the ability to produce speech.

Wernicke's area
The area deep in the left temporal lobe responsible for the ability to speak in meaningful sentences and to comprehend the meaning of speech.

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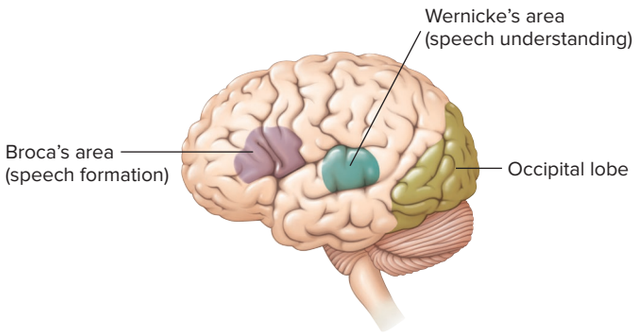


FIGURE **16**
WERNICKE'S AND BROCA'S AREAS AND THE OCCIPITAL LOBES.
The occipital lobes are home to the visual cortex. As we'll see later, thinking involves both verbal and visual representations.

a month ago, quite a little, I've done a lot well, I impose a lot, while, on the other hand, you know what I mean, I have to run around, look it over, trebbin and all that sort of stuff" (as quoted in Pinker, 1994, p. 316).

Although it is clear that the Broca's and Wernicke's regions are involved in language production and comprehension, recent evidence using more modern technologies than lesion studies—such as fMRI—has started to challenge the simple one-to-one model of these brain areas and language (Dick, Bernal, & Tremblay, 2013; Poeppel et al., 2012; Tremblay & Dick, 2016). It is becoming more and more clear that speaking and understanding language involves a wider network of brain regions than simply the Broca's and Wernicke's regions, including right hemisphere regions.

Communication between the Hemispheres As we have seen, the two hemispheres of the brain do not operate independently. All communication between one side of the brain and the other travels across the corpus callosum.

Recall that language—both speech and comprehension—resides in the left hemisphere of the human brain. In addition, information from our right visual field (the right portion of the visual scope of each eye) goes to the left occipital cortex, whereas information from the left visual field (the left portion of the visual scope of each eye) goes to the right occipital cortex (see Figure 17). The information from the left visual field could not get transferred to the language centers in the *left* hemisphere. He could, however, consistently pick up with his left hand the image he saw! Thus, because the right hemisphere (where the image was projected) controls the left side of the body, he could move his hand to the correct object (see Figure 18). This *split-brain research* shows that we can know something even if we cannot name it (Sperry, Gazzaniga, & Bogen, 1969).

Brain Plasticity and Neurogenesis

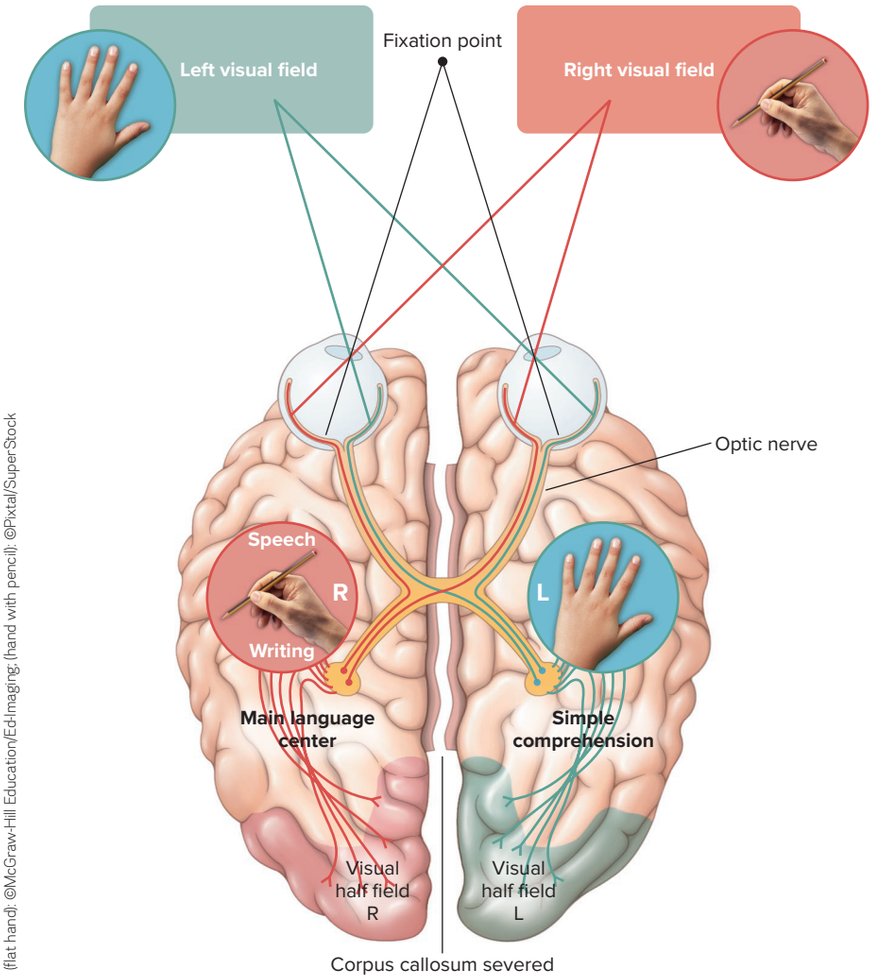
When scientists began mapping the brain in the late 19th century, they did so by stimulating various brain regions in animals and observing the behavioral changes that such stimulation caused; they then diagrammed the locations of functions in the cerebral cortex (Kandel, 2006). Such mapping contributed to the notion that brain function was fixed: Certain brain regions had certain functions. But as far back as the early 20th century, researchers had stimulated different places on the motor cortex in several different monkeys and had found that maps generated from such stimulation varied from monkey to monkey. They were as individual as fingerprints.

