13th EDITION

Physiology of Behavior

Neil R. Carlson
Melissa A. Birkett

Physiology of Behavior

Thirteenth edition

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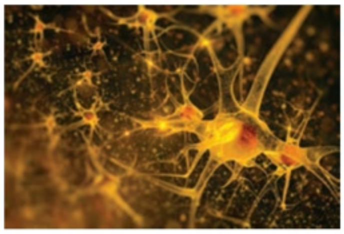

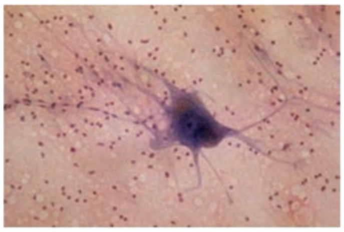

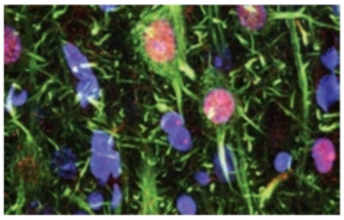

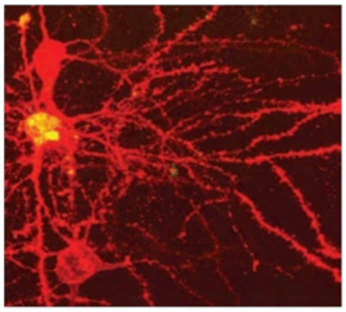

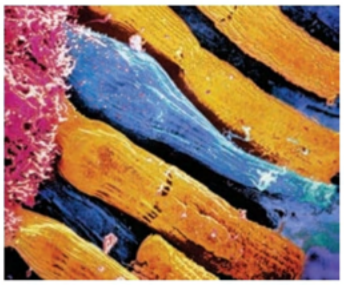

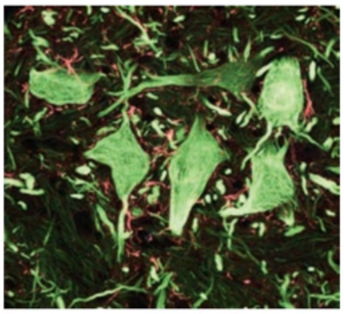

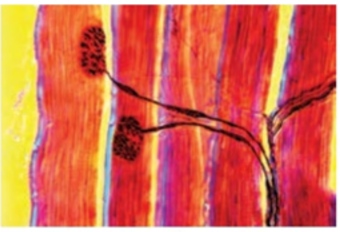

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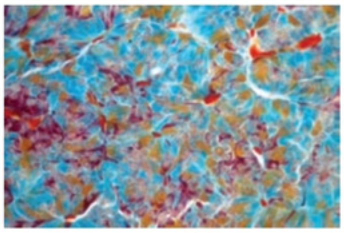

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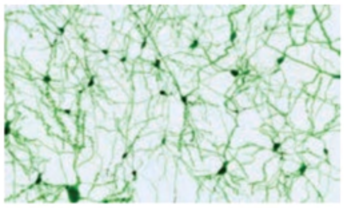

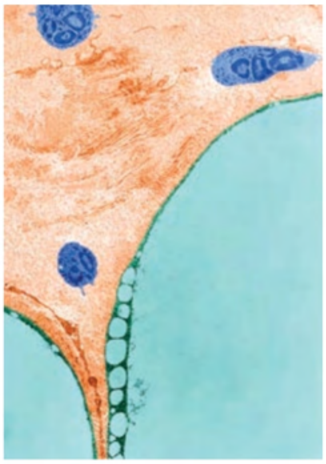

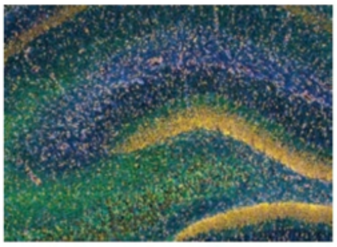

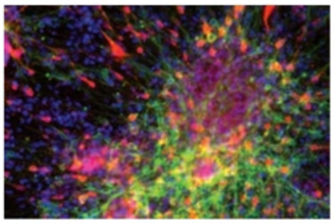

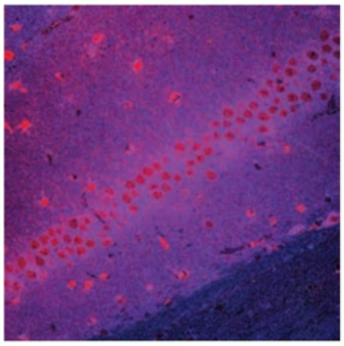

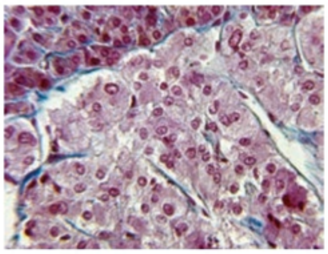

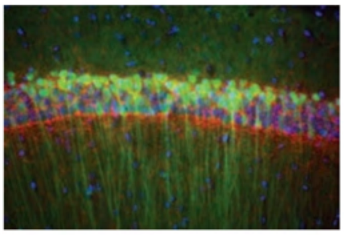

Preface

I wrote the first edition of *Physiology of Behavior* over 30 years ago. When I did so, I had no idea I would someday be writing the thirteenth edition. I'm still having fun, so I hope to do a few more. The interesting work coming out of my colleagues' laboratories—a result of their creativity and hard work—has given me something new to say with each edition. Because there was so much for me to learn, I enjoyed revising this edition just as much as writing the first one. That is what makes writing new editions interesting: learning something new and then trying to find a way to convey the information to the reader.

In this edition, Melissa Birkett updated content to reflect new research developments, and formulated a separate chapter on disorders of the developing nervous system. Together, we drew upon our teaching and experience working with students to create a comprehensive and accessible guide for students of behavioral neuroscience.

The first part of the book is concerned with foundations of behavioral neuroscience: the history of the field, the structure and functions of neurons, neuroanatomy, psychopharmacology, and research methods. The second part is concerned with inputs and outputs that guide behavior: the sensory systems and the motor system. The third part deals with classes of species-typical behavior: sleep, reproduction, emotional behavior, and ingestion. The chapter on reproductive behavior includes parental behavior as well as courting and mating. The chapter on emotion includes a discussion of fear, anger and aggression, communication of emotions, and feeling emotions. The chapter on ingestive behavior includes the neural and metabolic bases of drinking and eating. The fourth part of the book explores learning, including research on synaptic plasticity, the neural mechanisms that are responsible for perceptual learning and stimulus-response learning (including classical and operant conditioning), human amnesia, and the role of the hippocampal formation in relational learning. The final part of the book examines the neural basis of human communication as well as neurological, mental, and behavioral disorders. Behavioral disorders are addressed in four chapters; the first is a new chapter combining information about development of the nervous system with information about disorders of development, autism spectrum disorders, and attention-deficit/hyperactivity disorder; the second discusses schizophrenia and the affective disorders; the third discusses stress and anxiety; and the fourth discusses substance abuse. Each chapter begins with a *Case Study,* which describes the experience of people whose lives are impacted by an important issue in neuroscience. Other case studies are included within the text of the chapters. *Learning Objectives* to guide your reading are found at the beginning of each major section of the text. The learning objectives can help you identify and understand the key points from each section and are also summarized at the end of each module. *Thought Questions* are also located at the end of each module and are designed to stimulate your thinking about what you have learned. *Chapter Review Questions* conclude each chapter. They provide useful reviews of each chapter and a more comprehensive opportunity to test your understanding. In Revel, *Critical Concepts* features have been added to each chapter, with goals of highlighting important topics in neuroscience and providing opportunities to explore them in greater depth.

New to This Edition

The research reported in this edition reflects both the enormous advances made in research methods and the discoveries these methods have revealed. In neuroscience, as soon as a new method is developed in one laboratory, it is adopted by other laboratories and applied to a wide range of problems. Researchers are combining techniques that converge upon the solution to a problem and use many methods, often in collaboration with other laboratories.

The art in this book continues to evolve. For this thirteenth edition, the art has been updated to improve accessibility, as well as to keep up with the latest findings and studies in the field. We have always striven to be as up to date and as accurate as possible. We hope the new art in this edition reflects that ongoing effort.

You'll notice that many of the chapters contain new headings and subheadings, as well as more concise learning objectives. We believe that this approach will help the reader to more easily identify main themes and concepts.

The following list summarizes some of the updates new to this edition.

Chapter 1: Introduction

- New research on adult neurogenesis has been added.
- Epigenetics is included as an important concept in behavioral neuroscience.
- New media content has been incorporated into Revel.

Chapter 2: Structure and Functions of Cells of the Nervous System

- New media content has been incorporated into Revel.

Chapter 3: Structure of the Nervous System

- Figures were revised.
- Information about development of the nervous system was moved to Chapter 15.

Chapter 4: Psychopharmacology and Neurotransmitters

- A new case study has been added to the beginning of the chapter.

Chapter 5: Methods and Strategies of Research

- A new section about CRISPR techniques has been included.

Chapter 6: Vision

- An example of flat vision following damage to the parieto-occipital cortex has been added.

Chapter 7: Audition, the Body Senses, and the Chemical Senses

- An additional case study has been added to the beginning of the chapter.

Chapter 8: Control of Movement

- A new section on dyspraxia has been added.

Chapter 9: Sleep and Biological Rhythms

- Research on lucid dreaming has been included.

Chapter 10: Reproductive and Parental Behavior

- Several new topics have been added: research on 5α-reductase deficiency, research on changes across the menstrual cycle, information about trace amine-associated receptors, and research on paternal behavior.

Chapter 11: Emotion

- Research on heredity of aggression, and testosterone and environment have been added.

Chapter 12: Ingestive Behavior

- Information about food deserts has been added.
- New research related to leptin and reinforcement in weight loss has been added.
- New treatments for binge eating disorder have been included.

Chapter 13: Learning and Memory

- Organization and descriptions have been updated throughout the chapter.

