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1 Behavioral Neuroscience

Understanding Brain-Behavior Relationships

Chapter Contents

Learning Objectives

1.1.1 Know and understand what constitutes the study of brain-behavior relationships.

1.1.2 Have a broad understanding of the global structural aspects of the brain and some of its basic functions.

1.1.3 Explain the different levels of analysis that constitute the study of brain-behavior relationships.

1.1.4 Understand the basics of how genes influence behavior and how the environment influences genes.

1.2.1 Explain the concept of natural selection.

1.2.2 Understand the adaptive variations that gave rise to brain-behavior relationships.

1.3.1 Describe some of the views associated with brain function throughout antiquity.

1.3.2 Explain the philosophical roots that underlie the relationship between brain and body.

1.3.3 Understand how the idea that brain functions are localized to specific areas developed.

1.4.1 Explain how the study of brain-damaged patients can inform neuroscientists about brain-behavior relationships.

1.4.2 Describe how brain-behavior relationships can be inferred by lesioning, stimulating, and measuring the brain's activity.

1.4.3 Define the different fields of study related to behavioral neuroscience.

Brain-Behavior Relationships: From Holes in the Head to Brain Imaging

In the 1860s, American diplomat, archeologist, collector, and popular writer Ephraim George Squier (1821–1888) was shown an ancient skull. The skull was discovered at an ancient Inca burial site in Peru. One notable peculiarity of the skull was a large rectangular-shaped hole located near its front and on its top. Squier took the skull as evidence that the ancient Peruvians performed some type of brain surgery. Over the years, many more such skulls, dating back to the time of the Inca empire (1400–1532), and much earlier (800–100 B.C.E.), have been discovered on the coast of Peru. A slew of similar skulls have also been found at sites around the world. What is intriguing about those skulls is that the holes in them show signs of healing. This means that the holes were not inflicted during battle and were not meant to kill. Rather, the holes seemed to have been made purposely by the scraping, drilling, or boring of the skull bone, a procedure known as trepanation. Some of the skulls even showed evidence of postoperative treatments, such as the holes being covered with plaques made of metal or bone. Why did ancient civilizations practice trepanation? Several theories have been proposed in an attempt to answer this question. On the one hand, the holes may have been bored for spiritual reasons. For example, discs made of cranial bones may have been believed to ward off demons. The holes may also have been bored into the skulls to permit the release of spirits thought to cause mental illness. On the other hand, trepanation may have served some therapeutic purpose. For example, it may have been used in the treatment of seizures, headaches, diseases, and skull fractures. Trepanation was also used in ancient Greece and Rome. For example, Greek physician Hippocrates (460–370 B.C.E.) used trepanation to release intracranial pressure due to the swelling of the brain following injury. Galen (130–210 C.E.), physician to the gladiators, refined the technique.

Today, trepanation or, as it is commonly called, craniotomy is used to gain access to the brain in the treatment of various conditions such as epilepsy, aneurysms, or the removal of tumors. Modern craniotomy procedures bear little resemblance to their ancient counterparts. They can be performed under the guidance of computers and imaging methods so that the hole is drilled at a precise location over the brain area in need of treatment. A brain area can even be examined by drilling a small hole into the skull through which a lighted scope with a camera is inserted. In addition, brain-behavior relationships can be inferred by brain imaging methods that permit neuroscientists to observe the brain's activity while an individual is performing a task, and behaviors can be elicited by electrically stimulating the brain.

INTRODUCTION

In this chapter, you will be introduced to the study of brain-behavior relationships, also known as behavioral neuroscience. After having defined and explored some of the branches of behavioral neuroscience, you will get a quick tour of the brain, including its main structures and the specialized cells of which it is composed. Brain-behavior relationships can be better understood if they are studied from multiple perspectives. Therefore, neuroscientists study brain-behavior relationships from the perspectives of interacting molecules within brain cells, the functioning of brain cells themselves, and the interaction between systems in the brain, cognition, and social behavior. Brain-behavior relationships can also be understood as the outcome of an evolutionary process that resulted in adaptations that permit animals to survive in their environments. Finally, understanding the progress made in the quest to learn about brain-behavior relationships requires you to look at some of the major figures and discoveries throughout the history of neuroscience. We will survey these main historical figures and discoveries, followed by the methods used to study brain-behavior relationships today. You will also learn about the different fields of study that are related to behavioral neuroscience, as well as some of the fields that benefit from behavioral neuroscience research findings.

1.1 What Is Behavioral Neuroscience?

Module Contents

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1.1.1 THE STUDY OF BRAIN-BEHAVIOR RELATIONSHIPS

>> LO 1.1.1 Know and understand what constitutes the study of brain-behavior relationships.

