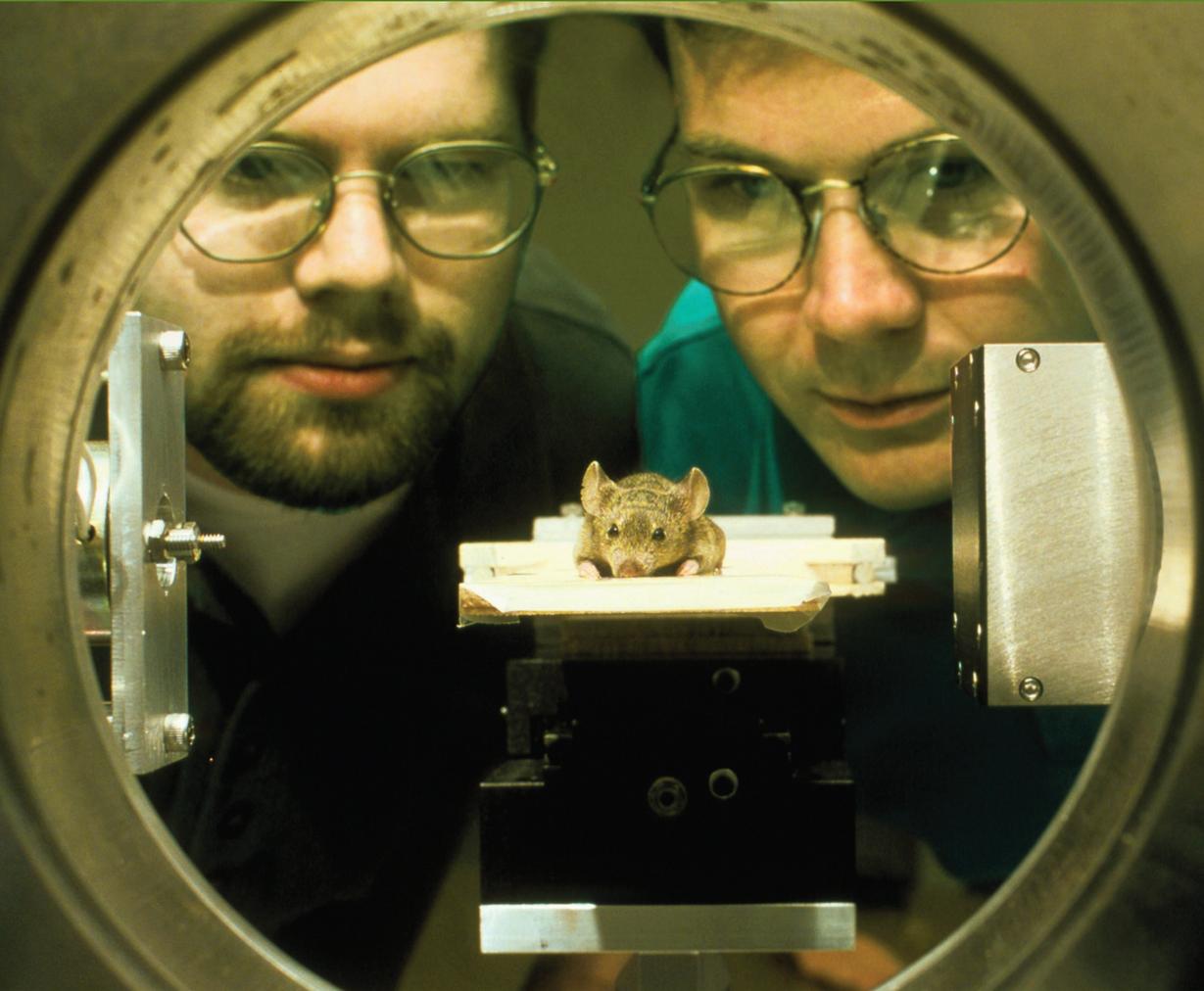


Origins of Behavioral Neuroscience

OUTLINE

- **Understanding Human Consciousness: A Physiological Approach**
Split Brains
- **The Nature of Behavioral Neuroscience**
The Goals of Research
Biological Roots of Behavioral Neuroscience
- **Natural Selection and Evolution**
Functionalism and the Inheritance of Traits
Evolution of the Human Brain
- **Ethical Issues in Research with Animals**
- **Careers in Neuroscience**
- **Strategies for Learning**



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LEARNING OBJECTIVES

1. Describe the behavior of people with split brains and explain what study of this phenomenon contributes to our understanding of self-awareness.
2. Describe the goals of scientific research.
3. Describe the biological roots of behavioral neuroscience.
4. Describe the role of natural selection in the evolution of behavioral traits.
5. Describe the evolution of the human species.
6. Discuss the value of research with animals and ethical issues concerning their care.
7. Describe career opportunities in neuroscience.
8. Outline the strategies that will help you learn as much as possible from this book.

PROLOGUE | René's Inspiration

René, a lonely and intelligent young man of eighteen years, had secluded himself in Saint-Germain, a village to the west of Paris. He had recently suffered a nervous breakdown and chose the retreat to recover. Even before coming to Saint-Germain, he had heard of the fabulous royal gardens built for Henri IV and Marie de Médicis, and one sunny day he decided to visit them. The guard stopped him at the gate, but when he identified himself as a student at the King's School at La Flèche, he was permitted to enter. The gardens consisted of a series of six large terraces overlooking the Seine, planted in the symmetrical, orderly fashion so loved by the French. Grottoes were cut into the limestone hillside at the end of each terrace; René entered one of them. He heard eerie music accompanied by the gurgling of water but at first could see nothing in the darkness. As his eyes became accustomed to the gloom, he could make out a figure illuminated by a flickering torch. He approached the figure, which he soon recognized as that of a young woman. As he drew closer, he saw that she was actually a bronze statue of Diana, bathing in a pool of water. Suddenly, the Greek goddess fled and hid behind a bronze rosebush. As René pursued her,

an imposing statue of Neptune rose in front of him, barring the way with his trident.

René was delighted. He had heard about the hydraulically operated mechanical organs and the moving statues, but he had not expected such realism. As he walked back toward the entrance to the grotto, he saw the plates buried in the ground that controlled the valves operating the machinery. He spent the rest of the afternoon wandering through the grottoes, listening to the music and being entertained by the statues.

During his stay in Saint-Germain, René visited the royal gardens again and again. He had been thinking about the relationship between the movements of animate and inanimate objects, which had concerned philosophers for some time. He thought he saw in the apparently purposeful, but obviously inanimate, movements of the statues an answer to some important questions about the relationship between the mind and the body. Even after he left Saint-Germain, René Descartes revisited the grottoes in his memory. He even went so far as to name his daughter Francine after their designers, the Francini brothers of Florence.



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.

One of the most universal of all human characteristics is curiosity. We want to explain what makes things happen. In ancient times, people believed that natural phenomena were caused by animating spirits. All moving objects—animals, the wind and tides, the sun, moon, and stars—were assumed to have spirits that caused them to move. For example, stones fell when they were dropped because their animating spirits wanted to be reunited with Mother Earth. As our ancestors became more sophisticated and learned more about nature, they abandoned this approach (which we call *animism*) in favor of physical explanations for inanimate moving objects. But they still used spirits to explain human behavior.

From the earliest historical times, people have believed that they possessed something intangible that animated them—a mind, a soul, or a spirit. This belief stems from the fact that each of us is aware of our own existence. When we think or act, we feel as though something inside us is thinking or deciding to act. But what is the nature of the human mind? We have physical bodies with muscles that move them 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 is the mind, and what role does it 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?

Behavioral neuroscientists take an empirical and practical approach to the study of human nature. Most of us believe that the mind is a phenomenon produced by the workings of the nervous system. We believe that once we understand the workings of the human body—especially the workings of the nervous system—we will be able to explain how we perceive, how we think, how we remember, and how we act. We will even be able to explain the nature of our own self-awareness. Of course, we are far from understanding the workings of the nervous system, so only time will tell whether this belief is justified.