Chapter 14: Human Communication

- New research on brain regions involved in multiple languages, tip of the tongue phenomenon, and stuttering have been added.

NEW! *Chapter 15: Disorders of the Developing Nervous System*

- Information about development of the nervous system and disorders of development was moved to this chapter.
- Information about autism spectrum disorder and attention-deficit/hyperactivity disorder was moved to this chapter.

Chapter 16: Neurological Disorders

- This chapter was renumbered.
- Information about disorders of development was moved to Chapter 15.
- New surgical techniques have been added.
- Research on possible treatments for Huntington's disease has been added.

Chapter 17: Schizophrenia and the Affective Disorders

- This chapter was renumbered.
- Information about neurodevelopmental disorders was moved to Chapter 15.
- Research on genetic factors involved in schizophrenia has been added.
- A new section on marijuana and schizophrenia has been added.
- Descriptions of new treatment options for postpartum depression have been added.

Chapter 18: Stress and Anxiety Disorders

- This chapter was renumbered.
- New research on the role of the hippocampus in chronic pain has been added.

Chapter 19: Substance Abuse

- This chapter was renumbered.
- Research on epigenetic factors related to cocaine abuse has been added.
- Information about opiate abuse interventions has been added.
- Research on e-cigarettes has been added.

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Please write to tell us what you like and dislike about the book at: nrc@psych.umass.edu.

About the Authors

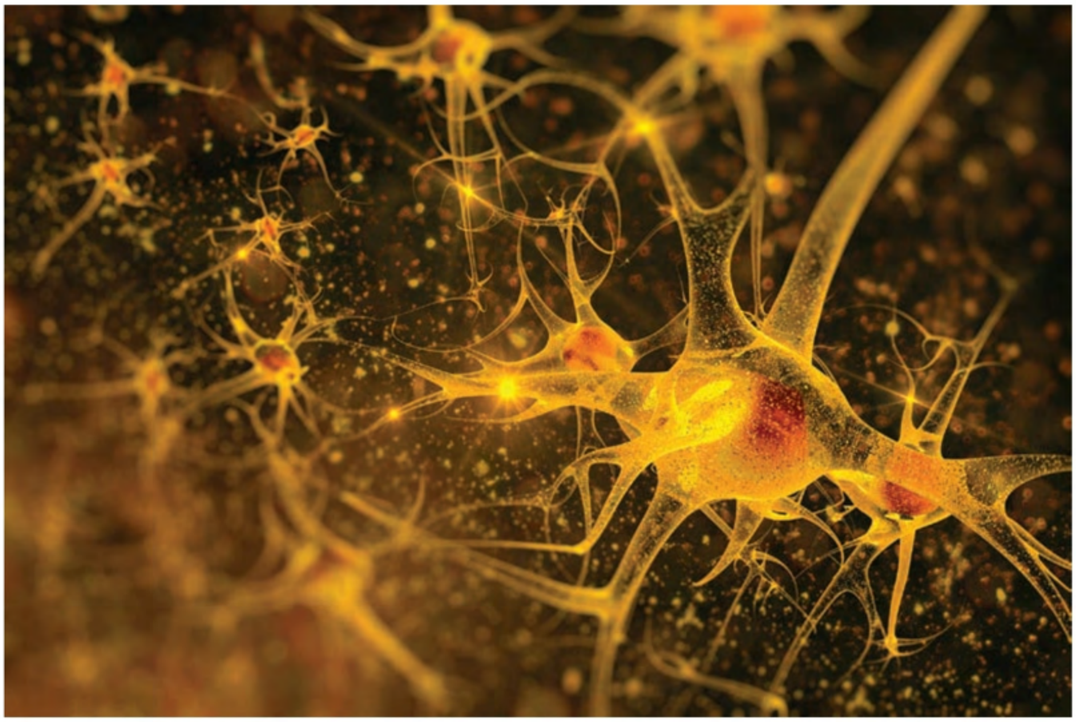
Neil R. Carlson pursued his undergraduate studies at the University of Illinois. He had planned to study nuclear physics, but when he discovered in an introductory psychology course that psychology was really a science, he decided that was what he wanted to do. Before changing his major, Carlson talked with several professors and visited their laboratories, and when he saw what physiological psychologists do, he knew that he had found his niche. He stayed on at Illinois and received his Ph.D. Then, after a two-year postdoctoral fellowship at the University of Iowa, Carlson came to the University of Massachusetts, where he taught throughout his entire career. He retired from UMass in the fall of 2004 but continues to keep up with developments in the field of behavioral neuroscience and to revise this book.

As an undergraduate psychology major at Cornell University, **Melissa A. Birkett** discovered courses in biopsychology, behavior, endocrinology, and evolutionary psychology. There, she was introduced to interdisciplinary research incorporating multiple perspectives in the challenging task of understanding behavior. She became interested in learning about behavior and its underlying mechanisms. She worked as an undergraduate research assistant in several laboratories on projects ranging from insect behavior to sleep in undergraduates. Those formative experiences and interactions with several influential research mentors convinced her to pursue a career in research.

Birkett completed her Ph.D. in the Neuroscience and Behavior program at the University of Massachusetts Amherst (where Neil Carlson was a faculty member at the time). In 2007, she became a faculty member at Northern Arizona University in the Department of Psychological Sciences, and in 2018 joined the psychology department at Southern Oregon University. Birkett currently conducts research related to the stress response and teaches undergraduate courses in psychology, research methods, statistics, behavioral neuroscience, and psychopharmacology. Each year, she supervises student researchers and seeks to provide them with the kinds of opportunities she found valuable as a student. Her work has been recognized with awards for outstanding teaching and teaching innovation, and she has contributed to several publications on best practices in teaching neuroscience.

Chapter 1

Introduction



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The human nervous system contains billions of neurons.

Chapter Outline

Learning Objectives

LO 1.1 Compare the roles of generalization and reduction in behavioral neuroscience research.

LO 1.2 Summarize historical and contemporary contributions to behavioral neuroscience from various scientific disciplines.

LO 1.3 Describe the role of natural selection in the evolution of behavioral traits.

LO 1.4 Identify factors involved in the evolution of human brains.

LO 1.5 Outline reasons for the use of animals in behavioral neuroscience research.

LO 1.6 Identify mechanisms for oversight of animal research.

LO 1.7 Discuss ethical considerations in research with human participants.

LO 1.8 Identify mechanisms for oversight of human research.

LO 1.9 Identify careers in behavioral neuroscience.

LO 1.10 Describe effective learning strategies for studying behavioral neuroscience.

Seven-year-old Jeremiah experienced a stroke while playing baseball. Although most strokes occur in older adults, they can affect anyone, even children. A stroke occurs when a part of the brain is deprived of blood flow and oxygen (you will read more about strokes, or cerebrovascular accidents, in Chapter 16). Because the stroke damaged the left side of his brain, Jeremiah lost sensation and motor control on the right side of his body. He received some rehabilitation immediately following the stroke and learned to walk with the assistance of a cane. Previously right-handed, he learned to write with his left hand after the stroke.

Jeremiah didn't regain full movement of the right side of his body, however, and so despite the progress he made, he fell frequently. As an adult, he fell nearly 150 times a year, fracturing bones in his hand, foot, and hip. Jeremiah's ongoing struggles over a span of four decades prompted him to seek a new treatment to improve his balance, coordination, and motor skills. Remarkably, after only two weeks of training for his right hand, and three weeks for his right leg, Jeremiah's balance improved and he was once again able to write his name with his right hand. What happened in Jeremiah's brain that allowed this drastic improvement?

Jeremiah received a form of therapy called constraint-induced (CI) movement therapy. The therapy is based on the idea that stroke-induced paralysis is due to disuse of the limb and fewer cells in the brain being devoted to the limb's movement. To help the brain to engage in behaviors once again, the therapy involves intensive physical activity using the affected parts of the body. Jeremiah spent hours each day working to move his affected limbs, doing things like picking up pencils, stacking blocks, and clipping clothespins to a yardstick. To force Jeremiah to work with his weaker right hand, therapists used mitts to cover his left hand. Incremental training of the affected body part helped the brain learn these motor functions. This kind of flexibility to learn new behaviors is known to neuroscientists as **plasticity**, or the ability of the nervous system to change over time. Due to the plasticity of the brain, Jeremiah's hours of intensive practice allowed him to regain much of the motor control he had lost decades before (Doidge, 2007).

Source: Norman Doidge, *The Brain That Changes Itself: Stories of Personal Triumph from the Frontiers of Brain Science*, 2008 Penguin Random House

At the end of the twentieth century, many researchers believed that the brain was incapable of change in adulthood. However, some neuroscientists suggested the cells and connections of the adult brain were flexible, or plastic, and attempted to change the view of the brain that had been held for more than a century. Changing this widely held view was not an easy process. Though they were equipped with revolutionary new data, the researchers were criticized for years, and their data and methods were questioned. Eventually, the data accumulated, and the scientific consensus became that the adult brain continues to experience neural changes. This change in understanding about the brain has been met with optimism and excitement. Therapies for brain injury and mental illness have been developed based on this new understanding of brain changes.

The adult brain modifies connections between the cells in the brain, called **neurons**, throughout a lifetime. Dozens of researchers are making new discoveries every year about **neurogenesis**, the generation of new neurons particularly in specific regions of the adult brain. New debates about neurogenesis have also arisen and understanding of this phenomenon remains incomplete (Kempermann et al., 2018). Some researchers have reported little to no evidence of neurogenesis in the dentate gyrus of the hippocampus (an area of the brain typically associated with neurogenesis) of adult humans, and suggested that neurogenesis in this region declines throughout childhood in our species (Sorrells et al., 2018). In contrast, other researchers report evidence that neurogenesis in this region continues throughout the human lifespan, well into older adulthood in healthy individuals (Moreno-Jiménez et al., 2019; Boldrini et al., 2018).