Key Terms

- **Behavioral neuroscience:** The scientific study of how brain activity influences behavior.
- **Overt behavior:** Behavior that is readily observable such as reaching out for a cup of coffee.
- **Covert behavior:** Behavior that cannot readily be observed, such as thinking, remembering, paying attention, experiencing emotions, and a range of others.
- **Cognitive neuroscience:** A branch of behavioral neuroscience that focuses on the processes within the brain that are associated with cognitive functions such as reasoning, problem solving, memory, and attention.
- **Affective neuroscience:** A branch of behavioral neuroscience in which researchers focus on the neurobiological processes that underlie emotions.
- **Social neuroscience:** A branch of behavioral neuroscience that focuses on the neurobiological processes of social behaviors such as those involved in empathy, affiliation, and morality.
- **Decision neuroscience:** A branch of behavioral neuroscience that focuses on the neurobiological basis of choice behavior; sometimes known as neuroeconomics.
- **Teratogens:** Factors that can cause malformations of the embryo.
- **Fetal alcohol spectrum disorders (FASDs):** A group of disorders associated with a mother drinking alcohol during pregnancy, which affects the development of the baby; characterized by abnormal facial features, short height, low body weight, low intelligence, and behavioral problems.

Behavioral neuroscience is the scientific study of how brain activity influences behavior. The study of behavioral neuroscience includes the study of how the brain is involved in both overt and covert behavior. **Overt behavior** refers to readily observable behavior such

FIGURE 1.1

The woman on the left is engaged in covert behavior. That is, she may be remembering, deciding, or planning. However, it is difficult to infer what is going on inside her mind by examining her overt behavior (sitting at home seemingly looking outside a window). By contrast, the woman on the right is engaged in overt behavior for which what she is covertly experiencing can more easily be inferred.

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as reaching out to grab a cup of freshly brewed coffee, behaving aggressively, or bursting out in laughter. **Covert behavior** refers to behavior that cannot readily be observed, such as remembering, experiencing emotions, dreaming, lying, reading silently, and a range of others (Figure 1.1). Of course, overt behaviors often inform us about covert behavior, such as when we infer that someone is thinking about a sad event (covert) when crying (overt) or that someone is remembering what was studied (covert) while taking an exam (overt).

Behavioral neuroscientists—the scientists who study brain-behavior relationships—may sometimes be more specific about what they study. For example, in **cognitive neuroscience**, the focus of study is on the processes within the brain that are associated with cognitive functions such as reasoning, problem solving, memory, and attention (Baars & Gage, 2010). In **affective neuroscience**, researchers focus on brain processes associated with the experience and expression of emotions (Dalgleish, 2004). In **social neuroscience**, researchers are interested in the brain processes involved in socially based functions such as empathy, affiliation, and morality (Decety & Keenan, 2006). Behavioral neuroscientists may also be interested in the brain processes involved in choice behavior, in what is known as **decision neuroscience**, sometimes called neuroeconomics (Doya, 2008).

The Importance of Environment and Experience

Behavioral neuroscientists are aware that behavior is influenced by environmental factors and life experiences. For example, expressing and experiencing fear requires both changes occurring in the brain and a situation perceived as a threat. Environmental factors also influence normal brain development. For example, stimulation of the senses is required for the normal development of brain areas that process sensory information.

A slew of environmental factors can adversely affect brain development. Some of these factors may take the form of substances (various chemicals or drugs) known as **teratogens** that can potentially cause birth defects. For example, a woman who consumes alcohol while pregnant puts her developing baby at risk for **fetal alcohol spectrum disorders (FASDs)**. Babies born with FASDs have varying degrees of abnormal facial features, short height, low body weight, low intelligence, and behavioral problems (Figure 1.2) (Wilhoit, Scott, & Simecka, 2017). Sadly, an estimated 1 in 100 babies in the United States is born with features of FASDs, the most preventable cause of developmental disabilities and birth defects (Lyons, 2016). See the "It's a Myth!" feature in Chapter 5 for more on this topic.

FIGURE 1.2

A child with FASD, which is characterized by abnormal facial features as well as short height and low body weight. FASD is also associated with low intelligence and behavioral problems.

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1.1.2 A QUICK LOOK AT THE BRAIN

>> LO 1.1.2 Have a broad understanding of the global structural aspects of the brain and some of its basic functions.