Scientists and engineers have developed research methods that enable neuroscientists to study activity of the human brain.

AJ Photo/Photo Researchers, Inc.

Understanding Human Consciousness: A Physiological Approach

How can behavioral neuroscientists study human consciousness? First, let's define our terms. The word *consciousness* can be used to refer to a variety of concepts, including simple wakefulness. Thus, a researcher may write about an experiment using “conscious rats,” referring to the fact that the rats were awake and not anesthetized. By *consciousness*, I am referring to something else: the fact that we humans are aware of—and can tell others about—our thoughts, perceptions, memories, and feelings.

We know that brain damage or drugs can profoundly affect consciousness. Because consciousness can be altered by changes in the structure or chemistry of the brain, we may hypothesize that consciousness is a physiological function, just as behavior is. We can even speculate about the origins of this self-awareness. Consciousness and the ability to communicate seem to go hand in hand. Our species, with its complex social structure and enormous capacity for learning, is well served by our ability to communicate: to express intentions to one another and to make requests of one another. Verbal communication makes cooperation possible and permits us to establish customs and laws of behavior. Perhaps the evolution of this ability is what has given rise to the phenomenon of consciousness. That is, our ability to send and receive messages with other people enables us to send and receive our own messages inside our own heads—in other words, to think and to be aware of our own existence. (See *Figure 1.1*.)

Split Brains

Studies of humans who have undergone a particular surgical procedure demonstrate dramatically how disconnecting parts of the brain that are involved with perceptions from parts involved with verbal behavior also disconnects them from consciousness. These results suggest that the parts of the brain involved in verbal behavior may be the ones responsible for consciousness.

The surgical procedure is one that has been used for people with very severe epilepsy that cannot be controlled by drugs. In these people, nerve cells in one side of the brain become overactive, and the overactivity is transmitted to the other side of the brain by a structure called the corpus callosum. The **corpus callosum** is a large bundle of nerve fibers that connects corresponding parts of one side of the brain with those of the other. Both sides of the brain then engage in wild activity and stimulate each other, causing a generalized epileptic seizure. These seizures can occur many times each day, preventing the person from leading a normal life. Neurosurgeons discovered that cutting the corpus callosum (the **split-brain operation**) greatly reduced the frequency of the epileptic seizures.



FIGURE 1.1 Studying the Brain.

Will the human brain ever completely understand its own workings? A sixteenth-century woodcut from the first edition of *De humani corporis fabrica* (*On the Workings of the Human Body*) by Andreas Vesalius.

National Library of Medicine.

corpus callosum (*core pus ka low sum*) A large bundle of nerve fibers that connects corresponding parts of one side of the brain with those of the other.

split-brain operation Brain surgery that is occasionally performed to treat a form of epilepsy; the surgeon cuts the corpus callosum, which connects the two hemispheres of the brain.

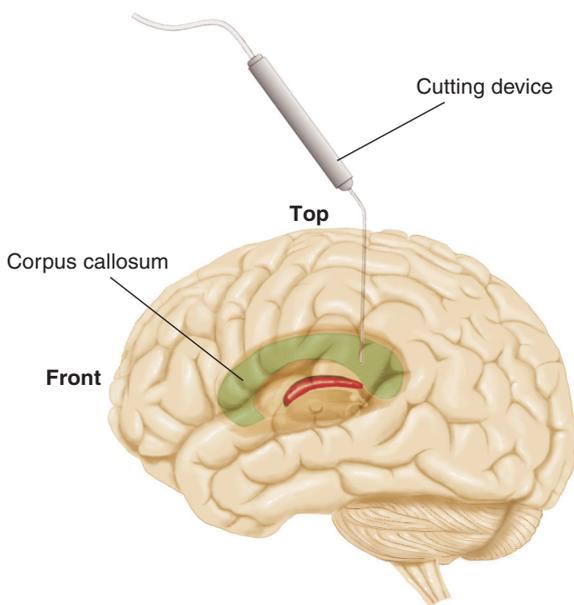


FIGURE 1.2 The Split-Brain Operation. A “window” has been opened in the side of the brain so that we can see the corpus callosum being cut at the midline of the brain.

cerebral hemispheres The two symmetrical halves of the brain; they constitute the major part of the brain.

Figure 1.2 shows a drawing of the split-brain operation. We see the brain sliced down the middle, from front to back, dividing it into its two symmetrical halves. A “window” has been opened in the left side of the brain so that we can see the corpus callosum being cut by the neurosurgeon’s special knife. (See **Figure 1.2**.)

Sperry (1966) and Gazzaniga and his associates (Gazzaniga and LeDoux, 1978; Gazzaniga, 2005) have studied these patients extensively. The largest part of the brain consists of two symmetrical parts, called the **cerebral hemispheres**, which receive sensory information from the opposite sides of the body. They also control movements of the opposite sides. The corpus callosum enables the two hemispheres to share information so that each side knows what the other side is perceiving and doing. After the split-brain operation is performed, the two hemispheres are disconnected and operate independently. Their sensory mechanisms, memories, and motor systems can no longer exchange information. The effects of these disconnections are not obvious to the casual observer, for the simple reason that only one hemisphere—in most people, the left—controls speech. The right hemisphere of an epileptic person with a split brain appears to be able to understand verbal instructions reasonably well, but it is incapable of producing speech.

Because only one side of the brain can talk about what it is experiencing, people who speak with a person with a split brain are conversing with only one hemisphere: the left. The actions of the right hemisphere are more difficult to detect. Even the patient’s left hemisphere has to learn about the independent existence of the right hemisphere. One of the first things that these patients say they notice after the operation is that their left hand seems to have a “mind of its own.” For example, patients may find themselves putting down a book held in the left hand, even if they have been reading it with great interest. This conflict occurs because the right hemisphere, which controls the left hand, cannot read and therefore finds the book boring. At other times, these patients surprise themselves by making obscene gestures (with the left hand) when they do not intend to. A psychologist once reported that a man with a split brain had attempted to beat his

wife with one hand and protect her with the other. Did he *really* want to hurt her? Yes and no, I guess.

One exception to the crossed representation of sensory information is the olfactory system. That is, when a person sniffs a flower through the left nostril, only the left brain receives a sensation of the odor. Thus, if the right nostril of a patient with a split brain is closed, leaving only the left nostril open, the patient will be able to tell us what the odors are (Gordon and Sperry, 1969). However, if the odor enters the right nostril, the patient will say that he or she smells nothing. But, in fact, the right brain *has* perceived the odor and *can* identify it. To show this, we ask the patient to smell an odor with the right nostril and then reach for some objects that are hidden from view by a partition. If asked to use the left hand, controlled by the hemisphere that detected the smell, the patient will select the object that corresponds to the odor—a plastic flower for a floral odor, a toy fish for a fishy odor, a model tree for the odor of pine, and so forth. But if asked to use the right hand, the patient fails the test because the right hand is connected to the left hemisphere, which did not smell the odor. (See **Figure 1.3**.)