Researchers previously believed that the adult brain also *lost* a large number of neurons during aging. These losses were thought to underlie the inevitable cognitive decline of older adulthood. Re-examination of this idea, along with additional data and development of new methods and technology, has produced a new consensus for a relatively modest (2-4 percent) decline in neurons in typical aging. Researchers are also currently re-evaluating long-held ideas about differences in the number of neurons in parts of the brain between men and women, the effects of chronic alcohol use on damage to neurons, and changes in neurons associated with mental illness and neurological disorders. The neuroscience community is actively engaged in understanding these apparently conflicting results, and as one neuroscientist has summarized the situation, "It is important to keep an open mind and to be inquisitive and creative, in order to separate truths from myths" (von Bartheld, 2018, p. 12).

Behavioral neuroscience is a dynamic and ever-changing field. As you read, consider not only the facts, but also the research process used to obtain those facts, and the exciting possibility that there is still much to learn about the brain and the nervous system. The last frontier in this world—and perhaps the greatest one—lies within us. The human nervous system makes possible all that we can do, all that we can know, and all that we can experience. Its complexity is immense, and the task of studying it and understanding it dwarfs all previous explorations our species has undertaken.

Foundations of Behavioral Neuroscience

Behavioral neuroscience was formerly known as *physiological psychology,* and it is still sometimes referred to by that name. In fact, the first psychology textbook, written by Wilhelm Wundt in the late nineteenth century, was titled *Principles of Physiological Psychology*. In recent years, the explosion of information from experimental biology, chemistry, animal behavior, psychology, computer science, and other fields has contributed to creating the diverse interdisciplinary field of behavioral neuroscience. This united effort is due to the realization that the ultimate function of the nervous system is behavior.

When we ask our students what they think the ultimate function of the brain is, they often say "thinking," or "logical reasoning," or "perceiving," or "remembering things." The nervous system does perform these functions, but they all support a single primary function: control of movement. (Note that movement includes speech and other forms of communication, an important category of human behavior.) The basic function of perception is to inform us of what is happening in our environment so that our behaviors will be adaptive and useful: Perception without the ability to act would be useless. Once perceptual abilities evolved, they could be used for purposes other than guiding behavior. For example, we can enjoy a beautiful sunset or a great work of art without our perception causing us to do anything in particular. And thinking can often take place without causing any overt behavior. However, the *ability to think* evolved because it permits us to perform complex behaviors that accomplish useful self-preserving goals. And whereas reminiscing about things that happened in our past can be an enjoyable pastime, the ability to learn and remember evolved—again—because it permitted our ancestors to profit from experience and perform behaviors that were useful to them.

The growing field of behavioral neuroscience has been formed by scientists who have combined the experimental methods of psychology with those of physiology and have applied them to the issues that concern researchers in many different fields. Research in neuroscience includes topics in perceptual processes, control of movement, sleep and waking, reproductive behaviors, ingestive behaviors, emotional behaviors, learning, and language. In recent years we have begun to study the neuroscience underlying significant human health concerns, such as substance abuse and neurological and mental disorders. These topics are discussed in subsequent chapters.

The Goals of Research

LO 1.1 Compare the roles of generalization and reduction in behavioral neuroscience research.

The goal of all scientists is to explain the phenomena they study. But what do we mean by *explain*? Scientific explanation takes two forms: generalization and reduction. **Generalization** refers to explanations as examples of general laws, which are revealed through experiments. **Reduction** refers to explanations of complex phenomena in terms of simpler ones.

Behavioral neuroscientists seek to explain behavior by studying the physiological processes that control it. But behavioral neuroscientists cannot *just* be reductionists. It is not enough to observe behaviors and correlate them with physiological events that occur at the same time. We also need to understand the function of a given behavior. For example, mice, like many other mammals, often build nests. Behavioral observations show that mice will build nests under two conditions: when the air temperature is low and when the animal is pregnant. A non-pregnant mouse will build a nest only if the temperature is cool, whereas a pregnant mouse will build one regardless of the temperature. The same behavior occurs for different reasons. Nest-building behavior is controlled by two different physiological mechanisms. Nest building can be studied as a behavior related to the process of temperature regulation, or it can be studied in the context of parental behavior. Although the same set of brain mechanisms will control the movements that a mouse makes in building a nest in both cases, these mechanisms will be activated by different parts of the brain. One part receives information from the body's temperature detectors, and the other part is influenced by hormones that are present in the body during pregnancy. It is not enough to observe behaviors and correlate them with physiological events that occur at the same time. We must understand the overall function of a given behavior.

Sometimes, physiological mechanisms can tell us something about psychological processes such as language, memory, or mood. For example, damage to a particular part of the brain can cause very specific impairments in a person's language abilities. The nature of these impairments suggests how these abilities are organized in the brain. When the damage involves a brain region that is important in analyzing speech sounds, it also produces deficits in spelling. This finding suggests that the ability to recognize a spoken word and the ability to spell it rely on related brain mechanisms. Damage to another region of the brain can produce extreme difficulty in reading unfamiliar words by sounding them out, but it does not impair the person's ability to read words with which they are already familiar. This finding suggests that reading comprehension can take two routes: one that is related to speech sounds and another that is primarily a matter of visual recognition of whole words.

In practice, the research efforts of behavioral neuroscientists involve both forms of explanation: generalization and reduction. Ideas for experiments are stimulated by the investigator's knowledge both of psychological generalizations about behavior and of physiological mechanisms. A good behavioral neuroscientist must therefore be an expert in the study of behavior *and* the study of physiology.

Roots of Behavioral Neuroscience

LO 1.2 Summarize historical and contemporary contributions to behavioral neuroscience from various scientific disciplines.

This section traces some of the discoveries of the past that have contributed to the field of behavioral neuroscience today and have helped advance our understanding of mind, brain, and behavior.

CONTRIBUTIONS FROM THE ANCIENT WORLD: ROLE OF THE HEART AND BRAIN Study of (or speculation about) the physiology of behavior has its roots in antiquity. A papyrus scroll from around 1700 B.C.E. contains surgical records of head injuries and the oldest surviving descriptions of the brain, cerebrospinal fluid, meninges, and skull (Feldman and Goodrich, 1999).

Because its movement was necessary for life and because emotions caused it to beat more strongly, ancient Egyptian, Indian, and Chinese cultures considered the heart to be the seat of thought and emotions. The ancient Greeks did too, but Hippocrates (460–370 B.C.E.) concluded that this role should be assigned to the brain.

Figure 1.1 Galen (130–200 C.E.)

Photo Researchers/Science History Images/Alamy Stock Photo

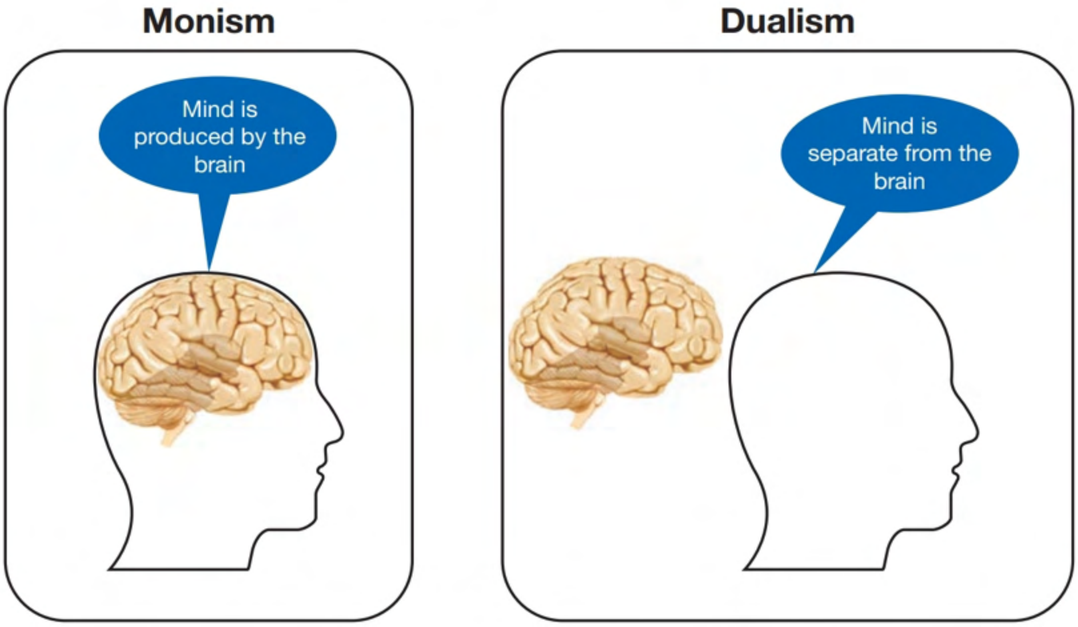
Not all ancient Greek scholars agreed with Hippocrates. Aristotle (384–322 B.C.E.), for example, thought the brain served to cool the passions of the heart. Galen (130–200 C.E.) dissected and studied the brains of cattle, sheep, pigs, cats, dogs, weasels, monkeys, and apes (Finger, 1994), and concluded that Aristotle's theory about the brain's role was "utterly absurd, since in that case Nature would not have placed the encephalon [brain] so far from the heart,…and she would not have attached the sources of all the senses [the sensory nerves] to it" (Galen, 1968 translation, p. 387). (See Figure 1.1.)

CONTRIBUTIONS FROM PHILOSOPHY: THE MIND–BODY QUESTION From the earliest historical times, human beings have believed that they possess something intangible that animates them: a mind, or a soul, or a spirit. We each also have a physical body, with muscles that move it and sensory organs such as eyes and ears that perceive information about the world around us. Within our bodies the nervous system plays a central role, receiving information from the sensory organs and controlling the movements of the muscles. But what role does the mind play? Does it *control* the nervous system? Is it a *part of* the nervous system? Is it physical and tangible, like the rest of the body, or is it a spirit that will always remain hidden?