Key Terms

- **Lateral view:** The surface of the brain as viewed from one of its sides.
- **Cortex:** The outermost layer of the brain.
- **Lobes:** Anatomical subdivisions of the brain.
- **Gyri:** Ridges (or bumps) on the surface of the cortex.
- **Sulci:** Grooves that separate the gyri.
- **Fissures:** Large grooves that can be used to delineate cortical areas.
- **Sylvian fissure:** The fissure that separates the frontal lobe from the temporal lobe.
- **Superior view:** The brain as viewed from the top.
- **Hemispheres:** The two halves of the brain.
- **Sagittal view:** A lateral view of the brain with one of the hemispheres missing.
- **Corpus callosum:** The thick bundle of fibers that connect the two hemispheres, permitting them to communicate with each other.
- **Inferior view:** The brain as viewed from the bottom.
- **Neurons:** Cells that perform the major computational functions of the nervous system.
- **Glia:** Cells that support neuronal function and clear debris, toxins, and bacteria from the brain.

General Structure and Views of the Brain

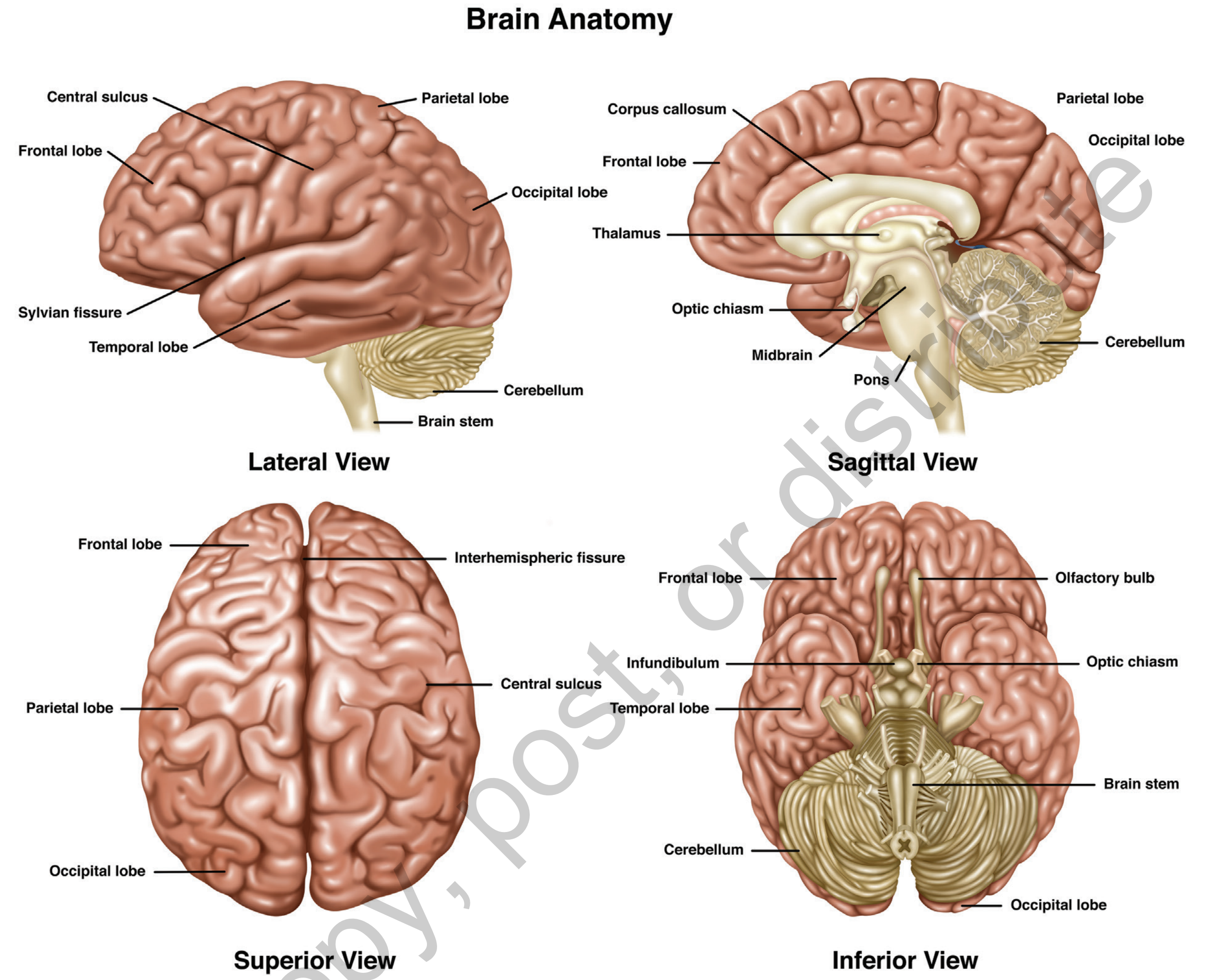
The average human brain weighs about 1.36 kilograms (3 lb.) and has a volume of 1,273.6 cm³ for men and 1,131.1 cm³ for women (Allen, Damasio, & Grabowski, 2002). Different views of the human brain are shown in Figure 1.3. The top left of the figure shows a **lateral view** of the brain, which means that only one of its sides is visible. From this view, the main superficial parts of the brain can be seen. The outermost layer of the brain is called the **cortex**, which is Latin for "bark" or "shell." What can also be seen is how the brain is divided into different parts called **lobes**. These are the frontal, temporal, parietal, and occipital lobes. As you will learn in Chapter 4, each one of these lobes is associated with a particular set of functions. The first thing that may strike you about the cortex is its pattern of bumps and grooves. The bumps are known as **gyri** (singular: *gyrus*) and the grooves are known as **sulci** (singular: *sulcus*), about which we will have more to say in Chapter 4. Some of the sulci in the cortex are larger than others. These are known as **fissures**. For example, the **Sylvian fissure** separates the frontal lobe from the temporal lobe.