The effects of cutting the corpus callosum reinforce the conclusion that we become conscious of something only if information about it is able to reach the parts of the brain responsible for verbal communication, which are located in the left hemisphere. If the information does

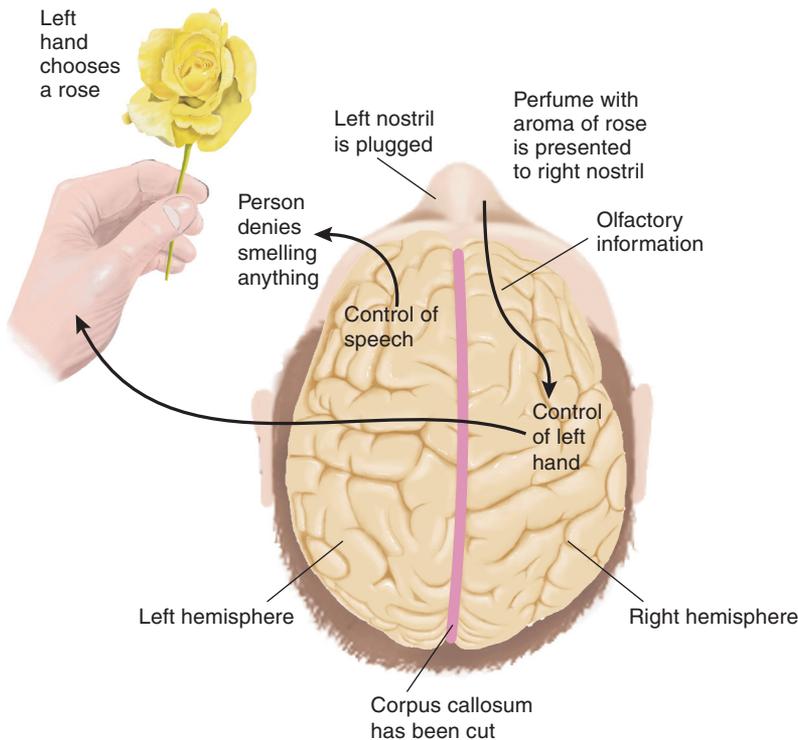


FIGURE 1.3 Smelling with a Split Brain. Identification of an object occurs in response to an olfactory stimulus by a person with a split brain.

not reach these parts of the brain, then that information does not reach the consciousness associated with these mechanisms. We still know very little about the physiology of consciousness, but studies of people with brain damage are beginning to provide us with some useful insights. This issue is discussed in later chapters.

SECTION SUMMARY

Understanding Human Consciousness: A Physiological Approach

The concept of the mind has been with us for a long time—probably from the earliest history of our species. Modern science has concluded that the world consists of matter and energy and that what we call the mind can be explained by the same laws that govern all other natural phenomena. Studies of the functions of the human nervous system tend to support this position, as the specific example of the split brain shows. Brain damage, by disconnecting brain functions from the speech mechanisms in the left hemisphere, reveals that the mind does not have direct access to all brain functions.

When sensory information about a particular object is presented only to the right hemisphere of a person who has had a split-brain operation, the person is not aware of the object but can, nevertheless, indicate by movements of the left hand that the object has been perceived. This phenomenon suggests that consciousness involves operations of the verbal mechanisms of the left hemisphere. Indeed, consciousness may be, in large part, a matter of us “talking to ourselves.” Thus, once we understand the language functions of the brain, we may have gone a long way to understanding how the brain can be conscious of its own existence.

Thought Questions

1. Could a sufficiently large and complex computer ever be programmed to be aware of itself? Suppose that someone someday claims to have done just that. What kind of evidence would you need to prove or disprove this claim?
2. Is consciousness found in animals other than humans? Is the ability of some animals to communicate with each other and with humans evidence for at least some form of awareness of self and others?
3. Clearly, the left hemisphere of a person with a split brain is conscious of the information it receives and of its own thoughts. It is not conscious of the mental processes of the right hemisphere. But is it possible that the right hemisphere is conscious too, but is just unable to talk to us? How could we possibly find out whether it is? Do you see some similarities between this issue and the one raised in the first question?

The Nature of Behavioral Neuroscience

The modern history of behavioral neuroscience has been written by psychologists who have combined the experimental methods of psychology with those of physiology and have applied them to the issues that concern all psychologists. Thus, we have studied perceptual processes, control of movement, sleep and waking, reproductive behaviors, ingestive behaviors, emotional behaviors, learning, and language. In recent years we have also begun to study the physiology of pathological conditions, such as addictions and mental disorders.

The Goals of 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. Most psychologists deal with **generalization**. They explain particular instances of behavior as examples of general laws, which they deduce from their experiments. For instance, most psychologists would explain a pathologically strong fear of dogs as an example of a particular form of learning called *classical conditioning*. Presumably, the person was frightened earlier in life by a dog. An unpleasant stimulus was paired with the sight of the animal (perhaps the person was knocked down by an exuberant dog or was attacked by a vicious one), and the subsequent sight of dogs evokes the earlier response: fear.

Most physiologists deal with **reduction**. They explain complex phenomena in terms of simpler ones. For example, they may explain the movement of a muscle in terms of the changes in the membranes of muscle cells, the entry of particular chemicals, and the interactions among protein molecules within these cells. By contrast, a molecular biologist would explain these events in terms of forces that bind various molecules together and cause various parts of the molecules to be attracted to one another. In turn, the job of an atomic physicist is to describe matter and

generalization Type of scientific explanation; a general conclusion based on many observations of similar phenomena.

reduction Type of scientific explanation; a phenomenon is described in terms of the more elementary processes that underlie it.



Studies of people with brain damage have given us insights into the brain mechanisms involved in language, perception, memory, and emotion.

Neil Carlson.

energy themselves and to account for the various forces found in nature. Practitioners of each branch of science use reduction to call on sets of more elementary generalizations to explain the phenomena they study.

The task of the behavioral neuroscientist is to explain behavior in physiological terms. But behavioral neuroscientists cannot simply be reductionists. It is not enough to observe behaviors and correlate them with physiological events that occur at the same time. Identical behaviors may occur for different reasons and thus may be initiated by different physiological mechanisms. Therefore, we must understand “psychologically” why a particular behavior occurs before we can understand what physiological events made it occur.

Let me provide a specific 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 nonpregnant mouse will build a nest only if the weather is cool, whereas a pregnant mouse will build one regardless of the temperature. The same behavior occurs for different reasons. In fact, 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.

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 both a good psychologist *and* a good physiologist.

Biological Roots of Behavioral Neuroscience

Study of (or speculations about) the physiology of behavior has its roots in antiquity. Because its movement is necessary for life, and because emotions cause it to beat more strongly, many ancient cultures, including the Egyptian, Indian, and Chinese, considered the heart to be the seat of thought and emotions. The ancient Greeks did, too, but Hippocrates (460–370 B.C.) concluded that this role should be assigned to the brain.

Not all ancient Greek scholars agreed with Hippocrates. Aristotle did not; he thought the brain served to cool the passions of the heart. But Galen (A.D. 130–200), who had the greatest respect for Aristotle, concluded that Aristotle’s role for the brain 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). Galen thought enough of the brain to dissect and study the brains of cattle, sheep, pigs, cats, dogs, weasels, monkeys, and apes (Finger, 1994).

René Descartes, a seventeenth-century French philosopher and mathematician, has been called the father of modern philosophy. Although he was not a biologist, his speculations about the roles of the mind and brain in the control of behavior provide a good starting point in the history of behavioral neuroscience. Descartes assumed that the world was a purely mechanical entity that, once having been set in motion by God, ran its course without divine interference. Thus, to understand the world, one had only to understand how it was constructed. To Descartes, animals were mechanical devices; 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** (from the Latin *reflectere*, “to bend back upon itself”). Energy coming from the outside source would be reflected back through the nervous system to the muscles, which would contract. The term is still in use today, but of course we explain the operation of a reflex differently.

reflex An automatic, stereotyped movement produced as the direct result of a stimulus.

Like most philosophers of his time, Descartes believed that each person possesses a mind—a uniquely human attribute that is 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 sense organs of the body supply the mind with information about what is happening in the environment, and that the mind, using this information, controls the body's movements. In particular, he hypothesized that the interaction between mind and body takes 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 contains hollow chambers (the *ventricles*) that are filled with fluid, and he believed that this fluid was under pressure. In his theory, when the mind decides to perform an action, it tilts the pineal body in a particular direction like a little joystick, causing pressurized fluid to flow from the brain into the appropriate set of nerves. This flow of fluid causes the same muscles to inflate and move. (See **Figure 1.4**.)

As we saw in the prologue, the young René Descartes was greatly impressed by the moving statues in the royal gardens (Jaynes, 1970). These devices served as models for Descartes in theorizing about how the body worked. The pressurized water of the moving statues was replaced by pressurized fluid in the ventricles; the pipes were replaced by nerves; the cylinders by muscles; and finally, the hidden valves by the pineal body. This story illustrates one of the first times that a technological device was used as a model for explaining how the nervous system works. In science, a **model** is a relatively simple system that works on known principles and is able to do at least some of the things that a more complex system can do. For example, when scientists discovered that elements of the nervous system communicate by means of electrical impulses, researchers developed models of the brain based upon telephone switchboards and, more recently, computers. Abstract models, which are completely mathematical in their properties, have also been developed.