In the early 20th century, other neuroscientists mapped the motor cortexes of several monkeys many times during a 4-month period. They found that neural areas corresponding to the movement of specific fingers changed to reflect changes in the animal's patterns of movement over that time period (Jenkins et al., 1990). By the 1970s, there was evidence that learning occurs through synaptic change. These findings were only the tip of the iceberg. Since the 1990s, numerous principles of brain plasticity have emerged (Perry, 2002). First and most generally, **neuroplasticity** is the brain's ability to adopt new functions, reorganize itself, or make new neural connections throughout life, as a function of experience. Second, almost every major structure of the neuron is capable of experience-based change.

neuroplasticity
The brain's ability to adopt new functions, reorganize itself, or make new neural connections throughout life, as a function of experience.

Third, not all regions of the brain are equally plastic. For example, the part of the brain most involved in learning, the hippocampus, is more plastic than just

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(flat hand): ©McGraw-Hill Education/Ed Imaging; (hand with pencil): ©Pixtal/SuperStock

FIGURE **17**
THE VISUAL FIELD AND THE BRAIN. Information from the two visual fields is processed in the opposite side of the brain—that is, images from the right visual field stimulate the left retina. From the retina, the optic nerves cross at the optic chiasm and project to the visual cortex in the occipital lobes.

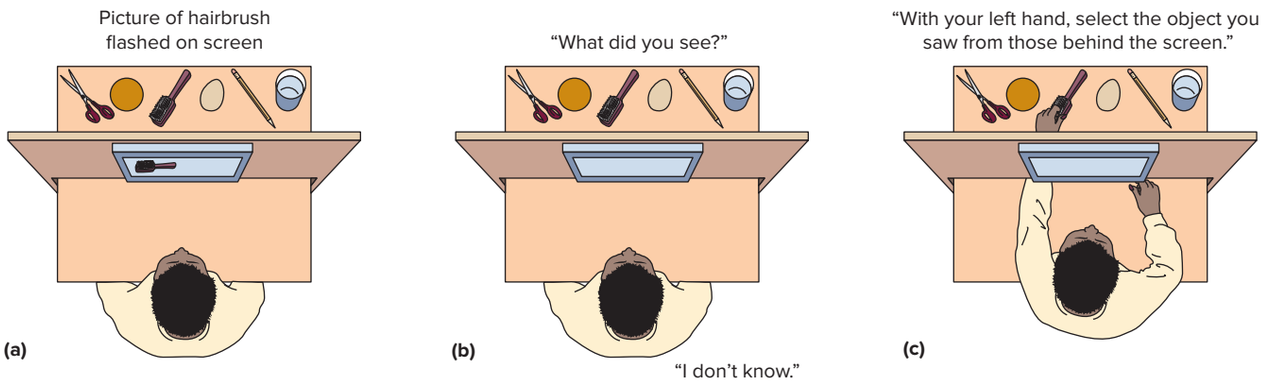
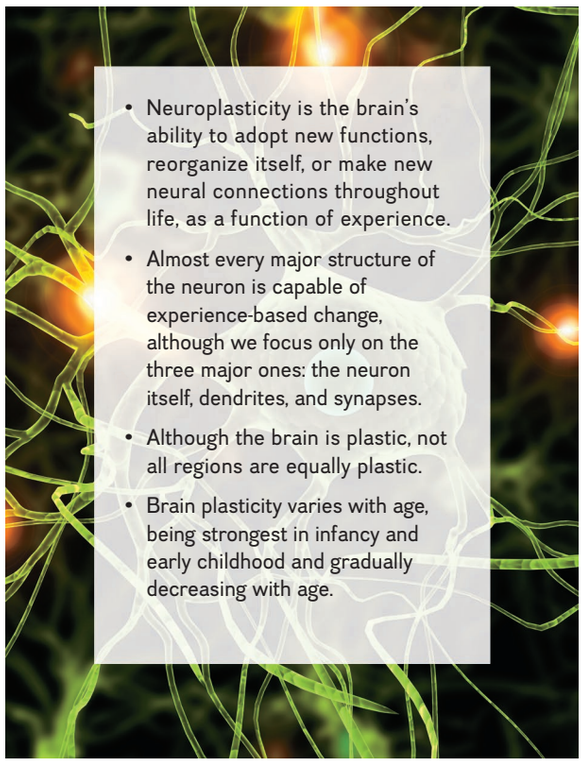


FIGURE **18**
PERCEPTION AND LANGUAGE IN A SPLIT-BRAIN PATIENT. In (a), a person who has had an operation to cut the corpus callosum is shown an object (hairbrush) to his left visual field. In (b), when asked what he saw, he cannot say, because his language production center (Broca's area) is in his left hemisphere. Because the image is shown to his left visual field, only his right visual cortex perceives it. With a split corpus callosum, there is no way for that information to cross from the right hemisphere to the left. So he is unable to say what he saw. In (c), however, he is able to pick up the object he saw with his left hand. Why his left hand? Because it is controlled by his right hemisphere, which did, in fact, perceive the brush.