Two structures at the back of the brain are prominent. One is the *cerebellum*, which is Latin for "small brain," and the other is the brainstem. The cerebellum is involved in the coordination of movements. Areas in the brainstem are involved in sleep, wakefulness, and vital functions such as respiration and heartbeat. The bottom left shows a **superior view** (or dorsal view) of the brain, which simply means that it is seen from the top. Most prominent from this view is the fact that the brain has two halves, called **hemispheres** (left and right), separated by the interhemispheric (or longitudinal) fissure. Also visible is the central sulcus, which separates the frontal lobe from the parietal lobe.

The top right of the figure shows a **sagittal view** of the brain. This view shows the brain as if one of the hemispheres was removed and then shown as a lateral view. This view shows the center of the brain. That is, other regions not visible from the surface can now be seen. This includes a structure of the brainstem called the *pons*, which is Latin for "bridge." The pons relays signals from the cerebellum to the cortex. Also visible are the midbrain and the thalamus. The midbrain contains areas important for perception and motivation, whereas the thalamus relays information from the senses to the appropriate area in the cortex. The optic chiasm is where the nerves bringing visual information to the brain from each eye meet, some crossing over to the opposite side of the brain while others remain on the same side. Also visible is the **corpus callosum**, which is a thick bundle of fibers

FIGURE 1.3

Different views of the brain.



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that connect the two hemispheres, permitting them to communicate with each other.

The bottom right of the figure shows an **inferior view** (or ventral view) of the brain, which simply means that it is viewed from the bottom. This view shows the olfactory bulb, which is where information from the sense of smell is first analyzed. Also visible from this view is the infundibulum, which connects the hypothalamus and pituitary gland (not shown), which we will have much to say about in Chapter 10.

Brain Cells

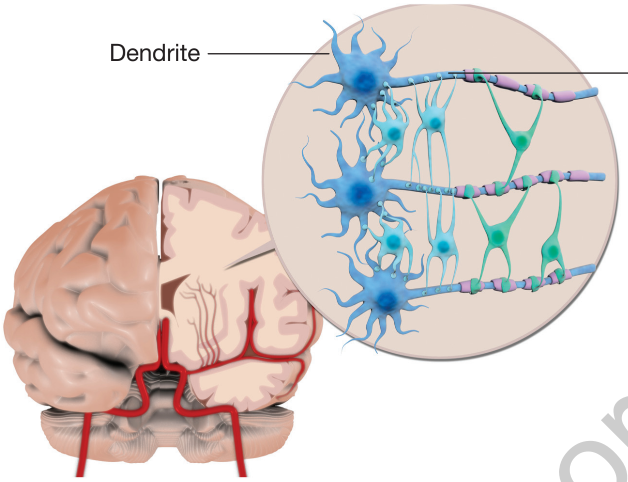
Like all tissues in the body, the brain is made up of its own kinds of cells. There are two major types of cells in the brain, neurons and glia. **Neurons** are the basic functional units of the brain. They communicate with other cells through electrical messages known as action potentials. Other cells with which neurons communicate include muscle and gland cells. It is this interaction between neurons and other cells that makes moving, thinking, emotions, and learning possible.

Glia come in many forms, each playing specific roles, from providing immune defense to the brain (Plog & Nedergaard, 2018) to ensuring that neurons communicate in an efficient manner (Verkhratsky & Nedergaard, 2018).