This puzzle has historically been called the *mind–body question.* Philosophers have been trying to answer it for many centuries, and more recently scientists have taken up the task. In general, people have followed two different approaches: dualism and monism. **Dualism** is a belief in the dual nature of reality, which means that mind and body are separate. From a dualist perspective the body is made of ordinary matter, but the mind is not. **Monism** is a belief that everything in the universe consists of matter and energy and that the mind is a phenomenon produced by the workings of the nervous system. (See Figure 1.2.)

Figure 1.2 The Mind–Body Question

Monism and dualism pose two possible answers to the mind–body question.



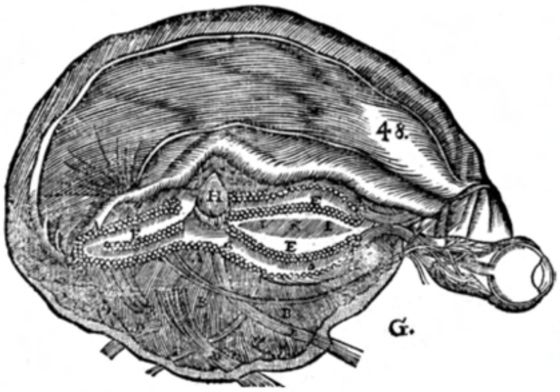
The French philosopher René Descartes's (1596–1650) speculations concerning the roles of the mind and brain in the control of behavior provide a good starting point in the modern history of behavioral neuroscience. To Descartes, animals were mechanical devices. He believed their behavior was controlled by environmental stimuli. His view of the human body was much the same: It was a machine. As Descartes observed, some movements of the human body were automatic and involuntary. For example, if a person's finger touched a hot object, the arm would immediately withdraw from the source of stimulation. Reactions like this did not require participation of the mind; they occurred automatically. Descartes called these actions **reflexes**. (See Figure 1.3.)

Like most philosophers of his time, Descartes was a dualist and believed that each person possessed a mind—a uniquely human attribute that was not subject to the laws of the universe. But his thinking differed from that of his predecessors in one important way: He was the first to suggest that a link exists between the human mind and its purely physical housing, the brain. He believed that the mind controlled the movements of the body, while the body, through its sense organs, supplied the mind with information about what was happening in the environment. In particular, he hypothesized that this interaction took place in the pineal body, a small organ situated on top of the brain stem, buried beneath the cerebral hemispheres. He noted that the brain contained hollow chambers (the *ventricles*) that were filled with fluid, and he hypothesized that this fluid was under pressure. When the mind decided to perform an action, it tilted the pineal body in a particular direction like a little joystick, causing fluid to flow from the brain into the appropriate set of nerves. This flow of fluid caused muscles to inflate and move. As you'll learn in the rest of this section, it did not take long for biologists to disprove Descartes's belief about the brain using pressurized fluid to control behavior.

Speculating about the nature of the mind can get us only so far. If we could answer the mind–body question simply by thinking about it, philosophers would have done so long ago. Behavioral neuroscientists take an empirical, monistic approach to the study of human nature. Most neuroscientists believe that once we understand the workings of the human body—and, in particular, the

Figure 1.3 Descartes's Model

Descartes believed that the "soul" (what we now call the mind) controls the movements of the muscles through its influence on the pineal body. According to his theory, the eyes sent visual information to the brain, where it could be examined by the soul. When the soul decided to act, it would tilt the pineal body (labeled H in the diagram), which would divert pressurized fluid through nerves to the appropriate muscles.



Oxford Science Archive/Heritage Images/The Print Collector/Alamy Stock Photo workings of the nervous system—the mind–body question will be resolved. We will be able to explain how we perceive, how we think, how we remember, and how we behave. We will even be able to explain the nature of our own self-awareness.

CONTRIBUTIONS FROM PHYSIOLOGY: ELECTRICAL COMMUNICATION IN THE NERVOUS SYSTEM Luigi Galvani (1737–1798), an Italian physiologist, found that electrically stimulating a frog's nerve contracted the muscle to which it was attached. Contraction occurred even when the nerve and muscle were detached from the rest of the body, so the ability of the muscle to contract and the ability of the nerve to send a message to the muscle were characteristics of these tissues themselves. Contrary to Descartes's description, the brain did not inflate muscles by directing pressurized fluid through the nerve. Galvani's experiment prompted others to study the nature of the message transmitted by the nerve and the means by which muscles contracted. One of the most important figures in the development of experimental physiology was Johannes Müller (1801–1858), a German physiologist. Müller applied experimental techniques to physiology. Previously, most natural scientists had been limited to observation and classification. Although these activities are essential, Müller insisted that major advances in our understanding of the workings of the body would be achieved only by experimentally removing or isolating animals' organs, testing their responses to various chemicals, and otherwise altering the environment to see how the organs responded. His most important contribution to the study of the physiology of behavior was his **doctrine of specific nerve energies**. Müller observed that although all nerves carry the same basic message—an electrical impulse—we perceive the messages of different nerves in different ways. For example, messages carried by the optic nerves produce sensations of visual images, and those carried by the auditory nerves produce sensations of sounds. How can different sensations arise from the same basic message?

Müller's answer was that the messages occur in different channels. The portion of the brain that receives messages from the optic nerves interprets the activity as visual stimulation, even if the nerves are actually stimulated mechanically. (For example, when we rub our eyes, we see flashes of light.) Because different parts of the brain receive messages from different nerves, the brain must be functionally divided: Some parts perform some functions, while other parts perform others.

In 1870, German physiologists Gustav Fritsch (1838–1927) and Eduard Hitzig (1838–1907) used electrical stimulation as a tool for understanding the physiology of the brain. They applied weak electrical current to the exposed surface of a dog's brain and observed the effects of the stimulation. They found that stimulating different portions of a specific region of the brain caused specific muscles to contract on the opposite side of the body. We now refer to this region as the *primary motor cortex*, and we know that nerve cells there communicate directly with those that cause muscular contractions. We also know that other regions of the brain communicate with the primary motor cortex to control behaviors. For example, regions of the brain involved in speech communicate with the portion of the primary motor cortex that controls the muscles of the lips, tongue, and throat, which we use to speak.

German physicist and physiologist Hermann von Helmholtz (1821–1894) studied many physiological processes and was the first scientist to attempt to measure the speed of conduction through nerves. Scientists had previously believed that such conduction was identical to the conduction that occurs in wires, traveling at approximately the speed of light. But Helmholtz found that neural conduction was much slower—only about 27.4 meters per second. This measurement proved that neural conduction was more than a simple electrical message, as we will see in Chapter 2.

CONTRIBUTIONS FROM ANATOMY: STRUCTURE OF THE NERVOUS SYSTEM Müller's advocacy of experimentation and the logical deductions from his doctrine of specific nerve energies set the stage for other scientists to perform experiments directly on the brain. Pierre Flourens (1794–1867), a French researcher, did just that. Flourens removed various parts of animals' brains and observed their behavior. By seeing what the animal could no longer do, he could infer the function of the missing portion of the brain. This method is called **experimental ablation**. Flourens claimed to have discovered the regions of the brain that control heart rate and breathing, purposeful movements, and visual and auditory reflexes.

Soon after Flourens performed his experiments, Paul Broca (1824–1880), a French surgeon, applied the principle of experimental ablation to the human brain. He did not intentionally remove parts of human brains to see how they worked but observed the behavior of people whose brains had been damaged by strokes. In 1861 he performed an autopsy on the brain of a man who had had a stroke that resulted in the loss of the ability to speak. Broca's observations led him to conclude that a portion of the cerebral cortex on the front part of the left side of the brain performs functions that are necessary for speech. This came to be known as Broca's area. (See Figure 1.4.) Other physicians soon obtained evidence supporting his conclusions. As you will learn in Chapter 14, the control of speech is not localized to only one particular region of the brain. Speech requires many different functions, which are organized throughout the brain. Nonetheless, the method of experimental ablation remains important to our understanding of the brains of both humans and laboratory animals.

Figure 1.4 Broca's Area

This region of the brain is named for French surgeon Paul Broca, who discovered that damage to a part of the left side of the brain disrupted a person's ability to speak.

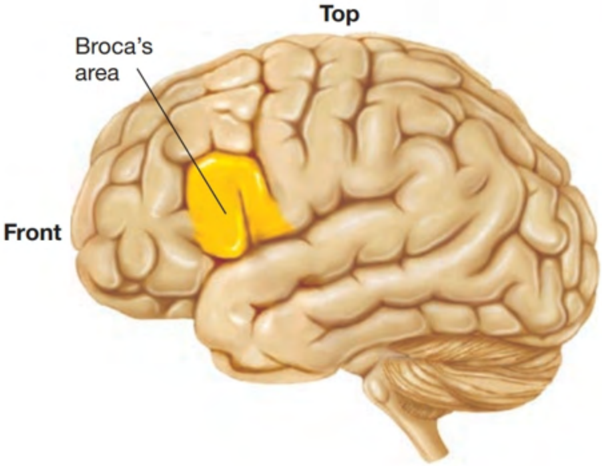
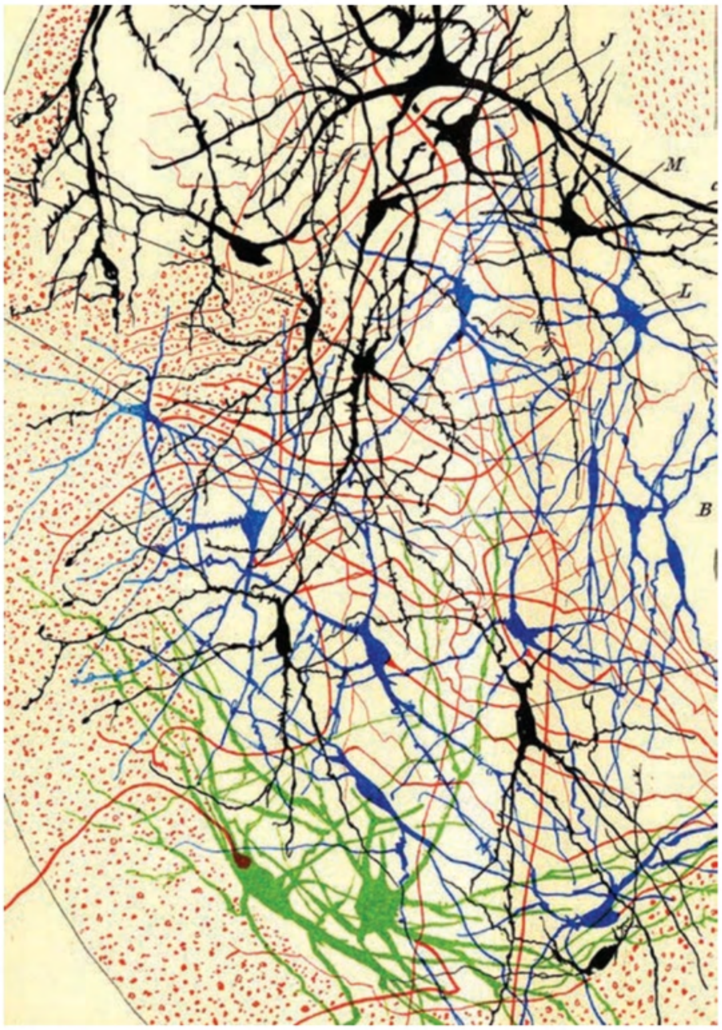