Descartes's model was useful because, unlike purely philosophical speculations, it could be tested experimentally. In fact, it did not take long for biologists to prove that Descartes was wrong. Luigi Galvani, a seventeenth-century Italian physiologist, found that electrical stimulation of a frog's nerve caused contraction of the muscle to which it was attached. Contraction occurred even when the nerve and muscle were detached from the rest of the body; therefore, Galvani concluded that the muscle's ability to contract and the nerve's ability to send a message to the muscle were characteristics of these tissues themselves. Thus, 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. The results of these efforts gave rise to an accumulation of knowledge about the physiology of behavior.

One of the most important figures in the development of experimental physiology was Johannes Müller, a nineteenth-century German physiologist. (See **Figure 1.5**.) Müller was a forceful advocate of the application of experimental techniques to physiology. Previously, the activities of most natural scientists were 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?

The answer is 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.

Müller's advocacy of experimentation and the logical deductions from his doctrine of specific nerve energies set the stage for performing experiments directly on the brain. Indeed, Pierre Flourens,

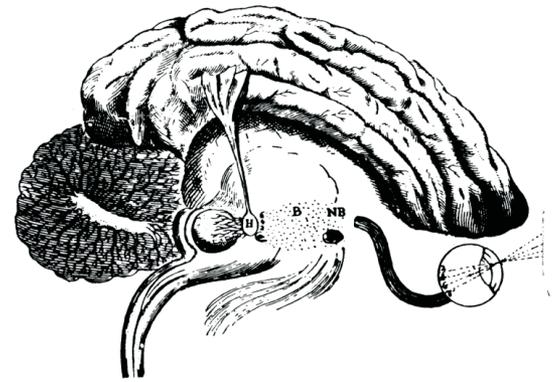


FIGURE 1.4 Descartes's Theory. This woodcut appears in *De homine* by René Descartes, which was published in 1662. Descartes believed that the “soul” (what we would today call the *mind*) controls the movements of the muscles through its influence on the pineal body. According to his theory, the eyes 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. His explanation is modeled on the mechanism that animated statues in the royal gardens near Paris.

George Bernard/Photo Researchers, Inc.



FIGURE 1.5 Johannes Müller (1801–1858).

National Library of Medicine.

model A mathematical or physical analogy for a physiological process; for example, computers have been used as models for various functions of the brain.

doctrine of specific nerve energies Müller's conclusion that because all nerve fibers carry the same type of message, sensory information must be specified by the particular nerve fibers that are active.

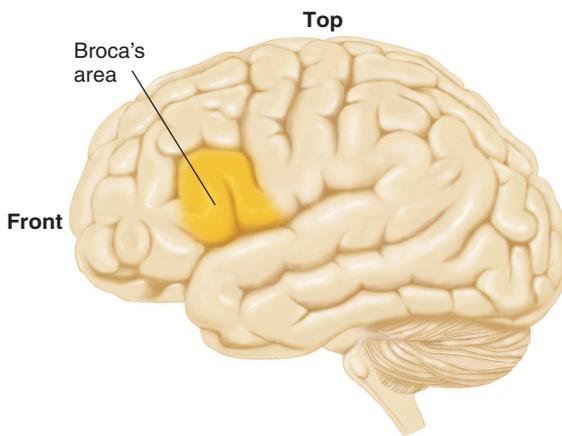


FIGURE 1.6 Broca's Area. This region of the brain is named for French surgeon Paul Broca, who discovered that damage to a part of the left side of the brain disrupted a person's ability to speak.

a nineteenth-century French physiologist, 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** (from the Latin *ablatus*, "carried away"). 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, a French surgeon, applied the principle of experimental ablation to the human brain. Of course, he did not intentionally remove parts of human brains to see how they worked. Instead, he 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 necessary for speech. (See **Figure 1.6**) Other physicians soon obtained evidence supporting his conclusions. As you will learn in Chapter 13, the control of speech is not localized in a particular region of the brain. Indeed, 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.

As I mentioned earlier, Luigi Galvani used electricity to demonstrate that muscles contain the source of the energy that powers their contractions. In 1870, German physiologists Gustav Fritsch and Eduard Hitzig 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 stimulation of different portions of a specific region of the brain caused contraction of specific muscles 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 and thus control behaviors. For example, the region that Broca found necessary for speech communicates with, and controls, the portion of the primary motor cortex that controls the muscles of the lips, tongue, and throat, which we use to speak.

One of the most brilliant contributors to nineteenth-century science was the German physicist and physiologist Hermann von Helmholtz. Helmholtz devised a mathematical formulation of the law of conservation of energy; invented the ophthalmoscope (used to examine the retina of the eye); devised an important and influential theory of color vision and color blindness; and studied audition, music, and many physiological processes. Helmholtz was also 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 ninety feet per second. This measurement proved that neural conduction was more than a simple electrical message, as we will see in Chapter 2.

Twentieth-century developments in experimental physiology include 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 see cells and their constituents. Because these developments belong to the modern era, they are discussed in detail in subsequent chapters.

experimental ablation The research method in which the function of a part of the brain is inferred by observing the behaviors an animal can no longer perform after that part is damaged.

SECTION SUMMARY

The Nature of Behavioral Neuroscience

All scientists hope to explain natural phenomena. In this context, the term *explanation* has two basic meanings: generalization and reduction. Generalization refers to the classification of phenomena according to their essential features so that general laws can be formulated. For example, observing that gravitational attraction is related to the mass of two bodies and to the distance between them

helps to explain the movement of planets. Reduction refers to the description of phenomena in terms of more basic physical processes. For example, gravitation can be explained in terms of forces and subatomic particles.

Behavioral neuroscientists use both generalization and reduction to explain behavior. In large part, generalizations use the traditional

Section Summary *(continued)*

methods of psychology. Reduction explains behaviors in terms of physiological events within the body—primarily within the nervous system. Thus, behavioral neuroscience builds upon the tradition of both experimental psychology and experimental physiology.

The behavioral neuroscience of today is rooted in important developments of the past. When René Descartes proposed a model of the brain based on hydraulically activated statues, his model stimulated observations that produced important discoveries. The results of Galvani's experiments eventually led to an understanding of the nature of the message transmitted by nerves between the brain and the sensory

organs and muscles. Müller's doctrine of specific nerve energies paved the way for study of the functions of specific parts of the brain through the methods of experimental ablation and electrical stimulation.

Thought Questions

1. What is the value of studying the history of behavioral neuroscience? Is it a waste of time?
2. Suppose we studied just the latest research and ignored explanations that we now know to be incorrect. Would we be spending our time more profitably, or might we miss something?

Natural Selection and Evolution

Following the tradition of Müller and von Helmholtz, other biologists continued to observe, classify, and think about what they saw, and some of them arrived at valuable conclusions. The most important of these scientists was Charles Darwin. (See **Figure 1.7**.) Darwin formulated the principles of *natural selection* and *evolution*, which revolutionized biology.

Functionalism and the Inheritance of Traits

Darwin's theory emphasized that all of an organism's characteristics—its structure, its coloration, its behavior—have functional significance. For example, the strong talons and sharp beaks of eagles permit them to catch and eat prey. Most 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. Obviously, the behavior itself is not inherited—how can it be? What *is* inherited is a brain that causes the behavior to occur. Thus, Darwin's theory gave rise to **functionalism**, a belief that characteristics of living organisms perform useful functions. So, to understand the physiological basis of various behaviors, we must first discover what these behaviors accomplish. We must therefore 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 a complex piece of machinery, we should know what its functions are. This principle is just as true for a living organism as it is for a mechanical device. However, an important difference exists between machines and organisms: Machines have inventors who had a purpose when they designed them, whereas organisms are the result of a long series of accidents. Thus, 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 forelimbs shown in Figure 1.8 are adapted for different uses in different species of mammals. (See **Figure 1.8**.)