Neurons and glia are illustrated in Figure 1.4. You can see that neurons have two main parts, a cell body and a tail-like extension called an axon. The neurons' electrical messages are conveyed through their axons. The glia that you see in the figure are specialized in coating the axons with a fatty substance called myelin, which increases their electrical conductivity. Much more is said about neurons and glia in Chapter 2. The details by which neurons communicate are explored in Chapter 3.

FIGURE 1.4

Neurons and glia (insert to the top right of the brain). Neurons (dark blue) are the basic functional units of the brain. Two major parts of a neuron are the cell body, which has extensions called dendrites that receive messages from other neurons, and a tail-like extension called an axon, through which electrical messages called action potentials travel. Also shown are two types of glia. Astrocytes (light blue), which serve diverse functions, and oligodendrocytes (green), which insulate axons by coating them with myelin (pink).



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IT'S A MYTH!

Left Brained/Right Brained

Are you left brained or right brained? Have you ever heard this question being asked? Chances are that you have. The idea that the left and right hemispheres of the brain are specialized for different types of thinking is pervasive in movies and magazines and on websites and social media.

Sun Sentinel/Tribune News Service/Getty Images

It is true that the left and right hemispheres of the brain were found to be involved in different functions. For example, in most people, the left hemisphere is associated with speech and the logical thinking skills required for processing verbal and numerical information. It is also the hemisphere that leads to analytical thinking, such as extracting details or the single parts that make up the structure of a whole. The left hemisphere's propensity to think logically and to be analytical means that it takes things quite literally. This means that the left hemisphere is incapable of getting the punchline of jokes or understanding the true meaning of common everyday sayings. For example, when you hear the expression "He kicked the bucket," you know that this means that a person has died. However, if you had only the left hemisphere of your brain, you would wonder why someone had literally kicked a bucket.

By contrast, the right hemisphere is associated with nonverbal and visuospatial skills. It processes information holistically instead of extracting meaning from the analysis of individual parts. For example, it is the right hemisphere that understands that someone has died when you hear the phrase "He kicked the bucket." The right hemisphere is also the one to which creativity is attributed.

The Myth

The myth states that some people are predominantly "left brained" and others "right brained" and that your left or right "brainedness" dictates your thinking style and personality. You are more likely left brained if you are the type to become an engineer, whereas you are more likely right brained if you are the artistic type.

Where Does the Myth Come From?

The source of the myth can be attributed at least partly to Arthur Ladbroke Wigan (1785–1847), who described the two hemispheres of the brain as independent entities thinking in different ways, in his book *A New View of Insanity: Duality of the Mind*. He wrote that the two halves of the brain usually cooperate but that they may work against each other in mental illness. This idea gained momentum after Paul Broca, in the 1860s, and Carl Wernicke, in the 1870s, found that different functions may be controlled by either the left or right hemisphere. They found that speech and the understanding of language were controlled by the left hemisphere, which became known as the dominant hemisphere.

However, the greatest boost to the myth came in the 1960s and 1970s, when neuropsychologist Roger Sperry studied the behavior of patients in whom the corpus callosum had been intentionally severed to limit the spread of epileptic seizures from one hemisphere to the other. These patients, who became known as split-brain patients, were assessed for their ability to process information presented to either one of the hemispheres at a time. For example, when Sperry asked split-brain patients to identify a hidden object held in their right hand, they could easily do so. However, if the object was held in the left hand, they were unable to name it. This was because limbs are controlled by the hemisphere opposite to the body part. Therefore, to name an object in the left hand, the information processed by the right hemisphere has to be transferred to the left hemisphere, which controls language, through the corpus callosum, which was cut in the split-brain patients. In contrast, the information from an object held in the right hand is directly represented in the left hemisphere, through which the object can be named. Further experiments with split-brain patients showed that the right hemisphere was superior at processing visuospatial and emotional information.

Why Is the Myth Wrong?

Although the left and right hemispheres appear to be specialized for processing different types of information when isolated in experimental studies, this does not mean that they function independently of each other with their very own thinking styles. There is no scientific evidence that the way people think—or their personalities—is determined by one hemisphere dominating over the other. In fact, when researchers examined the brain scans of 1,011 individuals, they found that the study participants could not be classified on the basis of whether they used one hemisphere more than the other (Nielsen, Zielinski, Ferguson, Lainhart, & Anderson, 2013).