Figure 1.5 Golgi-Stained Neurons

Drawing of Neurons by Santiago Ramón y Cajal



Science Source

Jan Purkinje (1787–1869), a Czech physiologist, studied both the central and peripheral nervous systems in the middle of the nineteenth century. He discovered Purkinje fibers—neurons terminating on cardiac cells responsible for controlling contractions of the heart. He also used the microscope to investigate the structure of neurons in many regions of the brain, which included discovering Purkinje cells in the cerebellum (Chvátal, 2017).

Late in the nineteenth century, Spanish anatomist Santiago Ramón y Cajal (1852–1934) used the Golgi staining technique (described in Chapter 5) to examine individual neurons of the brain. His drawings of neurons (made under magnification from a microscope) from the brain, spinal cord, and retina depicted the detailed structures of these cells for the first time. Cajal proposed that the nervous system consisted of billions of discrete, individual neurons, in opposition to the predominant idea of the time that the nervous system was a continuous network. In 1906, he was awarded the Nobel Prize for his work describing the structure of the nervous system. Figure 1.5 shows one of his drawings.

CONTEMPORARY RESEARCH CONTRIBUTIONS

Twentieth-century developments in experimental physiology included many important inventions, such as sensitive amplifiers to detect weak electrical signals, neurochemical techniques to analyze chemical changes within and between cells, and histological techniques to visualize cells and their constituents. These and many other important developments are discussed in detail in subsequent chapters.

Briefly, highlights in contributions to neuroscience during the twentieth century include discoveries ranging from the electrical and chemical messages used by neurons, to the circuits and brain structures involved in a wide variety of behaviors, such as the mirror neuron system for coordinating social behavior (described in Chapter 8). Other developments contributed to new brain-based treatments for disorders such as severe depression and Parkinson's disease (Chapters 16 and 17).

The twenty-first century has already witnessed several important advances and discoveries. As researchers continue to refine their understanding of the structures and functions of the brain, new discoveries about pathways and circuits abound. For example, the 2014 Nobel Prize was awarded to John O'Keefe (1939–), May-Britt Moser (1963–), and Edvard Moser (1962) for work on spatial positioning systems in the brain (also called the brain's global positioning system, or GPS). In 2017, Jeffrey Hall (1945–), Michael Rosbash (1944–), and Michael Young (1949–) received the Nobel Prize for their work describing the molecular mechanisms controlling circadian rhythms.

New genetic techniques have spurred many exciting discoveries in neuroscience as well. The development of optogenetics provides researchers with the ability to selectively activate single neurons and observe changes in behavior—using light! (See Chapter 5.) The development of CRISPR-Cas9 techniques have enabled precise editing of genetic material (DNA). This technique uses an enzyme (Cas9) to cut out pieces of DNA paired with a set of replacement directions (guide RNA) to create modified genes. The impact of this technique on behavioral neuroscience is just beginning to be understood. The field of **epigenetics** focuses on the role of the environment in the expression of genes. Researchers continue to learn more about how environmental-dependent gene expression can have a profound impact on an individual's behavior.

As behavioral neuroscience continues to progress as an interdisciplinary field, efforts such as the European Human Brain Project, which is working to develop a computer simulation of the brain, and the Brain Research through Advancing Innovative Neurotechnologies (BRAIN) initiative in the United States will continue to bring together groups of researchers from biology, chemistry, engineering, psychology, physiology, and other fields. Behavioral neuroscience, after all, has its roots—and its future—in interdisciplinary research.

DIVERSITY IN NEUROSCIENCE Neuroscience is a diverse interdisciplinary field whose researchers work around the globe. The Society for Neuroscience was founded in 1969, with 500 members committed to developing a professional organization for scientists and physicians devoted to understanding the brain and nervous system. This international organization now has approximately 37,000 members from over 90 different countries. Reviewing the list of Nobel Prizes related to neuroscience research in Table 1.1, you'll notice the names of men and women from several different countries. The field is currently striving to increase diversity through inclusivity of women and underrepresented groups in the sciences.

Table 1.1 Selected Nobel Prizes for Research Related to Neuroscience

Year	Recipients (country)	Field of Study
1906	Camillo Golgi (Italy) and Santiago Ramón y Cajal (Spain)	Structure of the nervous system
1936	Sir Henry Hallett Dale (U.K.) and Otto Loewi (Austria)	Chemical transmission of nerve impulses
1963	Sir John Carew Eccles (Australia), Sir Alan Lloyd Hodgkin (U.K.), and Sir Andrew Fielding Huxley (U.K.)	Ionic mechanisms of nerve cell membrane
1970	Julius Axelrod (U.S.), Sir Bernard Katz (Germany, U.S.), and Ulf Svante von Euler (Sweden)	Neurotransmitters
1981	David Hubel (Canada, U.S.), Torsten Wiesel (Sweden, U.S.), and Roger Sperry (U.S.)	Functions of the nervous system
2000	Arvid Carlsson (Sweden), Paul Greengard (U.S.), and Eric Kandel (U.S.)	Neural communication
2014	John O'Keefe (U.S., U.K.), Edvard Moser (Norway), and May-Britt Moser (Norway)	Spatial positioning system in the brain
2017	Jeffrey Hall (U.S.), Michael Rosbash (U.S.), and Michael Young (U.S.)	Molecular mechanisms controlling circadian rhythms

Module Review: Foundations of Behavioral Neuroscience

The Goals of Research

LO 1.1 Compare the roles of generalization and reduction in behavioral neuroscience research.

To explain the results of behavioral neuroscience research, generalization can be used to reveal general laws of behavior. Reduction can be used to explain complex phenomena in terms of smaller, discrete phenomena. Both are critical to understanding human behavior.

Roots of Behavioral Neuroscience

LO 1.2 Summarize historical and contemporary contributions to behavioral neuroscience from various scientific disciplines.

Ancient scholars disagreed on the importance of the brain in behavior, and some attributed thought and emotion to the heart. The mind–body question influenced both historical (dualist) and contemporary (monist) views of the brain. French philosopher Descartes described reflexes but believed that other behavior was the product of pressurized fluid causing muscles to contract. Early physiologists influenced the study of electrical components of neural communication. Müller proposed the doctrine of specific nerve energies while Fritsch and Hitzig studied the effects of electrical stimulation of different brain regions. Galvani discovered that nerves convey electrical messages, and von Helmholtz refined that understanding to begin to account for chemical communication between cells. Advances in research revealed the structure of the brain and the cells of the nervous system. Flourens and Broca studied the functions of brain regions using ablation. Purkinje and Cajal studied the structures and functions of specific sets of neurons. Contemporary research continues in these areas and others, particularly with regard to the genetic and molecular bases of behavior. Today, behavioral neuroscience is a diverse, international, and interdisciplinary field.

Thought Question

Several new areas of research, such as the Brain Activity Map initiative and the Human Brain Project, are poised to shape the future of behavioral neuroscience. Write an email message to a friend suggesting future research in behavioral neuroscience and possible discoveries that may be made.

Natural Selection and Evolution

Following the tradition of Müller and von Helmholtz, other biologists continued to observe, classify, and think about what they saw, to arrive at new conclusions. One of the most important and influential of these scientists was Charles Darwin (1809–1882). (See Figure 1.6.) Darwin formulated the principles of natural selection and the theory of evolution, which revolutionized biology at the time and continues to shape the field of behavioral neuroscience today. In science, a *theory* is an explanation that is strongly supported by multiple lines of research with many converging results.

Figure 1.6 Charles Darwin (1809–1882)

Darwin's theory of evolution revolutionized biology and strongly influenced early psychologists.