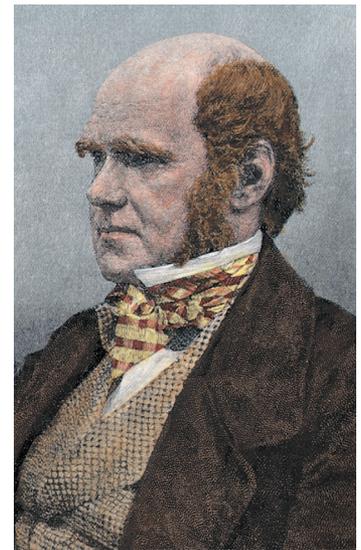


FIGURE 1.7 Charles Darwin (1809–1882). Darwin's theory of evolution revolutionized biology and strongly influenced early psychologists.

North Wind Picture Archives.

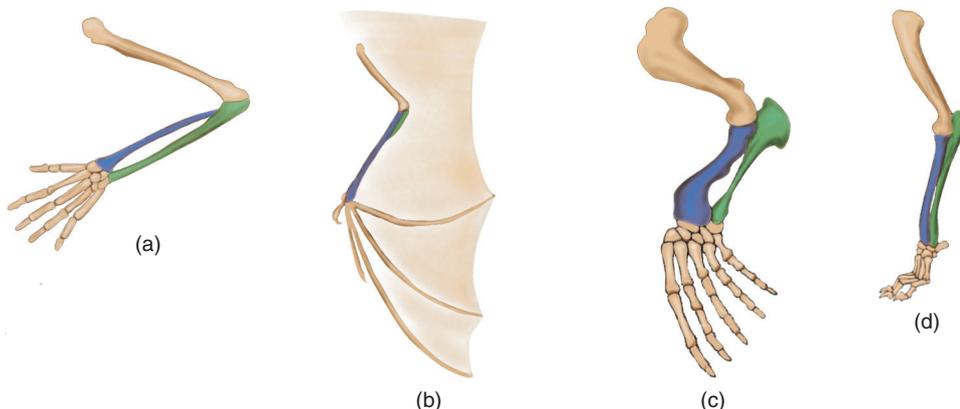


FIGURE 1.8 Bones of the Forelimb. The figure shows the bones of a (a) human, (b) bat, (c) whale, and (d) dog. Through the process of natural selection, these bones have been adapted to suit many different functions.

functionalism The principle that the best way to understand a biological phenomenon (a behavior or a physiological structure) is to try to understand its useful functions for the organism.



FIGURE 1.9 The Owl Butterfly. This butterfly displays its eyespots when approached by a bird. The bird usually will fly away.

Neil Carlson.

A good example of the functional analysis of an adaptive trait was demonstrated in an experiment by Blest (1957). Certain species of moths and butterflies have spots on their wings that resemble eyes—particularly the eyes of predators such as owls. (See **Figure 1.9**.) These insects normally rely on camouflage for protection; the backs of their wings, when folded, are colored like the bark of a tree. However, when a bird approaches, the insect’s wings flip open, and the hidden eyespots are suddenly displayed. The bird then tends to fly away, rather than eat the insect. Blest performed an experiment to see whether the eyespots on a moth’s or butterfly’s wings really disturbed birds that saw them. He placed mealworms on different backgrounds and counted how many worms the birds ate. Indeed, when the worms were placed on a background that contained eyespots, the birds tended to avoid them.

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. Of course, it was the natural environment, not the hand of the animal breeder, that shaped the process of evolution.

To *evolve* means to develop gradually (from the Latin *evolvere*, “to unroll”). The process of **evolution** is a gradual change in the structure and physiology of plant and animal 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.

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 prenatal development) of a particular member of a particular species. If the plans are altered, a different organism is produced.

The plans do get altered; mutations occur from time to time. **Mutations** are accidental changes in the chromosomes of sperms or eggs that join together and develop into new organisms. For example, cosmic radiation might strike a chromosome in a cell of an animal’s testis or ovary, thus producing a mutation that affects that animal’s offspring. Most mutations are deleterious; the offspring either fails to survive or survives with some sort of defect. However, a small percentage of mutations are beneficial and confer a **selective advantage** to the organism that possesses them. That is, the animal is more likely than other members of its species to live long enough to reproduce and hence to 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 members of the other sex (after all, one must reproduce in order to pass on one’s chromosomes).

Naturally, 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. Thus, 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 stop moving and freeze when it perceives a novel stimulus, 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, thus passing on its genes 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.

natural selection The process by which inherited traits that confer a selective advantage (increase an animal’s likelihood to live and reproduce) become more prevalent in the population.

evolution A gradual change in the structure and physiology of plant and animal species—generally producing more complex organisms—as a result of natural selection.

mutation A change in the genetic information contained in the chromosomes of sperms or eggs, which can be passed on to an organism’s offspring; provides genetic variability.

selective advantage A characteristic of an organism that permits it to produce more than the average number of offspring of its 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 that permit them to adapt to the new environment, their offspring will survive, and the species will continue.

Evolution of the Human Brain

Our early human ancestors possessed several characteristics that enabled 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, game animals, and dangerous predators. Their mastery of fire enabled them to cook food, provide warmth, and frighten nocturnal predators. Their upright posture and bipedalism (the ability to walk on two feet) 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 larger brain.

A large brain requires a large skull, and an upright posture limits the size of a woman's birth canal. A newborn baby's head is about as large as it can be. As it is, the birth of a baby is much more arduous than the birth of mammals with proportionally smaller heads, including those of our closest primate relatives. Because a baby's brain is not large or complex enough to perform the physical and intellectual abilities of an adult, it 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 (and, 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 nerve cells that performed specialized tasks. Instead, it could simply produce a larger 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, of course (for example, those involved in analyzing the complex sounds we use for speech), but by and large, the brain is a general-purpose, programmable computer.

Our closest living relatives—the only present-day hominids (humanlike apes) besides ourselves—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 98.8 percent of their DNA. (See *Figure 1.10*.)

What types of genetic changes are required to produce a larger brain? This question will be addressed in more detail in Chapter 3, but the most important principle appears to be a slowing of the process of maturation, 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 weighing an average of 350 g and containing approximately 100 billion neurons. 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; other types of brain cells, which protect and support neurons, then begin to proliferate. Not until late adolescence does the human brain reach its adult size of approximately 1400 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 1.11* shows fetal and adult skulls of chimpanzees and humans. As you can see, the fetal skulls are much more similar than those of the adults. The grid lines show the pattern of growth, indicating much less change in the human skull from birth to adulthood. (See *Figure 1.11*.)

neoteny A slowing of the process of maturation, allowing more time for growth; an important factor in the development of large brains.

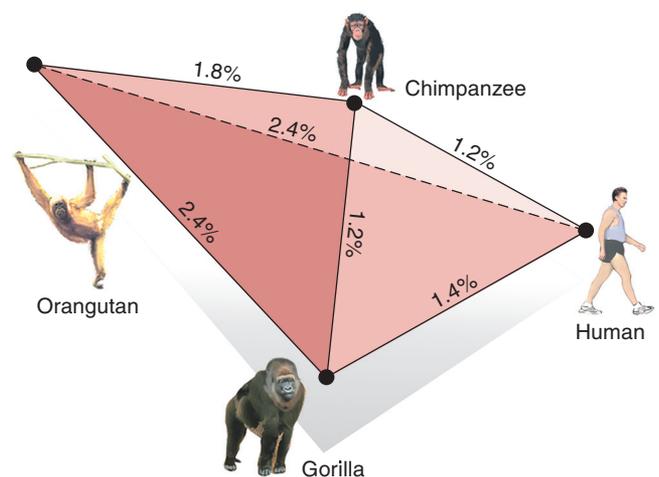


FIGURE 1.10 DNA Among Species of Hominids. A pyramid illustrating the percentage differences in DNA among the four major species of hominids.

Redrawn from Lewin, R. *Human Evolution: An Illustrated Introduction*. Boston: Blackwell Scientific Publications, 1993.