1.1.3 LEVELS OF ANALYSIS: PUTTING BRAIN-BEHAVIOR RELATIONSHIPS IN PERSPECTIVE

>> **LO 1.1.3 Explain the different levels of analysis that constitute the study of brain-behavior relationships.**

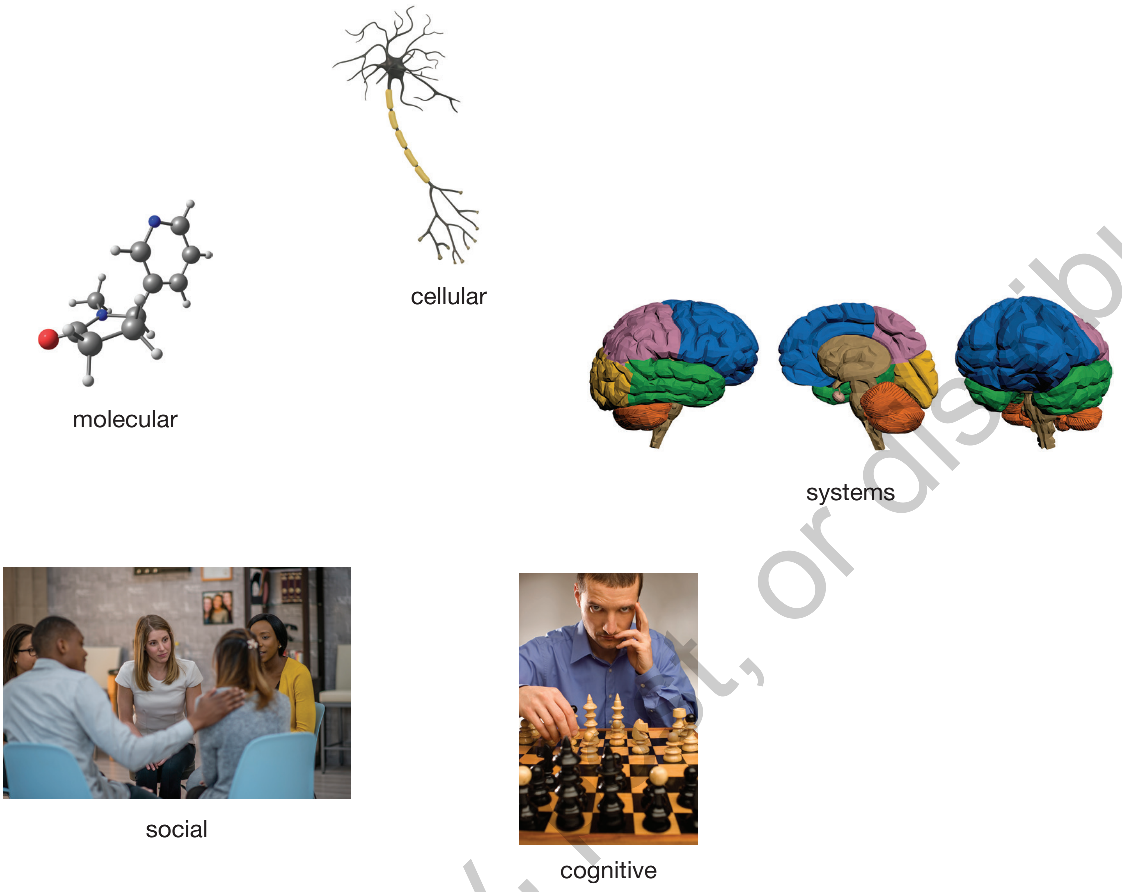
Key Terms

- **Level of analysis:** Refers to the location, scale, or size of what is being studied.
- **Molecular level of analysis:** The study of the workings of the nervous system using methods that permit the study of the genes and the chemistry of proteins within neurons.
- **Cellular level of analysis:** The study of the morphology and physiological properties of cells within the nervous system.
- **Systems level of analysis:** The study of how the activity in patterns of neuronal connections gives rise to overt and covert behaviors and how information is encoded and stored in the patterns of connections between neurons that are part of functional systems.
- **Cognitive level of analysis:** The study of the neurobiological basis of higher mental processes.
- **Social level of analysis:** The study of how neurobiological processes are involved in social behavior.

To have a broad understanding of brain-behavior relationships, one must know how they can be studied from different **levels of analysis**, as illustrated in Figure 1.5. A level of analysis refers to the location, scale, or size of what is being studied. For example, behavioral neuroscientists can study brain-behavior relationships at the

FIGURE 1.5

Behavioral neuroscientists are interested in studying behavior at the molecular, cellular, systems, cognitive, and social levels of analysis.



(Clockwise from top left) iStock.com/ollaweila; iStock.com/3drenderings; iStock.com/Slim3D; iStock.com/dulezidar; iStock.com/FatCamera

molecular, cellular, systems, cognitive, and social levels of analysis. Let's take a look at what it means to study brain-behavior relationships at each of these levels.