North Wind Picture Archives

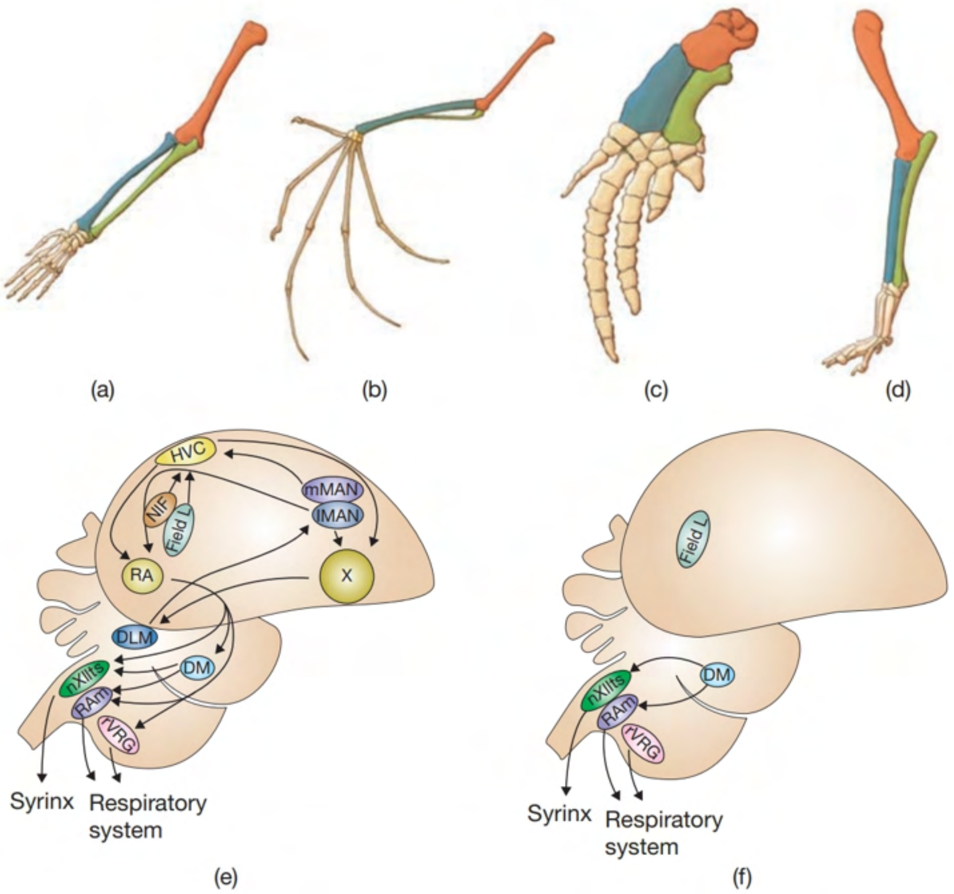
Functionalism and the Inheritance of Traits

LO 1.3 **Describe the role of natural selection in the evolution of behavioral traits.**

Darwin's theory emphasizes that all of an organism's characteristics—its structure, its coloration, its behavior—have functional significance. For example, the strong talons and sharp beaks that eagles possess permit the birds to catch and eat prey. Caterpillars that eat green leaves are themselves green, and their color makes it difficult for birds to see them against their usual background. Mother mice construct nests, which keep their offspring warm and out of harm's way. The behavior itself is not inherited. What *is* inherited is a structure—the brain—that causes the behavior to occur. Darwin's theory gave rise to **functionalism**, the principle that characteristics of living organisms perform useful functions. So, to understand the physiological basis of various behaviors, we must first understand what these behaviors accomplish (their function). This means that we must understand something about the natural history of the species being studied so that the behaviors can be seen in context. To understand the workings of something as complex as a nervous system, we should know what its functions are. Organisms of today are the result of a long series of changes due to genetic variability. Strictly speaking, we cannot say that any physiological mechanisms of living organisms have a *purpose.* But they do have *functions*, and these we can try to determine. For example, the forelimb structures shown in Figure 1.7 are adapted for different functions in different species of mammals. Adaptations also occur in brain structures. For example, male songbirds such as the white-crowned sparrow possess highly developed brain structures (such as the *robust nucleus of the archistriatum, high vocal center,* and *Area X)* that differ from some of their close, non-songbird relatives. (See Figure 1.7.) The songbirds' unique structures allow them to learn and produce songs in response to complex social and environmental stimuli. The function of male song behavior in these species is to attract a mate and deter rivals. The non-songbirds lack these brain structures and their associated functions (Beecher and Brenowitz, 2005). Among the various songbirds, in species in which only the males sing, males have larger song brain structures compared to females. In species in which both sexes sing duets, there is no difference between the size of the structures in males and females (Brenowitz, 1997).

Figure 1.7 Adaption of Structures for Different Functions

The figure shows the forelimb bones of (a) human, (b) bat, (c) whale, and (d) dog. Through the process of natural selection, these bones have been adapted to suit many different functions. Songbird (e) and non-songbird (f) brain structures also differ, corresponding with the different functions of song in these species. Various song-related brain regions and their output to the structures used to produce song (the syrinx and respiratory system) are labeled.



Darwin formulated his theory of evolution to explain the means by which species acquired their adaptive characteristics. The cornerstone of this theory is the principle of **natural selection**. Darwin noted that members of a species were not all identical and that some of the differences they exhibited were inherited by their offspring. If an individual's characteristics permit it to reproduce more successfully, some of the individual's offspring will inherit the favorable characteristics and will themselves produce more offspring. As a result, the characteristics will become more prevalent in that species. He observed that animal breeders were able to develop strains that possessed particular traits by mating together only animals that possessed the desired traits. If artificial selection, controlled by animal breeders, could produce so many varieties of dogs, cats, and livestock, perhaps natural selection could be responsible for the development of species. Over the course of time in the natural world, it was the environment, not the choices of the animal breeder, that shaped the process of evolution.

Darwin and his fellow scientists knew nothing about the mechanism by which the principle of natural selection works. In fact, the principles of molecular genetics were not discovered until the middle of the twentieth century. Briefly, here is how the process works: Every sexually reproducing multicellular organism consists of a large number of cells, each of which contains chromosomes. Chromosomes are large, complex molecules that contain the recipes for producing the proteins that cells need to grow and to perform their functions. In essence, the chromosomes contain the blueprints for the construction (that is, the embryological development) of a particular member of a particular species. If the plans are altered, a different organism is produced.

The plans do get altered from time to time; mutations occur. **Mutations** are accidental changes in the chromosomes of sperm or eggs that join together and develop into new organisms. For example, a random mutation of a chromosome in a cell of an animal's testis or ovary could produce a mutation that affects that animal's offspring. Most mutations are deleterious; the offspring either fails to survive or survives with detrimental effects of the mutation. Some mutations are beneficial and confer a **selective advantage** to the organism that possesses them. An individual with a selective advantage is more likely than other members of its species to live long enough to reproduce and pass on its chromosomes to its own offspring. Many different kinds of traits can confer a selective advantage: resistance to a particular disease, the ability to digest new kinds of food, more effective weapons for defense or for procurement of prey, and even a more attractive appearance to potential mates.

The traits that can be altered by mutations are physical ones; chromosomes make proteins, which affect the structure and chemistry of cells. But the *effects* of these physical alterations can be seen in an animal's behavior. This means that the process of natural selection can act on behavior indirectly. For example, if a particular mutation results in changes in the brain that cause a small animal to change its behavior and freeze when it perceives a nearby movement, that animal is more likely to escape undetected when a predator passes nearby. This tendency makes the animal more likely to survive and produce offspring, passing on genes related to freezing behavior to future generations.

Other mutations are not immediately favorable, but because they do not put their possessors at a disadvantage, they are inherited by at least some members of the species. As a result of thousands of such mutations, the members of a particular species possess a variety of genes, and are all at least somewhat different from one another. Variety is a definite advantage for a species. Different environments provide optimal habitats for different kinds of organisms. When the environment changes, species must adapt or run the risk of becoming extinct. If some members of the species possess assortments of genes that provide characteristics permitting them to adapt to the new environment, their offspring will survive, and the species will continue.

An understanding of the principle of natural selection plays some role in the thinking of every scientist who undertakes research in behavioral neuroscience. Some researchers explicitly consider the genetic mechanisms of various behaviors and the physiological processes on which these behaviors depend. Others are concerned with comparative aspects of behavior and its physiological basis; they compare the nervous systems of animals from a variety of species to make hypotheses about the evolution of brain structure and the behavioral capacities that correspond to this evolutionary development. But even though many researchers do not directly study evolution, the principle of natural selection guides the thinking of behavioral neuroscientists. We ask ourselves what the selective advantage of a particular trait might be. We think about how nature might have used a physiological mechanism that already existed to perform more complex functions in more complex organisms. When we entertain hypotheses, we ask ourselves whether a particular explanation makes sense in an evolutionary perspective.

Evolution of Human Brains

LO 1.4 Identify factors involved in the evolution of human brains.

To *evolve* means to develop gradually. The process of **evolution** is a gradual change in the structure and physiology of a species as a result of natural selection. New species evolve when organisms develop novel characteristics that can take advantage of unexploited opportunities in the environment.

Appearance of the earliest humans can be traced back to the Cenozoic period, when tropical forests covered much of the land areas. In these forests our most direct ancestors, the primates, evolved. The first primates were small and preyed on insects and small cold-blooded vertebrates such as lizards and frogs. They had grasping hands that permitted them to climb about in small branches of the forest. Over time, larger species developed, with larger, forward-facing eyes (and the brains to analyze what the eyes saw), which facilitated moving among the trees and capturing prey.

The evolution of fruit-bearing trees provided an opportunity for fruit-eating primates. In fact, the original advantage of color vision (and the associated sensory regions of the brain) was probably the ability to discriminate ripe fruit from green leaves in order to eat the fruit before it spoiled—or some other animals got to it first. And because fruit is such a nutritious form of food, its availability provided an opportunity that could be exploited by larger primates, which were able to travel farther in quest of food.