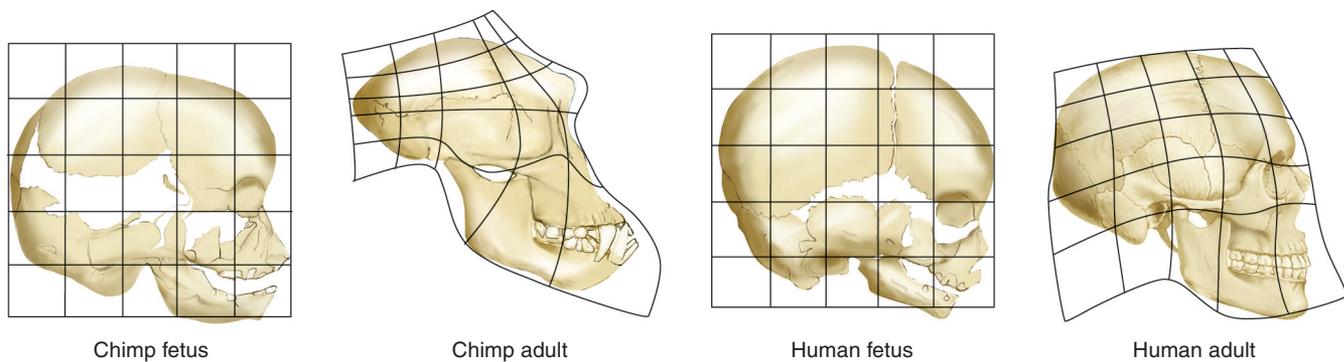


FIGURE 1.11 Neoteny in Evolution of the Human Skull. The skulls of fetal humans and chimpanzees are much more similar than are those of the adults. The grid lines show the pattern of growth, indicating much less change in the human skull from birth to adulthood.

Redrawn from Lewin, R. *Human Evolution: An Illustrated Introduction*, 3rd ed. Boston: Blackwell Scientific Publications, 1993.

SECTION SUMMARY

Natural Selection and Evolution

Darwin's theory of evolution, which was based on the concept of natural selection, provided an important contribution to modern behavioral neuroscience. The theory asserts that we must understand the functions performed by an organ or body part or by a behavior. Through random mutations, changes in an individual's genetic material cause different proteins to be produced, which results in the alteration of some physical characteristics. If the changes confer a selective advantage on the individual, the new genes will be transmitted to more and more members of the species. Even behaviors can evolve, through the selective advantage of alterations in the structure of the nervous system.

The evolution of large brains made possible the development of toolmaking, fire building, and language, which in turn permitted the development of complex social structures. Large brains also provided a large memory capacity and the abilities to recognize patterns of events in the past and to plan for the future. Because an upright posture limits the size of a woman's birth canal and therefore the size of the head that passes through it, much of the brain's growth must take place after birth,

which means that children require an extended period of parental care. This period of apprenticeship enables the developing brain to be modified by experience.

Although human DNA differs from that of chimpanzees by only 1.2 percent, our brains are more than three times larger, which means that a small number of genes is responsible for the increase in the size of our brains. These genes appear to retard the events that stop brain development, resulting in a phenomenon known as neoteny.

Thought Questions

1. What useful functions are provided by the fact that a human can be self-aware? How was this trait selected for during the evolution of our species?
2. Are you surprised that the difference in the DNA of humans and chimpanzees is only 1.2 percent? How do you feel about this fact?
3. If our species continues to evolve (and most geneticists believe that this is the case), what kinds of changes do you think might occur?

Ethical Issues in Research with Animals

Most 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. I believe that a good case can be made that research on the physiology of behavior 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 very strict regulations about the care of animals and require approval of the experimental procedures used on them. There is no excuse for mistreating animals in our care. In fact, the vast majority of laboratory animals *are* treated humanely.

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.

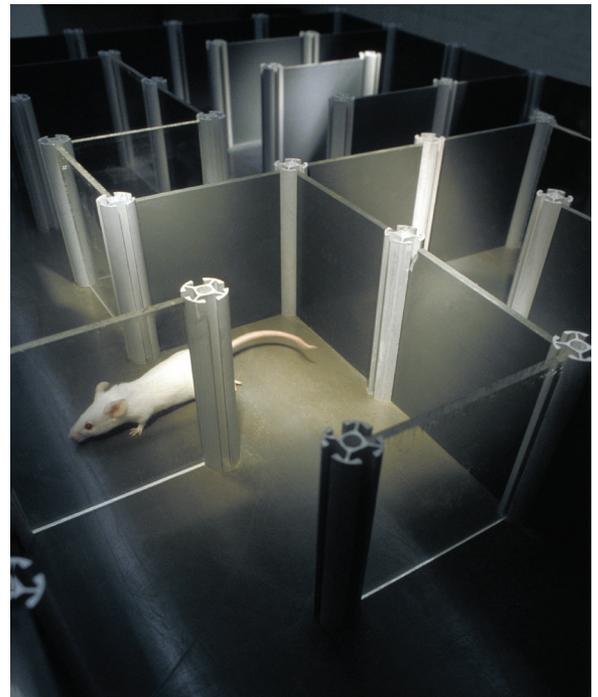
Pet owning causes much more suffering among animals than scientific research does. As Miller (1983) notes, pet owners are not required to receive permission from a board of experts that includes a veterinarian to house their pets, nor are they subject to periodic inspections to be sure that their homes are clean and sanitary, that their pets have enough space to exercise properly, or that their pets' diets are appropriate. Scientific researchers are. Miller also notes that fifty times more dogs and cats are killed by humane societies each year because they have been abandoned by former pet owners than are used in scientific research.

If a person believes that it is wrong to use another animal in any way, regardless of the benefits to humans, there is nothing anyone can say to convince him or her of the value of scientific research with animals. For this person the issue is closed from the very beginning. Moral absolutes cannot be settled logically; like religious beliefs, they can be accepted or rejected, but they cannot be proved or disproved. My arguments in support of scientific research with animals are based on an evaluation of the benefits the research has to humans. (We should also remember that research with animals often helps *other animals*; procedures used by veterinarians, as well as those used by physicians, come from such research.)

Before describing the advantages of research with animals, let me point out that the use of animals in research and teaching is a special target of animal rights activists. Nicholl and Russell (1990) examined twenty-one books written by such activists and counted the number of pages devoted to concern for different uses of animals. Next, they compared the relative concern the authors showed for these uses to the numbers of animals actually involved in each of these categories. The results indicate that the authors showed relatively little concern for animals used for food, hunting, or furs, or for those killed in pounds. In contrast, although only 0.3 percent of the animals were used for research and education, 63.3 percent of the pages were devoted to criticizing this use. In terms of pages per million animals used, the authors devoted 0.08 to food, 0.23 to hunting, 1.27 to furs, 1.44 to killing in pounds—and 53.2 to research and education. The authors showed 665 times more concern for research and education than for food and 231 times more than for hunting. Even the use of animals for furs (which consumes two-thirds as many animals as research and education) attracted 41.9 times less attention per animal.

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 our scientists will probably have developed vaccines that will prevent the further spread of diseases such as malaria and AIDS. Some animal rights activists believe that preventing the deaths of laboratory animals in the pursuit of such vaccines is a more worthy goal than preventing the deaths of millions of humans that will occur as a result of these diseases if vaccines are not developed. Even diseases that we have already conquered would take new victims if drug companies could no longer use animals. If they were deprived of animals, these companies could no longer extract some of the hormones used to treat human diseases, and they could not prepare many of the vaccines that we now use to prevent them.

Our species is beset by medical, mental, and behavioral problems, many of which can be solved only through biological research. Let us consider some of the major neurological disorders. Strokes, caused by bleeding or obstruction of a blood vessel within the brain, often leave people partially paralyzed, unable to read, write, or converse with their friends and family. Basic 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.



Unlike pet owners, scientists who use animals in their research must follow stringent regulations designed to ensure that the animals are properly cared for.

Patrick Landmann/Science Source/Photo Researchers, Inc.