At the **molecular level of analysis**, neuroscientists are interested in studying the brain using methods that permit them to study the genes and the chemistry of proteins within neurons. This may include the study of how genes and the chemistry of proteins can be altered by environmental influences (see the next unit for a description of genes).

For example, researchers found that different genes respond to specific types of environmental stressors in rats, whereas other genes respond to stress regardless of its source (Jacobson, Kim, Patro, Rosati, & McKinnon, 2018). The researchers reported that they could tell which rats were exposed to stress by studying the expression of a subset of their genes. In addition, by looking at the expression of other genes, they could tell the type of stressors to which the rats were exposed.

At the **cellular level of analysis**, neuroscientists are interested in studying the morphology and physiological properties of cells within the brain. This includes studying how the integrity of certain types of cells is crucial for proper functioning of the brain. For example, scientists studying the brain at the cellular level found that the degeneration of what are known as gatekeeper cells, which control the flow of blood inside the brain, is partly responsible for Alzheimer's disease, in which people suffer a slow decline in memory and other thinking skills (Kisler et al., 2017).

At the **systems level of analysis**, neuroscientists are interested in how activity in patterns of neuronal connections gives rise to overt and covert behaviors. They are also interested in how information is encoded and stored in the patterns of connections between neurons that are part of functional systems (e.g., the visual system, motor systems, memory systems) and the possible interactions that exist between them. For example, researchers found that networks of neurons in a part of the brain called the entorhinal cortex are involved in representing time in rats as they encode new experiences. They proposed that this information is combined with the memory for places and objects, which is encoded by networks of neurons in other brain areas (Tsao et al., 2018).

At the **cognitive level of analysis**, neuroscientists are interested in the neurobiological basis of higher mental processes. This includes the processes involved in language, attention, self-awareness, consciousness, and mental imagery. For example, researchers found that interpreters, who perform the simultaneous translation of one language into another, have hyperconnectivity between the frontal parts of the two hemispheres of their brains compared to non–language experts who speak more than one language (C. Klein, Metz, Elmer, & Jancke, 2018).

At the **social level of analysis**, neuroscientists are interested in how neurobiological processes are involved in social behavior. For example, researchers have found that prosocial behavior in adolescents was associated with levels of activity in a part of the brain called the anterior cingulate cortex (Okada et al., 2019).

1.1.4 A CLOSER LOOK AT THE MOLECULAR LEVEL: GENETICS

>> LO 1.1.4 Understand the basics of how genes influence behavior and how the environment influences genes.

Key Terms

- **Genetics:** The study of inherited traits and their variation.
- **Genes:** Once referred to as the basic functional units of heredity, genes are sequences of deoxyribonucleic acid (DNA), some of which code for proteins.
- **Deoxyribonucleic acid (DNA):** A molecule composed of sequences of smaller molecules called nucleotides, bound together by molecules of sugar and phosphate.
- **Phenotype:** The characteristic traits observed in individuals resulting from the interactions between their genotype and the environment.
- **Genotype:** Every individual's unique genetic constitution.
- **Behavioral genetics:** The field of study that seeks to understand how the variation of a trait in a population is related to the variation of genes within that population.
- **Heritability estimates:** The proportion of variation in a trait that can be accounted for by genetic variation in a population.
- **Epigenetics:** The study of changes in gene expression with no changes in DNA sequences, which can occur naturally or through the influence of environmental factors.

Genetics is the study of inherited traits and their variation. **Genes** are often defined as being the basic functional units of heredity. However, this definition of genes is not accurate. We now know that such basic units of heredity do not exist (Portin & Wilkins, 2017). Rather, genes are sequences of what is known as **deoxyribonucleic acid (DNA)**, which resides in the nucleus of every cell in the body. Some genes contain the instructions for building proteins. Other genes are noncoding and are involved in regulating protein synthesis along with a host of other functions (Pennisi, 2012). Estimates of the number of human genes have changed over the years (Salzberg, 2018). One of the latest counts sets the number of human genes at 43,162, of which 20,352 code for protein (Pertea et al., 2018).

DNA is a molecule composed of sequences of smaller molecules called nucleotides, which are bound together by molecules of sugar and phosphate. DNA takes the form of two strands bound together in a double helix. Nucleotides differ from each other only by the nature of what is known as a nitrogenous base. There are four nitrogenous bases. These are adenine, thymine, guanine, and cytosine. The nitrogenous bases bind the two single strands of DNA by forming base pairs. Base pairs are not formed randomly. That is, adenine is always paired with thymine and guanine is always paired with cytosine. DNA is present in almost all living organisms. The only exceptions to this are found in certain viruses (Hiyoshi, Miyahara, Kato, & Ohshima, 2011).