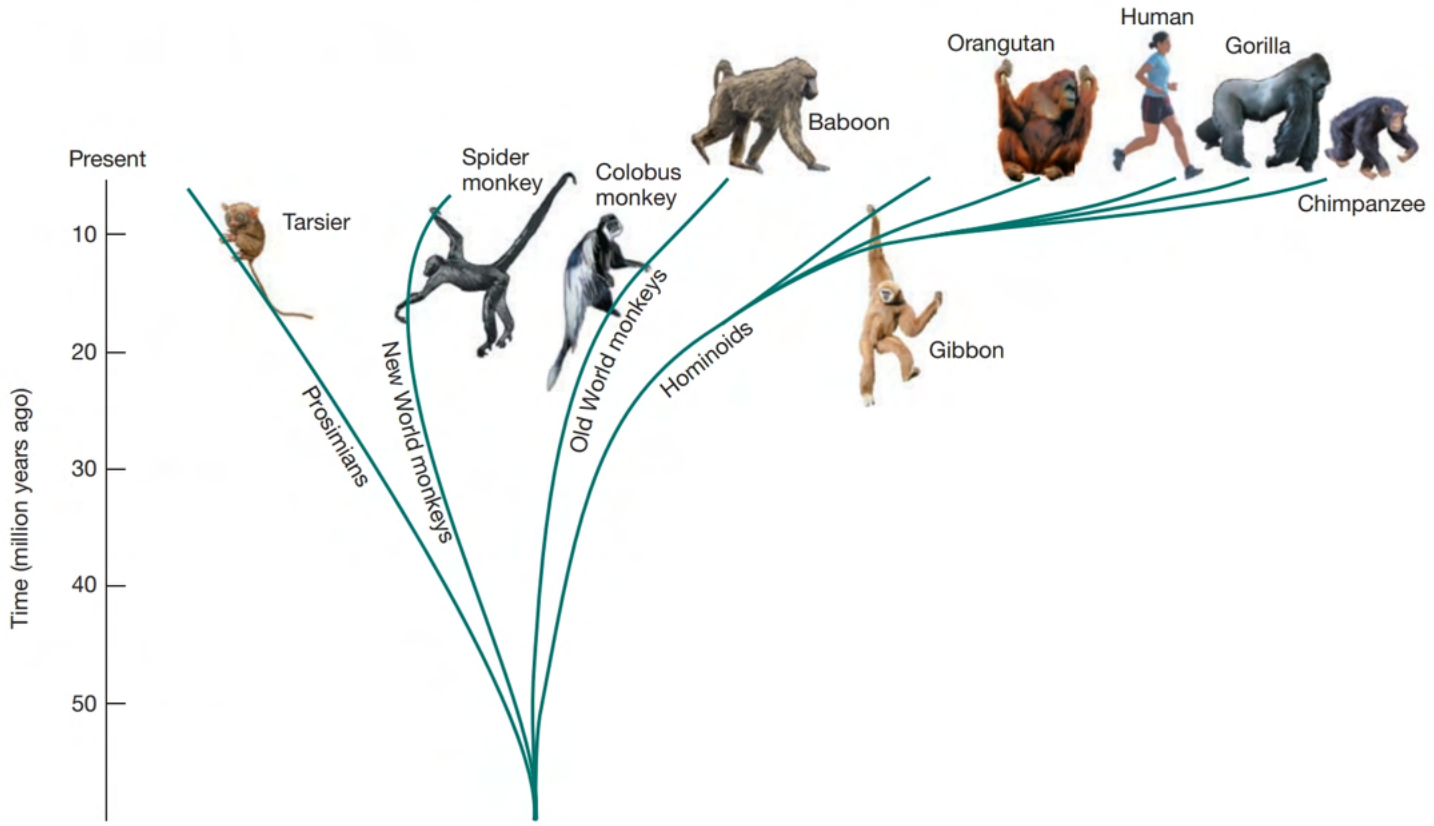
The first *hominids* (humanlike apes) appeared in Africa. They appeared not in dense tropical forests but in drier woodlands and in the savanna. Our fruit-eating ancestors continued to eat fruit, but they evolved characteristics that enabled them to gather roots and tubers as well, to hunt and kill game, and to defend themselves against other predators. They made tools that could be used to hunt, produce clothing, and construct dwellings; they discovered the many uses of fire; they domesticated dogs, which greatly increased their ability to hunt and helped warn of attacks by predators; and they developed the ability to communicate symbolically, by means of spoken words.

Figure 1.8 shows the primate family tree. Our closest living relatives—the only hominids besides ourselves who have survived—are the chimpanzees, gorillas, and orangutans. DNA analysis shows that genetically, there is very little difference between these four species. For example, humans and chimpanzees share almost 99 percent of their DNA.

The first hominid to leave Africa did so around 1.7 million years ago. This species, *Homo erectus* ("upright man"), scattered across Europe and Asia. One branch of *Homo erectus* appears to have been the ancestor of *Homo neanderthalis,* which inhabited Western Europe between 120,000 and 30,000 years ago. Neanderthals resembled modern humans. They made tools out of stone and wood

Figure 1.8 Evolution of Primate Species

Source: Redrawn from Lewin, R. (1993.) *Human evolution: An illustrated introduction* (3rd ed.). Boston: Blackwell Scientific Publications. Reprinted with permission by Blackwell Science Ltd.



and discovered the use of fire. Our own species, *Homo sapiens,* evolved in East Africa around 100,000 years ago. Some of our ancestors migrated to other parts of Africa and out of Africa to Asia, Polynesia, Australia, Europe, and the Americas. (See Figure 1.9.)

Humans possessed several characteristics that allowed them to compete with other species. Their agile hands enabled them to make and use tools. Their excellent color vision helped them to spot ripe fruit, prey, and dangerous predators. Their mastery of fire enabled them to cook food, provide warmth, and frighten nocturnal predators. Their upright posture and bipedalism (ability to walk using two rear limbs) made it possible for them to walk long distances efficiently, with their eyes far enough from the ground to see long distances across the plains. Bipedalism also permitted them to carry tools and food with them, which meant that they could bring fruit, roots, and pieces of meat back to their tribe. Their linguistic abilities enabled them to combine the collective knowledge of all the members of the tribe, to make plans, to pass information on to subsequent generations, and to form complex civilizations that established their status as the dominant species. All of these characteristics required a primate brain capable of these complex abilities.

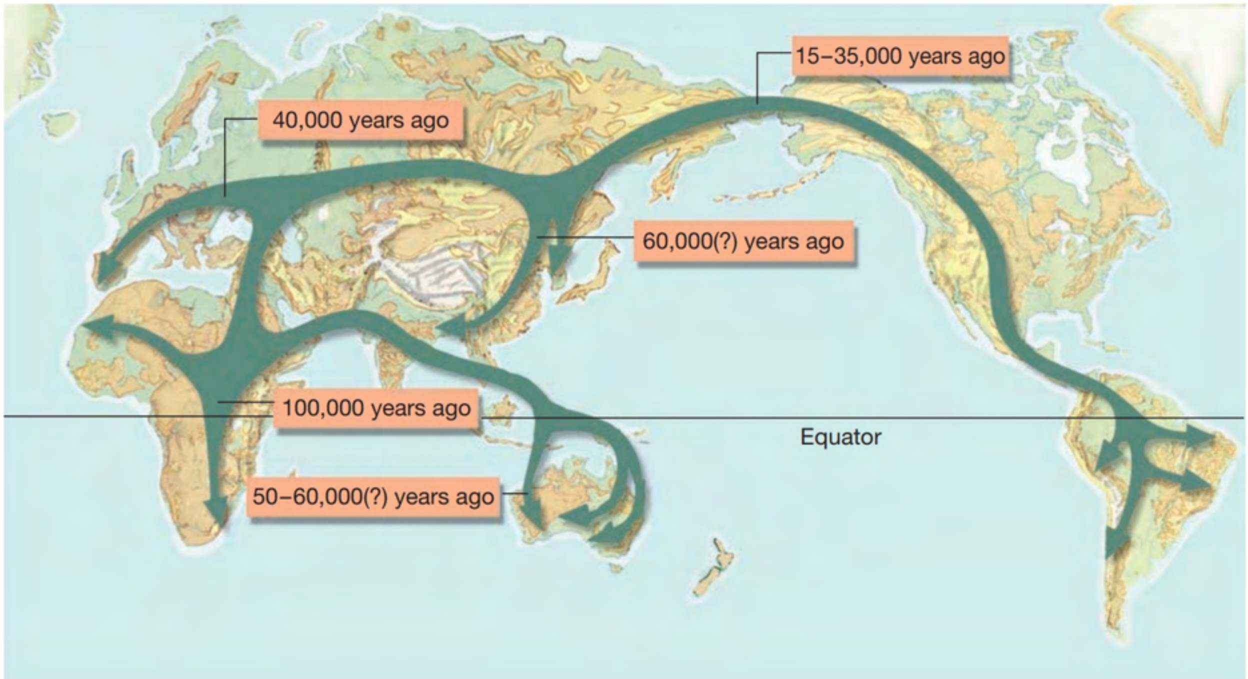
Sophisticated primate brains developed within the constraints of the size of a mother's birth canal, and an upright posture limits the size of a woman's birth canal. A newborn primate's head is about as large as it can safely be. Because a baby's brain is not large or complex enough to perform the physical and intellectual abilities of an adult, the brain must continue to grow after the baby is born. In fact, all mammals (and all birds, for that matter) require parental care for a period of time while the nervous system develops. The fact that young mammals (particularly young humans) are guaranteed to be exposed to the adults who care for them means that a period of apprenticeship is possible. Consequently, the evolutionary process did not have to produce a brain that consisted solely of specialized circuits of neurons that performed specialized tasks. Instead, it produced a primate brain with an abundance of neural circuits that could be modified by experience. Adults would nourish and protect their offspring and provide them with the skills they would need as adults. Some specialized circuits were necessary (for example, those involved in analyzing the complex sounds we use for speech), but, by and large, the primate brain is more similar to a general-purpose, programmable computer.

What counts, as far as intellectual ability goes, is having a brain with plenty of neurons that are available for behavior, learning, remembering, reasoning, and making plans. Herculano-Houzel and colleagues (2007)

Figure 1.9 Migration of *Homo sapiens*

The figure shows proposed migration routes of *Homo sapiens* after evolution of the species in East Africa.

Source: Redrawn with permission from Cavalli-Sforza, L. L. (1991.) Genes, peoples and languages. *Scientific American, 265*(5), p. 75.