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, manic-depressive illness, anxiety disorders, obsessive-compulsive disorders, anorexia nervosa, obesity, and drug addictions. Although much progress has been made, these problems are still with us, and they cause much human suffering. Unless we continue our research with laboratory animals, the problems will not be solved. Some people have suggested that instead of using laboratory animals in our research, we could use tissue cultures or computers. Unfortunately, neither tissue cultures nor computers are substitutes for living organisms. We have no way to study behavioral problems such as addictions 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 that we already had all the answers.)

The easiest way to justify research with animals is to point to actual and potential benefits to human health, as I have just done. However, we can also justify this research with a less practical, but perhaps equally important, argument. One of the things that characterize our species is a quest for an understanding of our world. For example, astronomers study the universe and try to uncover its mysteries. Even if their discoveries never lead to practical benefits such as better drugs or faster methods of transportation, the fact that they enrich our understanding of the beginning and the fate of our universe justifies their efforts. The pursuit of knowledge is itself a worthwhile endeavor. Surely, the attempt to understand the universe within us—our nervous system, which is responsible for all that we are or can be—is also valuable.

Careers in Neuroscience

What is behavioral neuroscience, and what do behavioral neuroscientists do? By the time you finish this book, you will have as complete an answer as I can give to these questions, but perhaps it is worthwhile for me to describe the field and careers that are open to those who specialize in it before we begin our study in earnest.

Behavioral neuroscientists study all behavioral phenomena that can be observed in nonhuman animals. They attempt to understand the physiology of behavior: the nervous system's role, through interacting with the rest of the body (especially the endocrine system, which secretes hormones), in controlling behavior. They study such topics as sensory processes, sleep, emotional behavior, ingestive behavior, aggressive behavior, sexual behavior, parental behavior, and learning and memory. They also study animal models of disorders that afflict humans, such as anxiety, depression, obsessions and compulsions, phobias, psychosomatic illnesses, and schizophrenia.

Although the original name for the field described in this book was *physiological psychology*, several other terms are now in general use, such as *biological psychology*, *biopsychology*, *psychobiology*, and—the most common one—*behavioral neuroscience*. Most professional behavioral neuroscientists have received a Ph.D. from a graduate program in psychology or from an interdisciplinary program. (My own university awards a Ph.D. in neuroscience and behavior. The program includes faculty members from the departments of psychology, biology, biochemistry, and computer science.)

Behavioral neuroscience belongs to a larger field that is simply called *neuroscience*. Neuroscientists concern themselves with all aspects of the nervous system: its anatomy, chemistry, physiology, development, and functioning. The research of neuroscientists ranges from the study of molecular genetics to the study of social behavior. The field has grown enormously in the last few years; the membership of the Society for Neuroscience is currently over thirty-eight thousand.

Most professional behavioral neuroscientists are employed by colleges and universities, where they are engaged in teaching and research. Others are employed by institutions devoted to research—for example, laboratories owned and operated by national governments or by private philanthropic organizations. A few work in industry, usually for pharmaceutical companies that are interested in assessing the effects of drugs on behavior. To become a professor or independent researcher, one must receive a doctorate—usually a Ph.D., although some people turn to research after receiving an M.D. Nowadays, most behavioral neuroscientists spend two years in a temporary postdoctoral position, working in the laboratory of a senior scientist to gain more research experience. During this time, they write articles describing their research findings and submit them for publication in scientific journals. These articles and the publications they appear in are important factors in obtaining a permanent position.

behavioral neuroscientist (Also called *physiological psychologist*) A scientist who studies the physiology of behavior, primarily by performing physiological and behavioral experiments with laboratory animals.

Two other fields often overlap with behavioral neuroscience: *neurology* and *cognitive neuroscience*. Neurologists are physicians who are involved in the diagnosis and treatment of diseases of the nervous system. Most neurologists are solely involved in the practice of medicine, but a few engage in research devoted to advancing our understanding of the physiology of behavior. They study the behavior of people whose brains have been damaged by natural causes, using advanced brain-scanning devices to study the activity of various regions of the brain as a subject participates in various behaviors. This research is also carried out by cognitive neuroscientists—scientists with a Ph.D. and specialized training in the principles and procedures of neurology.

Not all people who are engaged in neuroscience research have doctoral degrees. Many research technicians perform essential—and intellectually rewarding—services for the scientists with whom they work. Some of these technicians gain enough experience and education on the job to enable them to collaborate with their employers on their research projects rather than simply work for them.

SECTION SUMMARY

Ethical Issues in Research with Animals and Careers in Neuroscience

Research on the physiology of behavior necessarily involves the use of laboratory animals. It is incumbent on all scientists using these animals to see that they are housed comfortably and treated humanely, and laws have been enacted to ensure that they are. Such research has already produced many benefits to humankind and promises to continue to do so.

Behavioral neuroscience (originally called physiological psychology and also called biological psychology, biopsychology, and psychobiology) is a field devoted to our understanding of the physiology of behavior. Behavioral neuroscientists are allied with other scientists in the

broader field of neuroscience. To pursue a career in behavioral neuroscience (or in the sister field of cognitive neuroscience), one must obtain a graduate degree and (usually) serve two years or more as a “postdoc”—a scientist working in the laboratory of an established scientist.

Thought Question

1. Why do you think some people are apparently more upset about using animals for research and teaching than about using them for other purposes?

Strategies for Learning

The brain is a complicated organ. After all, it is responsible for all our abilities and all our complexities. Scientists have been studying this organ for a good many years and (especially in recent years) have been learning a lot about how it works. It is impossible to summarize this progress in a few simple sentences; therefore, this book contains a lot of information. I have tried to organize this information logically, telling you what you need to know in the order you need to know it. (After all, to understand some things, you need to understand other things first.) I have also tried to write as clearly as possible, making my examples as simple and as vivid as I can. Still, you cannot expect to master the information in this book by simply giving it a passive read; you will have to do some work.

Learning about the physiology of behavior involves much more than memorizing facts. Of course, there *are* facts to be memorized: names of parts of the nervous system, names of chemicals and drugs, scientific terms for particular phenomena and procedures used to investigate them, and so on. But the quest for information is nowhere near completed; we know only a small fraction of what we have to learn. And almost certainly, many of the “facts” that we now accept will someday be shown to be incorrect. If all you do is learn facts, where will you be when these facts are revised?

The antidote to obsolescence is knowledge of the process by which facts are obtained. Scientific facts are the conclusions that scientists make about their observations. If you learn only the conclusions, obsolescence is almost guaranteed. You will have to remember which conclusions are overturned and what the new conclusions are, and that kind of rote learning is hard to do. But if you learn about the research strategies the scientists use, the observations they make, and the reasoning that leads to the conclusions, you will develop an understanding that is easily revised

when new observations are made and new “facts” emerge. If you understand what lies behind the conclusions, then you can incorporate new information into what you already know and revise these conclusions yourself.

In recognition of these realities about learning, knowledge, and the scientific method, this book presents not just a collection of facts, but also a description of the procedures, experiments, and logical reasoning that scientists have used in their attempt to understand the physiology of behavior. If, in the interest of expediency, you focus on the conclusions and ignore the process that leads to them, you run the risk of acquiring information that will quickly become obsolete. On the other hand, if you try to understand the experiments and see how the conclusions follow from the results, you will acquire knowledge that lives and grows.

Now let me offer some practical advice about studying. You have been studying throughout your academic career, and you have undoubtedly learned some useful strategies along the way. Even if you have developed efficient and effective study skills, at least consider the possibility that there might be some ways to improve them.

If possible, the first reading of the assignment should be as uninterrupted as you can make it; that is, read the chapter without worrying much about remembering details. Next, after the first class meeting devoted to the topic, read the assignment again in earnest. Use a pen or pencil as you go, making notes. *Don't use a highlighter.* Sweeping the felt tip of a highlighter across some words on a page provides some instant gratification; you can even imagine that the highlighted words are somehow being transferred to your knowledge base. You have selected what is important, and when you review the reading assignment you have only to read the highlighted words. But this is an illusion.