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FIGURE **19**
FOUR PRINCIPLES OF BRAIN PLASTICITY.

about any other part of the brain. Finally, brain plasticity varies with age, being strongest in infancy and early childhood and gradually decreasing with age. Contrary to popular belief, at no time in our lives does the brain lose its ability to grow new neurons. Neuroplasticity occurs in all stages of life, though the different parts of the brain are not equally plastic at all times. In fact, a woman's brain is most plastic during reproduction—a flexibility that appears to benefit the baby (Pawluski, Lambert, & Kinsley, 2016).

These four principles of brain plasticity are summarized in Figure 19. Experience-based change in the nervous system occurs in several ways. Most common are the formation of new neurons, the growth of dendrites in existing neurons, and the formation of new synapses. The process of developing new neurons is known as **neurogenesis**. The growth and formation of new dendrites is called **arborization** (from the Latin *arbor*, meaning "tree"), because dendrites are like branches on a tree. Probably the best-known example of neuroplasticity, however, is **synaptogenesis**, the formation of entirely new synapses or connections with other neurons—the basis of learning (Yates, 2016).

In most hearing people, the area called the *auditory cortex* processes sound. Although labeled by its function, anatomically the auditory cortex is actually a section of the temporal lobe. It is called the auditory cortex because the sensory neurons from the inner ear go there. But if those neurons don't pick up any sounds, what does this area of the brain do?

For centuries, scientists and others have observed that deaf people see better than hearing people and that blind people hear better than sighted people. The neuroscientist Helen Neville always thought there must be truth to these observations. In the process of testing these assumptions, she discovered that, overall, blind people are not better at hearing. They are not more sensitive to softer sounds than sighted people. Similarly, deaf people do not excel at all kinds of vision, nor are they able to see fainter images than do hearing people.

What Neville found, however, was that deaf and blind people are more expert in peripheral sensory experiences. Deaf people have better *peripheral* vision than sighted people—they are better at seeing things "out of the corner

neurogenesis
The development of new neurons.

arborization
The growth and formation of new dendrites.

synaptogenesis
The formation of entirely new synapses or connections with other neurons.



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Stevie Wonder, blind since infancy, is a gifted and successful musician.

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of their eyes" (Bavelier et al., 2000). They have better motion detection as well, and this seems to be processed by the auditory cortex. Just as deaf people see better at the periphery, those who are blind don't hear better overall, but their *peripheral* hearing—hearing for things around the edges of a sound field (rather than the center)—is better than that of sighted people. These peripheral sounds are processed by the visual cortex (Bavelier et al., 2000). According to Neville, "This was some of the first evidence that brain specializations such as auditory cortex are not anatomically determined" (Neville, as quoted in Begley, 2007, p. 84). In short, by virtue of neural plasticity, the brain compensates for deficits in one sensory modality by reorganizing and rewiring unused regions to take on new functions (Murphy et al., 2016). Once again, we see how forces of nature and nurture interact to shape human thought and behavior and how psychological research leads to startling changes in our assumptions.

Challenge Your Assumptions

True or False? In people who are blind, the areas of the brain involved in vision do not function.

False: The visual cortex takes on new functions, such as processing auditory information, in blind people.

Quick Quiz 3: The Brain

1. This region of the brain was the last to evolve. It is also the biggest part of the brain.
   a. cerebellum
   b. forebrain
   c. hindbrain
   d. pons
2. Which limbic structure plays a crucial role in fear?
   a. hypothalamus
   b. basal ganglia
   c. amygdala
   d. hippocampus
3. Where is the somatosensory cortex?
   a. in the occipital lobes
   b. in the frontal lobes
   c. in the temporal lobes
   d. in the parietal lobes

Answers can be found at the end of the chapter.

CHALLENGING ASSUMPTIONS ABOUT NEURAL GROWTH IN THE ADULT BRAIN

Neurons are unique cells in the body. Unlike many other cells, including hair, blood, and skin cells, nerve cells do not grow and die on an hourly basis. Nor do they divide. Because of these two facts, discovered by the Spanish physician and Nobel Prize–winner Santiago Ramón y Cajal more than 100 years ago, the prevailing wisdom was that neurons were incapable of growth, at least after early childhood.

These observations led Ramón y Cajal to put forth the *neuron doctrine*, which declared that neurons do not regenerate. Until the 1990s, researchers and physicians alike accepted the idea that, once a region of the brain was damaged, its function was lost forever. All neural growth and change were understood to be limited to fetal and childhood development, and the adult brain did not change.

Early Evidence of Neurogenesis in Adults

By the early 1960s, however, an accumulation of evidence began to suggest that adult brains do change. Perhaps the first empirical demonstration of neural growth (neurogenesis) occurred when neuroscientists detected evidence of cell division (evidence of growth) in the brains of adult rats (Bryans, 1959).

In the early 1960s, Joseph Altman published a series of groundbreaking studies with adult rats and cats. Armed with a new cell-labeling technique, Altman found evidence of the growth of new neurons in several brain areas that are

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crucial for learning and memory (Altman & Das, 1966; Gross, 2000). Even though his reports appeared in prestigious journals, Altman's findings were almost completely ignored or discounted. Why? He was working alone, and he was a little-known researcher who violated the dogma, or strongly accepted view.