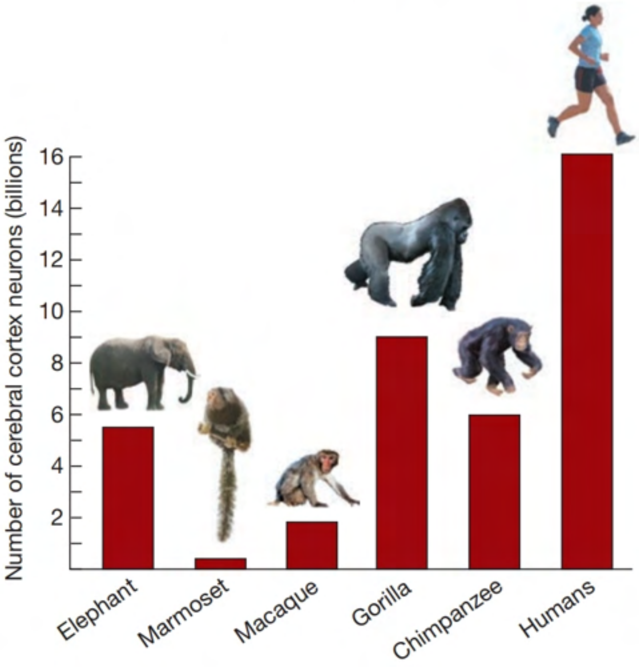
compared the brains of several species of rodents and primates and found that primate brains contain more neurons per gram than rodent brains. (See Figure 1.10.) Reflecting on their results, the researchers concluded that "our standing among primates as the proud owners of the largest living brain assures that, at least among primates, we enjoy the largest number of neurons from which to derive cognition and behavior as a whole" (Herculano-Houzel, 2009, p. 10). Can you predict what types of functions these additional neurons might be devoted to in humans?

What types of genetic changes were responsible for the evolution of the human brain? This question will be addressed in more detail in Chapter 15, but evidence suggests that the most important principle is slowing the process of brain development, allowing more time for growth. As we will see, the prenatal period of cell division in the brain is prolonged in humans, which results in a brain that weighs an average of 350 g and contains approximately 86 billion neurons (Azevedo et al., 2009). After birth the brain continues to grow. Production of new neurons almost ceases, but those that are already present grow and establish connections with each other, and other brain cells, which protect and support neurons, begin to proliferate. Not until late adolescence does the human brain reach its adult size of approximately 1,400 g—about four times the weight of a newborn's brain. This prolongation of maturation is known as **neoteny** (roughly translated as "extended youth"). The mature human head and brain retain some infantile characteristics, including their disproportionate size relative to the rest of the body.

Figure 1.10 Comparison of Mammalian Brains

Species with more complex behaviors have brains with more neurons that are available for behavior, learning, remembering, reasoning, and making plans. Primate brains contain more neurons per gram than rodent brains and more neurons in the cortex.

Source: Herculano-Houzel, S., and Marino, L. (1998.) A Comparison of Encephalization between Odontocete Cetaceans and Anthropoid Primates. *Brain, Behavior and Evolution, 51*(4), 230–238.



Module Review: Natural Selection and Evolution

Functionalism and the Inheritance of Traits

LO 1.3 Describe the role of natural selection in the evolution of behavioral traits.

Natural selection is the process responsible for evolution of structures with specific functions. Members of a species possess a variety of structures. If the structures permit an individual to reproduce more successfully, its offspring will also have these structures, and they will become more prevalent in the population. An example of inherited structures responsible for behavior is the set of brain structures responsible for male song behavior in some species of songbirds.

Evolution of Human Brains

LO 1.4 Identify factors involved in the evolution of human brains.

The evolution of specialized structures responsible for functions such as color vision, fine motor control, complex vision, and language required a more complex primate brain. Primate brains contain many more neurons per gram than other species. These additional cells are responsible for behavior, learning, remembering, reasoning, and making plans. Additional brain development occurs after birth and throughout an extended period of development and parental care in humans.

Thought Question

Kavoi and Jameela (2011) reported that a part of the brain responsible for olfaction, the olfactory bulb, is larger in dogs than in humans, even after accounting for differences in overall brain size. Using the principles of natural or artificial selection, hypothesize how dogs came to have this larger structure in their brain and predict how it might impact their behavior.

Ethical Issues in Research with Humans and Other Animals

This book contains many facts about what is currently known about the structure and function of the nervous system. Where do these facts come from? They are the result of carefully designed experiments that can include computer simulations, individual cells, and often humans and other animals. Neuroscience research involving humans and other animals is subject to important ethical considerations and oversight. This section addresses these issues in more detail.

Research with Animals

LO 1.5 Outline reasons for the use of animals in behavioral neuroscience research.

Much of the research described in this book involves experimentation on living animals. Any time we use another species of animals for our own purposes, we should be sure that what we are doing is both humane and worthwhile. It is important that a good case can be made that research in behavioral neuroscience qualifies on both counts. Humane treatment is a matter of procedure. We know how to maintain laboratory animals in good health in comfortable, sanitary conditions. We know how to administer anesthetics and analgesics so that animals do not suffer during or after surgery, and we know how to prevent infections with proper surgical procedures and the use of antibiotics. Most industrially developed societies have strict regulations about the care of animals and require approval of the experimental procedures that are used on them. There is no excuse for mistreating animals in our care. In fact, the vast majority of laboratory animals *are* treated humanely and many animal researchers are also strong animal welfare advocates.

Whether an experiment is *worthwhile* can be difficult to say. We use animals for many purposes. We eat their meat and eggs, and we drink their milk; we turn their hides into leather; we extract insulin and other hormones from their organs to treat people's diseases; we train them to do useful work on farms or to entertain us. Even having a pet is a form of exploitation; it is we—not they—who decide that they will live in our homes. The fact is we have been using other animals throughout the history of our species.

Pet ownership has the potential to cause much more suffering among animals than scientific research does. Pet owners are not required to receive permission from a board of experts that includes a veterinarian to house their pets, nor are they subject to periodic inspections to be sure that their home is clean and sanitary, that their pets have enough space to exercise properly, or that their pets' diets are appropriate. Scientific researchers are required to have all those things. The disproportionate amount of concern that animal rights activists show toward the use of animals in research and education is puzzling, particularly because this is the one indispensable use of animals. We *can* survive without eating animals, we *can* live without hunting, we *can* do without furs; but without using animals for research and for training future researchers, we *cannot* make progress in understanding and treating diseases. In not too many years scientists will probably have developed a vaccine that will prevent the further spread of diseases such as Ebola virus disease, malaria, or AIDS. Even diseases that we have already conquered would impact new lives if drug companies could no longer use animals to develop and test new treatments. If they were deprived of animals, these companies could no longer extract hormones used to treat human diseases, and they could not prepare many of the vaccines we now use to prevent disease.

Our species is beset by medical, psychological, and behavioral problems, many of which can be solved only through biological research. Consider some of the major neurological disorders. Strokes, like the one experienced by Jeremiah at the beginning of this chapter, are caused by bleeding or obstruction of a blood vessel within the brain, and often leave people partly paralyzed, unable to read, write, or converse with their friends and family. Basic animal research on the means by which nerve cells communicate with each other has led to important discoveries about the causes of the death of brain cells. This research was not directed toward a specific practical goal; the potential benefits actually came as a surprise to the investigators.

Experiments based on these results have shown that if a blood vessel leading to the brain is blocked for a few minutes, the part of the brain that is nourished by that vessel will die. However, the brain damage can be prevented by first administering a drug that interferes with a particular kind of neural communication. This research is important, because it may lead to medical treatments that can help to reduce the brain damage caused by strokes. But it involves operating on a laboratory animal, such as a rat, and pinching off a blood vessel. (The animals are anesthetized.) Some of the animals will sustain brain damage, and all will be euthanized so that their brains can be examined. However, you will probably agree that research like this is just as legitimate as using animals for food.

As you will learn later in this book, research with laboratory animals has produced important discoveries about the possible causes or potential treatments of neurological and mental disorders, including Parkinson's disease, schizophrenia, bipolar disorder, anxiety disorders, obsessive-compulsive disorder, anorexia nervosa, obesity, and substance abuse. Although much progress has been made, these problems persist, and they cause much human suffering. Unless we continue our research with laboratory animals, they will not be solved.

Some people have suggested that instead of using laboratory animals in our research, we could use tissue cultures or computers. While these techniques can be used to pursue some research questions, unfortunately, tissue cultures or computers are not substitutes for complex, living organisms. We have no way to study behavioral problems such as substance abuse in tissue cultures, nor can we program a computer to simulate the workings of an animal's nervous system. (If we could, that would mean we already had all the answers.)

OVERSIGHT OF ANIMAL RESEARCH

LO 1.6 Identify mechanisms for oversight of animal research.

In the United States, any institution that receives federal research funding to use animals in research is required to have an Institutional Animal Care and Use Committee (IACUC). The IACUC is typically composed of a veterinarian, scientists who work with animals, non-scientist members, and community members not affiliated with the institution. This group reviews all proposals for research involving animals, with the intent of ensuring humane and ethical treatment of all animals involved. Even noninvasive research with animals (such as fieldwork or observational studies) must pass review and be approved by the IACUC. This approval process ensures not only the welfare of the animals, but also that the research is compliant with local, state, and federal regulations.

Research with Humans

LO 1.7 Discuss ethical considerations in research with human participants.

Not all neuroscience research is conducted with animal models. Much of what we currently understand about the brain and behavior is the result of research with human participants. In addition to humane research conditions, research with human participants must also include informed consent and precautions to protect the identity of the participants. **Informed consent** describes the process in which researchers must inform any potential participant about the nature of the study, how any data will be collected and stored, and what the anticipated benefits and costs of participating will be. Only after obtaining this information can the participant make an informed decision about whether to participate in a study. Violating the informed consent process can have ethical, legal, and financial consequences. In 2010, the case of *Havasupai Tribe v. Arizona Board of Regents* was settled, including the return of biological samples and a payment of $700,000 to the Havasupai tribe after six years of dispute. The settlement was issued in response to a vague and incomplete informed consent process that resulted in the use of blood samples originally intended for research on diabetes being used in contested research