Be active, not passive. Force yourself to write down whole words and phrases. The act of putting the information into your own words will not only give you something to study shortly before the next exam but also put something into your head (which is helpful at exam time). Using a highlighter puts off the learning until a later date; rephrasing the information in your own words starts the learning process *right then*.

Before you begin reading the next chapter, let me say a few things about the design of the book that might help you with your studies. The text and illustrations are integrated as closely as possible. In my experience, one of the most annoying aspects of reading some books is not knowing when to look at an illustration. Therefore, in this book you will find figure references in boldfaced italics (like this: **Figure 5.6**), which means “stop reading and look at the figure.” These references appear in locations I think will be optimal. If you look away from the text then, you will be assured that you will not be interrupting a line of reasoning in a crucial place and will not have to reread several sentences to get going again. You will find sections like this: “Figure 4.1 shows an alligator and a human. This alligator is certainly laid out in a linear fashion; we can draw a straight line that starts between its eyes and continues down the center of its spinal cord. (See **Figure 4.1**.)” This particular example is a trivial one and will give you no problems no matter when you look at the figure. But in other cases the material is more complex, and you will have less trouble if you know what to look for before you stop reading and examine the illustration.

You will notice that some words in the text are *italicized* and others are printed in **boldface**. Italic type means one of two things: Either the word is being stressed for emphasis and is not a new term, or I am pointing out a new term that you probably do not need to learn. On the other hand, a word in boldface is a new term that you should try to learn. Most of the boldfaced terms in the text are part of the vocabulary of behavioral neuroscience. Often, they will be used again in a later chapter. As an aid to your studying, definitions of these terms are printed in the margin of the page, along with pronunciation guides for those terms whose pronunciation is not obvious. In addition, a comprehensive index at the end of the book provides a list of terms and topics, with page references.

At the end of each major section (there are usually three to five of them in a chapter) you will find a *Section Summary*, which provides a place for you to stop and think again about what you have just read to make sure that you understand the direction in which the discussion has gone. Many section summaries are followed by some thought questions, which may serve to stimulate your thoughts about what you have learned and apply them to questions that have not yet been answered. Taken together, these sections provide a detailed summary of the information introduced in the chapter. My students tell me that they review the interim summaries just before taking a test.

Okay, the preliminaries are over. The next chapter starts with something you can sink your (metaphorical) teeth into: the structure and functions of neurons, the most important elements of the nervous system.

EPILOGUE | Models of Brain Functions

René Descartes had no way to study the operations of the nervous system. He did, however, understand how the statues in the royal gardens at Saint-Germain were powered and controlled, which led him to view the body as a complicated piece of plumbing. Many scientists have followed Descartes's example, using technological devices that were fashionable at the time to explain how the brain worked.

What motivates people to use artificial devices to explain the workings of the brain? The most important reason, I suppose, is that the brain is enormously complicated. Even the most complex human inventions are many times simpler than the brain, and because they have been designed and made by people, people can understand them. If an artificial device can do some of the things that the brain does, then perhaps both the brain and the device accomplish their tasks in the same way.

Most models of brain function developed in the last half of the twentieth century have been based on the modern, general-purpose digital computer. Actually, they have been based not on the computers themselves but on computer *programs*. Computers can be programmed to store any kind of information that can be coded in numbers or words, can solve any logical problem that can be explicitly described, and can compute any mathematical equations that can be written. Therefore, in principle at least, they can be programmed to do the things we do: perceive, remember, make deductions, and solve problems.

The construction of computer programs that simulate human brain functions can help to clarify the nature of these functions. For instance, to construct a program and simulate, say, perception and classification of certain types of patterns, the investigator is forced to specify precisely what is required by the task of pattern perception. If the program fails to recognize the patterns, then the investigator knows that something is wrong with the model or with the way it has been implemented in the program. The investigator revises the model, tries again, and keeps working until it finally works (or until he or she gives up the task as being too ambitious).

Ideally, this task tells the investigator the kinds of processes the brain must perform. However, there is usually more than one way to accomplish a particular goal; critics of computer modeling have pointed out that it is possible to write a program that performs a task that the human brain performs and comes up with exactly the same results but does the task in an entirely different way. In fact,

some say, given the way that computers work and what we know about the structure of the human brain, the computer program is *guaranteed* to work differently.

When we base a model of brain functions on a physical device with which we are familiar, we enjoy the advantage of being able to think concretely about something that is difficult to observe. However, if the brain does not work like a computer, then our models will not tell us very much about the brain. Such models are *constrained* ("restricted") by the computer metaphor; they will be able to do things only the way that computers can do them. If the brain can actually do some different sorts of things that computers cannot do, the models will never contain these features.

In fact, computers and brains are fundamentally different. Modern computers are *serial devices*; they work one step at a time. (*Serial*, from the Latin *serere* "to join," refers to events that occur in order, one after the other.) Programs consist of a set of instructions stored in the computer's memory. The computer follows these instructions, one at a time. Because each of these steps takes time, a complicated program will take more time to execute. But we do some things extremely quickly that computers take a very long time to do. The best example is visual perception. We can recognize a complex figure about as quickly as a simple one; for example, it takes about the same amount of time to recognize a friend's face as it does to identify a simple triangle. The same is not true at all for a serial computer. A computer must "examine" the scene through an input device like a video camera. Information about the brightness of each point of the picture must be converted into a number and stored in a memory location. Then the program examines each memory location, one at a time, and does calculations that determine the locations of lines, edges, textures, and shapes; finally, it tries to determine what these shapes represent. Recognizing a face takes *much* longer than recognizing a triangle.

Unlike serial computers, the brain is a *parallel processor*, in which many different modules (collections of circuits of neurons) work simultaneously at different tasks. A complex task is broken down into many smaller ones, and separate modules work on each of them. Because the brain consists of many billions of neurons, it can afford to devote different clusters of neurons to different tasks. With so many things happening at the same time, the task gets done quickly.



KEY CONCEPTS

UNDERSTANDING HUMAN CONSCIOUSNESS: A PHYSIOLOGICAL APPROACH

1. Behavioral neuroscientists believe that the mind is a function performed by the brain.
2. The study of human brain functions has helped us gain some insight into the nature of human consciousness, which appears to be related to the language functions of the brain. This chapter described one example, the effects of the split-brain operation.

THE NATURE OF BEHAVIORAL NEUROSCIENCE

3. Scientists attempt to explain natural phenomena by means of generalization and reduction. Because behavioral neuroscientists use the methods of psychology and physiology, they employ both types of explanations.
4. Descartes developed the first model to explain how the brain controls movement, based on the animated statues in the royal gardens. Subsequently, investigators tested their ideas with scientific experiments.

NATURAL SELECTION AND EVOLUTION

5. Darwin's theory of evolution, with its emphasis on function, helps behavioral neuroscientists discover the relations between brain mechanisms, behaviors, and an organism's adaptation to its environment.

6. We owe our status as the dominant species to our bipedal stance, our agile hands, our excellent vision, and the behavioral and cognitive abilities provided by our large, complex brains, which enable us to adapt to a wide variety of environments, exploit a wide variety of resources, and, with the development of language, form large, complex communities.

ETHICAL ISSUES IN RESEARCH WITH ANIMALS

7. Scientific research with animals has taught us most of what we know about the functions of the body, including that of the nervous system. This knowledge is essential in developing ways to prevent and treat neurological and mental disorders.

CAREERS IN NEUROSCIENCE

8. Behavioral neuroscientists study the physiology of behavior by performing research with animals. They use the research methods and findings of other neuroscientists in pursuit of their particular interests.

EXPLORE the Virtual Brain in MyPsychLab

The Virtual Brain is an interactive application in MyPsychLab. It contains a series of modules that cover the different subjects you will encounter in your course. Each module contains a tour of relevant neuroanatomy, physiological animations that help students visualize complex processes, case studies that connect biology to behavior, and assessments that allow you to review your understanding. The Brain is also available as a web application for iPad. Look for references to the Virtual Brain at the end of each chapter!