As often happens with ideas that radically challenge basic assumptions and long-held beliefs, neuroscientists and others either trivialized or ignored Altman's findings of adult neurogenesis. What does it take for a movement to change a well-entrenched, century-old idea? In this case, three scientific events took place during the 1980s and 1990s that finally turned the tide of disbelief.

First, a series of studies on birds showed exceptional neural growth in many areas of the adult avian brain, including the hippocampus (Nottebohm, 1985). Second, there was increasing evidence for the formation of new synaptic connections in the brains of rats when they were raised in enriched environments, more so than normally occurs with development (Comery et al., 1996). For example, rats that lived in cages with playmates, wheels to run on, and toys showed more dendritic growth than those that lived alone in sparse cages (Rosenzweig & Bennett, 1969). Third, in the 1990s, researchers began to find solid evidence for neurogenesis in one region of the hippocampus in adult rats, monkeys, and humans. Neurogenesis was no longer something seen only in birds and rats. There was no more denying that neural growth occurs in humans.

Key Figures in the Discovery of Neural Growth in Adults

The person most responsible for demonstrating neurogenesis in humans is Fred "Rusty" Gage (ironically, a cousin of the famous Phineas Gage who had an iron rod blast through his skull; Gage, 2002; Gage, Kemperman, & Song, 2008). How is this research done in humans if researchers cannot train humans and then slice open their brains to see if neural growth has occurred? Current brain imaging techniques cannot detect the growth of new cells. Gage and his researchers, some of whom did medical research, hit upon the solution that allowed them to detect new neural growth in humans. It involves injecting people with a substance called BrdU, which is incorporated into dividing cells so that they can be identified.

Challenge Your Assumptions

True or False? Only infants and children are capable of forming new neurons.

False: Although neural growths slows in adulthood compared to childhood, it never stops.



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Animals reared in naturalistic settings have higher rates of neurogenesis than those reared in cages.

Why is that?

However, there is a problem with BrdU: You can't simply inject humans with it, because it is radioactive, but—here was the big breakthrough—some people have to have it injected for medical reasons. Gage and his colleague Peter Erikkson knew that some cancer patients receive this injection as part of their therapy. Because it identifies new cells, it is used to track how aggressively cancerous tumors are growing. After some patients who had been injected with BrdU died, Gage and Erikkson examined their hippocampus tissue. Based on the presence of BrdU, they found new cells in the adult human hippocampus (Begley, 2007; Erikkson et al., 1998). It was the same part of the hippocampus that earlier had shown the greatest neuronal growth in rats and monkeys.

Another of the key figures in demonstrating new neural growth in adult primates has been Elizabeth Gould (Glasper, Leuner, & Gould, 2008). She and her colleagues have compared rates of neurogenesis and synaptic growth in the brains of primates living in naturalistic settings with those living in lab cages. The naturalistic settings simulated a wild environment, with natural vegetation where the animals could search for food, among

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other activities. The brains of the animals that lived in these environmentally complex settings showed brain growth in areas important for thinking and feeling. They also had higher rates of neurogenesis and more connections between neurons than the animals reared in cages. In other studies, Gould and her colleagues found that stress and impoverished environments resulted in less neurogenesis in mammals (Mirescu & Gould, 2006; Mirescu et al., 2006).

Because of the onslaught of findings demonstrating neurogenesis in adult animals during the 1990s, the dogma of no new neural growth finally died. Now we know that neurons and their dendrites and synapses change, grow, and die in both young and old animals—including humans—depending on the kind of stimulation they receive from the outside world. When we learn anything, and even when we exercise, neurons in the brain are changed.

Connection

Learning results in new synapses, dendrites, and even neurons in certain regions of the brain. Regular exercise also stimulates neural growth.

See "Synaptic Change during Learning," in the chapter "Learning," p. 291; and "Research on Health-Relevant Behavior," in the chapter "Stress and Health," p. 420.

Quick Quiz 4: Challenging Assumptions about Neural Growth in the Adult Brain

1. The brain's ability to adopt new functions, reorganize itself, and make new neural connections is known as
   a. neuroplasticity.
   b. neurogenesis.
   c. the neuron doctrine.
   d. localization of function.
2. In what region of the human brain is there the most evidence of neurogenesis?
   a. frontal cortex
   b. hypothalamus
   c. amygdala
   d. hippocampus

Answers can be found at the end of the chapter.

MEASURING THE BRAIN

To be able to look into the brain as it is working was a long-time dream of philosophers and scientists. In the last few decades, realizing this wish has become possible. At least three techniques are now commonly used to measure brain activity in psychological research.

Electroencephalography

Researchers use **electroencephalography (EEG)** to record the electrical activity of the brain. The procedure involves placing electrodes, metal disks attached to wires, on a person's scalp. The electrodes are usually mounted in a fabric cap that fits snugly over the head. Typically, the person is performing certain tasks while the electrical activity is recorded. EEG is superior to other brain imaging techniques in showing *when* brain activity occurs. It is not very accurate, however, at indicating precisely *where* activity occurs (see Figure 20).

electroencephalography (EEG)
A method for measuring brain activity in which the electrical activity of the brain is recorded from electrodes placed on a person's scalp.

Event-related potential (ERP) is a special technique that extracts electrical activity from raw EEG data to measure cognitive processes. To examine ERPs, one gathers electrical recordings from an EEG cap on research participants who are performing cognitive or emotional tasks, such as trying to attend to an object on a computer screen, remember a list of words, or view emotionally charged slides. Typically, raw EEG data provide a summary of all the electrical activity in the brain that happens at a particular time. Generally, this level of detail is fine for measuring states of wakefulness, for example, but more temporal precision is needed to see a brain reaction to a particular stimulus, such as a flashing light or a line. To examine ERPs, researchers use an averaging process that allows them

event-related potential (ERP)
A technique that extracts electrical activity from raw EEG data to measure cognitive processes.

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Courtesy of Erika Rosenberg

FIGURE **20**

ELECTROENCEPHALOGRAPHY (EEG). One of the authors (Erika) in an EEG cap for a study on brain activity and facial expression of emotion: The dots on her face allow for video motion capture of facial expression changes.

Do measurements taken from the scalp determine precisely where in the brain activity is happening for different tasks such as whether the amygdala or hippocampus is activated? Explain.

to filter out all electrical activity except the activity related to the stimulus the person is processing in a controlled experiment.

Because they are based on EEG, ERPs provide excellent temporal resolution (they show brain activity linked with psychological tasks almost immediately in time) but poor spatial resolution. Spatial resolution involves how tiny an area can be pinpointed as being active at a certain time. Two other techniques provide better spatial resolution than EEG: MRI and PET.

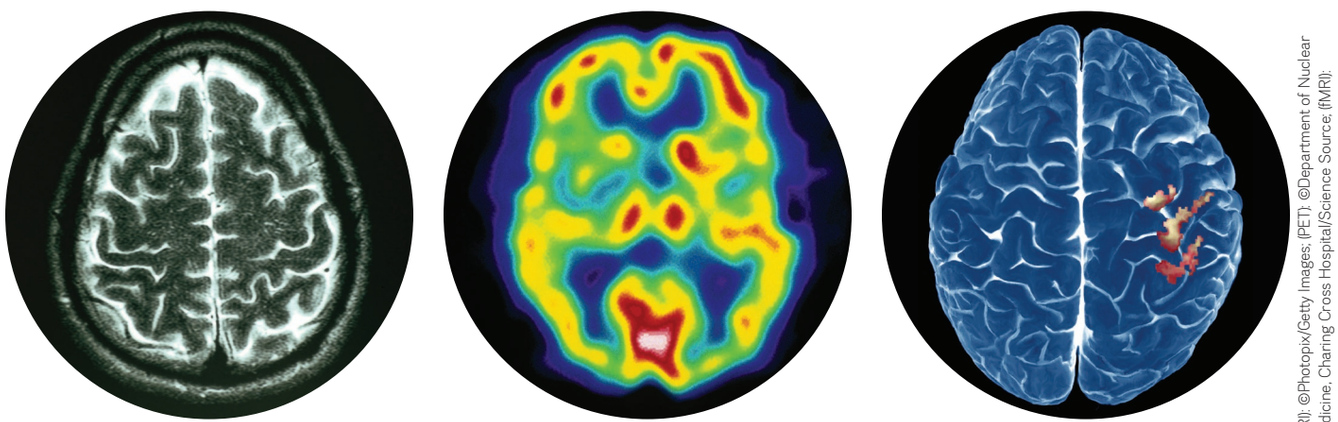
Magnetic Resonance Imaging (MRI) and Functional MRI (fMRI)

MRI stands for **magnetic resonance imaging**. MRI uses magnetic fields to produce very finely detailed images of the structure of the brain and other soft tissues. In MRI, the patient lies on a platform or bed, which slides into a tube surrounded by a circular magnet. The magnet, along with radio waves, is used to produce a signal, which is then processed by computer. The computer then produces an image with an amazing level of detail (see Figure 21). MRI provides static pictures, very useful for looking at structures, such as when someone is injured, but MRI does not tell us anything about *activity*.

A variation on MRI, **functional MRI (fMRI)**, does tell us about brain activity. Using magnets, fMRI produces indirect, high-resolution images of activity based on how the brain uses oxygen, rather than a direct "readout" of nerve impulses. The images show where brain activity is occurring during particular tasks by tracking blood oxygen use in brain tissue, as shown in Figure 21. In this way, researchers can see which areas of the brain are using the most oxygen (and presumably are most active) during certain tasks (Casey, Davidson, & Rosen, 2002; Lagopoulos, 2007), which indicates which areas are active during each task.

Although fMRI provides a much better measure of *where* activity occurs than EEG does, it still has drawbacks. For one thing, it is very expensive. Also,

magnetic resonance imaging (MRI)
A brain imaging technique that uses magnetic fields to produce detailed images of the structure of the brain and other soft tissues.



MRI scan | PET scan | fMRI scan

(MRI): ©Photopix/Getty Images; (PET): ©Department of Nuclear Medicine, Charing Cross Hospital/Science Source; (fMRI): ©ISM/Medicalimages.com

FIGURE **21**

BRAIN IMAGING TECHNOLOGY. MRI equipment takes very clear, detailed images of soft tissue, including the brain, but it doesn't record brain activity. Both PET scans and fMRI, in contrast, highlight brain activity.

Which of these techniques gives the most precise location of brain activity?

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it does not provide very precise measures of *when* activation occurs in response to a particular stimulus or task. It is not entirely clear exactly how directly fMRI images reflect underlying neural activity (Lagopoulos, 2007), even though people assume that the signal changes reflect brain activity in directly underlying areas.

Regardless of any limitations, fMRI has become the favored measure of brain activity in psychology and neuroscience—so much so that many nonexperts think we have the ability to infer psychological processes or feeling states from fMRI data (Rose, 2016). The Research Process for this chapter illustrates one such example—the use of fMRI to study how people perceive faces (see Figure 22).

functional MRI (fMRI)
A brain imaging technique that uses magnetic fields to produce detailed images of activity in areas of the brain and other soft tissues.



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A young boy being prepped for a brain imaging procedure in an fMRI machine.

Positron Emission Tomography (PET)

Positron emission tomography (PET) measures blood flow to brain areas in the active brain (see Figure 21). From these measurements, researchers and doctors can determine which brain areas are active during certain situations. PET involves injecting the participant or patient with a radioactive form of oxygen (or glucose). The brain then takes up the oxygen during cell metabolism. Thanks to the radioactive label on the oxygen, scanners and computers can be used to create images of the brain regions using that oxygen during a certain task. Although the results are very informative, the use of radioactive substances means PET is not completely risk-free. fMRI is a much safer way to image metabolism in the brain.

positron emission tomography (PET)
A brain imaging technique that measures blood flow to active areas in the brain.

Research Process

1 Research Question

Is any part of the brain dedicated to seeing faces and no other object? Likewise, is there a part of the brain dedicated exclusively to perceiving places (such as buildings)? If so, are these brain regions equally active when you imagine a face or place and when you actually see one?

2 Method

Previous research had found one distinct part of the brain activated when we see a face (the fusiform face area, FFA) and a different area of the brain (the parahippocampal place area, PPA) activated when we see a place or a building. O'Craven and Kanwisher (2000) wanted to confirm this result and extend it by seeing whether the activity was as strong when just imagining faces or places as it was when seeing these images.

Eight participants were placed inside an fMRI machine and then viewed images of either famous faces or familiar buildings on their university campus. For the imagining condition, participants were read the names of famous people and places and asked to close their eyes and form a "vivid mental image" of each one.

3 Results

Results confirmed the FFA showed high activity (% signal change) for faces but low activity for places, whereas the PPA showed the opposite (see graph). Moreover, the results for imagining faces and places showed the same pattern of results, only less strongly.

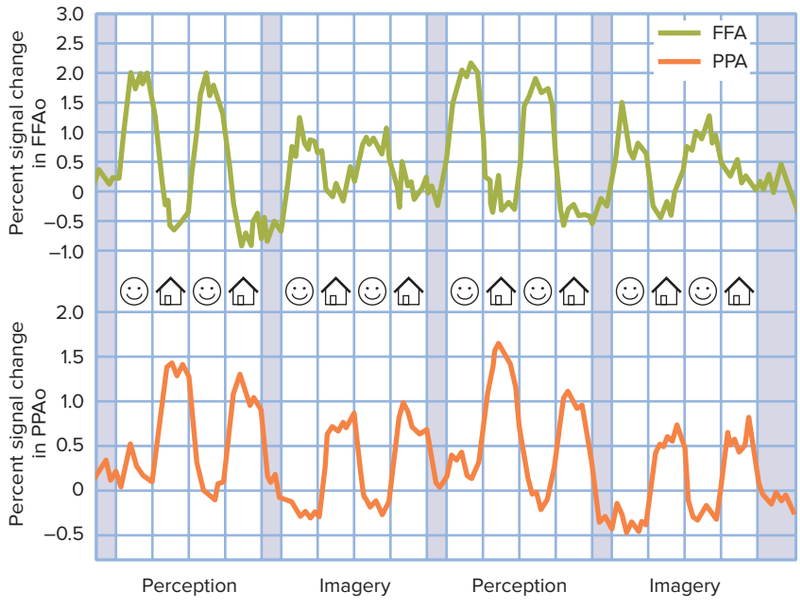
4 Conclusion

Different regions of the brain are dedicated to very specific kinds of visual stimuli. We know this only because fMRI technology allows us to see specific areas of brain activity when we are shown different kinds of objects and given different kinds of tasks.

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FIGURE **22**
DISTINCT BRAIN REGIONS INVOLVED IN IMAGINING AND PERCEIVING FACES AND PLACES.

Source: "Mental Imagery of Faces and Places Activates Corresponding Stimulus-Specific Brain Regions," by K. M. OCraven and N. N. Kanwisher, 2000, *Journal of Cognitive Neuroscience, 12*, 1013–1023. doi:10.1162/08989290051137549



Quick Quiz 5: Measuring the Brain

1. Which brain measurement technique best shows when neural activity has occurred?
   a. PET
   b. MRI
   c. EEG
   d. fMRI
2. Betty has an injury to a particular part of her brain and suddenly has trouble imagining, recognizing, and interpreting faces. What region of the brain was likely affected and which technology told us this?
   a. parahippocampal place area (PPA); MRI
   b. parahippocampal place area (PPA); fMRI
   c. fusiform face area (FFA); EEG
   d. fusiform face area (FFA); fMRI

Answers can be found at the end of the chapter.

THE ENDOCRINE SYSTEM

endocrine system
The system of glands that secrete and regulate hormones in the body.

hormones
Chemicals, secreted by glands, that travel in the bloodstream and carry messages to tissues and organs all over the body.

pituitary gland
The master endocrine gland of the body; controls the release of hormones from glands throughout the body.

adrenal glands
Endocrine structures that release hormones important in regulating the stress response and emotions.

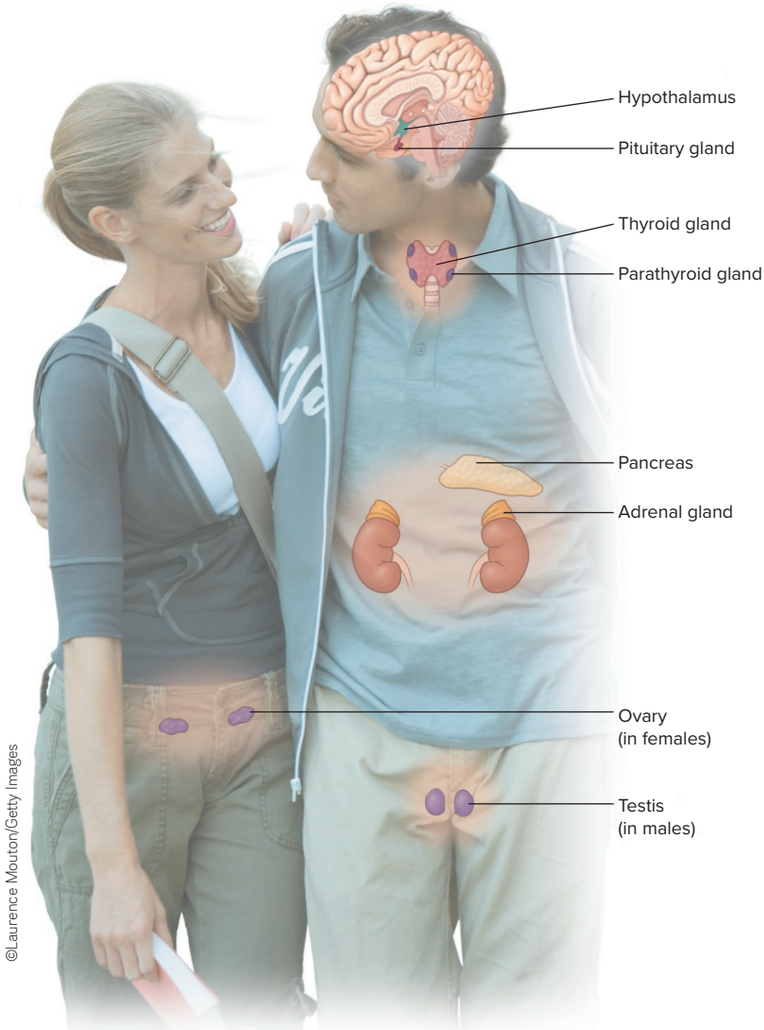
catecholamines
Chemicals released from the adrenal glands that function as hormones and as neurotransmitters to control ANS activation.

In the nervous system, neurons communicate information electrochemically by means of membrane changes and neurotransmitters released into the synaptic cleft. In the **endocrine system**, glands secrete chemicals called **hormones**, which travel through the bloodstream to tissues and organs all over the body and regulate body functions. Hormones also play a crucial role in regulating metabolism, growth, reproduction, mood, and other processes.

Figure 23 depicts some of the major endocrine glands of the body. The hypothalamus is a brain structure that controls the **pituitary gland**, known as the master gland of the body because it secretes hormones that control the release of hormones from glands elsewhere in the body. The *thyroid* gland sits in the neck region and releases hormones that control the rate of metabolism, the process by which the body converts nutritional substances into energy. The *pancreas* releases hormones, including insulin, that play a vital role in regulating blood sugar levels. The sex glands (ovaries and testes) release sex hormones, which lead to the development of sex characteristics (such as body hair and breast development), sex drive, and other aspects of sexual maturation.

The **adrenal glands**, which sit atop the kidneys, release hormones in response to stress and emotions. They also help regulate heart rate, blood pressure, and blood sugar. In addition, the adrenal glands produce **catecholamines**, a class of chemicals that includes the neurotransmitters dopamine, norepinephrine, and epinephrine, which control ANS activation. Norepinephrine activates the

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FIGURE **23**
THE ENDOCRINE SYSTEM. The endocrine system consists of numerous glands throughout the body. The pancreas, for example, releases insulin, which is important in transporting sugars (glucose) from the bloodstream into the cells. Cells then use the glucose as their energy source. The thyroid gland regulates metabolism.

sympathetic nervous system, increasing the heart rate, rate of respiration, and blood pressure in order to support rapid action of the body. The adrenal glands also release stress hormones, such as **cortisol**, which is responsible for maintaining the activation of bodily systems during prolonged stress.

The endocrine system works in conjunction with the nervous system and in a dynamic relationship with the brain. An example is its control of the female menstrual cycle. Each month, the hypothalamus sends signals to the pituitary gland to release hormones that stimulate a woman's ovaries to develop (mature) an egg. As part of the process, the ovary itself releases hormones that prepare the womb to receive a fertilized egg. If the egg is fertilized, the ovaries send hormonal feedback to the hypothalamus, so that it will not stimulate further egg development.

cortisol
A stress hormone produced by the body to ensure that the body gets enough fuel during emotional arousal and stress.

Quick Quiz 6: The Endocrine System

1. How do hormones differ from neurotransmitters?
   a. Hormones are proteins; neurotransmitters are fats.
   b. Hormones carry messages in the bloodstream; neurotransmitters carry messages across synapses.
   c. Hormones have no effect on mood; neurotransmitters do.
   d. All of the above are correct.
2. What is the name of the stress hormone released by the adrenal glands?
   a. catecholamine
   b. insulin
   c. thyroxin
   d. cortisol

Answers can be found at the end of the chapter.

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Chapter Review



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GENES AND BEHAVIOR

- At least four principles of behavioral genetics are important for psychology: (1) The relationship between specific genes and behavior is complex. (2) Most specific behaviors derive from many genes. (3) Behavioral genetics employs studies of twins and adoptees to disentangle the contributions of heredity and environment to behavior. (4) The environment influences how and when genes affect behavior.
- The extent to which a characteristic is influenced by genetics is known as heritability. Researchers use twin-adoption studies and gene-by-environment designs to study heritability.

THE NERVOUS SYSTEM

- There are two kinds of cells in the central nervous system: glial cells and neurons.
- Glial cells provide structural support, among other important functions.
- Neurons transmit information throughout the nervous system by means of action potentials. Messages are received by the branchlike dendrites and cell bodies of neighboring neurons; these messages create changes in the membrane of the receiving neuron. If the right conditions are met, then neurons fire in an all-or-none fashion.
- Action potentials move down the length of the axon as channels in the membrane open and close, allowing ions to move into and out of the axon. The action potential stimulates the release of neurotransmitters from the terminal buttons into the synaptic cleft.
- Neurotransmitters bind to receptor sites on the dendrites of postsynaptic neurons, allowing an action potential to be generated if the charge threshold is surpassed. Excess neurotransmitter is either taken back into the original neuron or broken down in the synaptic cleft.

THE BRAIN

- The brain is divided into three major regions: the hindbrain, midbrain, and forebrain.
- The topmost brain structures are the cerebrum and cerebral cortex, which are the seat of abstract reasoning, planning, and higher-order thought.
- The cerebrum comprises four lobes: The frontal lobes are involved in abstract reasoning, self-control, and motor control; the temporal lobes house the auditory cortex; the parietal lobes process tactile and spatial information; and the occipital lobes house the visual cortex.
- The left and right hemispheres of the brain carry out somewhat different functions. The biggest difference between the hemispheres is language, which is usually controlled by the left hemisphere.
- One major shift in our understanding of the brain over the last 15–20 years is how much neurons and brain structures are shaped by experience. New neurons form, new dendrites grow, and new synapses are created across the life span, especially in infancy and early childhood.

CHALLENGING ASSUMPTIONS ABOUT NEURAL GROWTH IN THE ADULT BRAIN

- Although first uncovered in the 1960s, evidence for neural growth in adult brains was not fully appreciated and accepted until the 1990s and 2000s.

MEASURING THE BRAIN

- Various methods offer glimpses into the brain and its functions.
- Electroencephalography (EEG) measures electrical activity from scalp readings.

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- Magnetic resonance imaging (MRI) measures blood flow changes in the brain without the added risk of the radioactive dyes used in PET scans. The adaptation of MRI to functional MRIs (fMRI) allows researchers to determine which brain areas are active during specific tasks.

THE ENDOCRINE SYSTEM

- In the endocrine system, glands secrete chemicals called hormones, which travel in the bloodstream to tissues and organs all over the body.
- The pituitary gland, called the master gland of the body, controls the release of hormones from other glands in the body.
- The adrenal glands secrete hormones involved in sympathetic nervous system responses and stress.

Key Terms

acetylcholine (ACh)
action potential
adrenal glands
alleles
all-or-none principle
amygdala
aphasia
arborization
autonomic nervous system (ANS)
axon
basal ganglia
behavioral genetics
Broca's area
catecholamines
central nervous system (CNS)
cerebellum
cerebral cortex
cerebrum
chromosome
cingulate gyrus
corpus callosum
cortisol
dendrites
DNA (deoxyribonucleic acid)
dominant alleles
dopamine
electroencephalography (EEG)
endocrine system
epigenetics
epinephrine
event-related potential (ERP)
functional MRI (fMRI)
GABA (gamma-aminobutyric acid)
genes
genome
genotype
glial cells
glutamate
graded potentials
heritability
hippocampus
hormones
hypothalamus
insula
interneurons
ions
limbic system
magnetic resonance imaging (MRI)
medulla
mirror neurons
monogenic
motor neurons
mutation
myelin sheath
neurogenesis
neurons
neuroplasticity
neurotransmitters
node of Ranvier
norepinephrine
parasympathetic nervous system
peripheral nervous system
phenotype
pituitary gland
polygenic
pons
positron emission tomography (PET)
recessive alleles
reflexes
refractory period
resting potential
reticular formation
sensory neurons
serotonin
soma
somatic nervous system
somatosensory cortex
sympathetic nervous system
synapse
synaptic vesicles
synaptogenesis
terminal button
thalamus
Wernicke's area

Quick Quiz Answers

Quiz Quiz 1: 1. b; **2.** a; **3.** a **Quick Quiz 2: 1.** c; **2.** a; **3.** b; **4.** c **Quick Quiz 3: 1.** b; **2.** c; **3.** d
Quick Quiz 4: 1. a; **2.** d **Quick Quiz 5: 1.** c; **2.** d **Quick Quiz 6: 1.** b; **2.** d

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