As shown in Figure 1.6, the sequences of DNA that compose genes are contained in what are known as chromosomes. In humans, each cell has 23 pairs of chromosomes. Twenty-two of those pairs are called autosomes, whereas one pair consists of the sex chromosomes (male XY and female XX), which determine gender. Figure 1.7 shows a picture of an individual's set of chromosomes in what is called a karyotype. The information contained in DNA dictates the synthesis of proteins. The variations in the proteins synthesized give rise to the differences in **phenotype**, which are the characteristic traits observed in individuals resulting from their **genotype**.

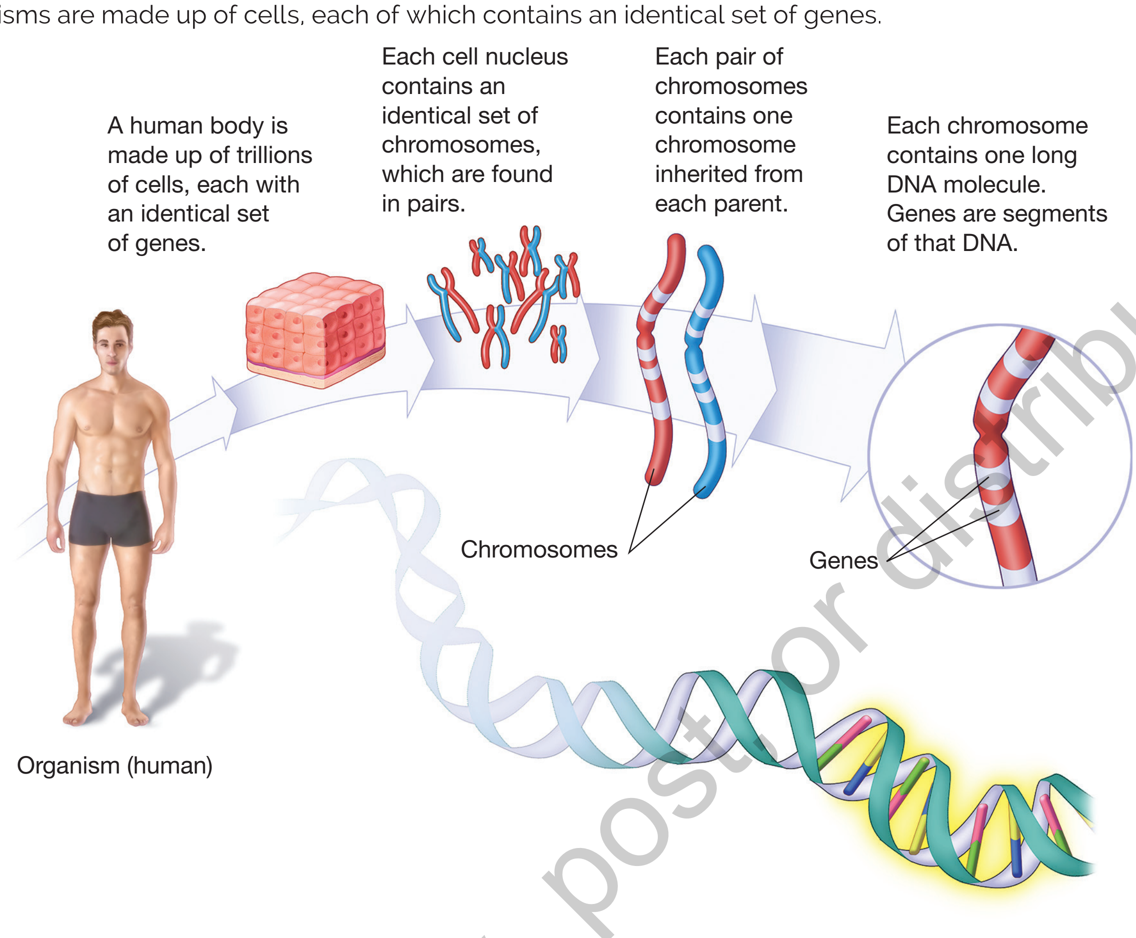
The influence that genes have in the synthesis of proteins depends on how they interact with the environment. Traits, whether physical or psychological, are considered to be the product of these interactions (Moore & Shenk, 2017). This means that there are no single genes or combinations of genes that, by themselves, directly result in the development of any given trait.

How Genes Are Transmitted From Parent to Offspring

Cells replicate through division. There are two types of cell divisions: mitosis and meiosis. Mitosis refers to the division of somatic cells (the ones that compose the various tissues of the body). Genes are passed on to the next generation through the division of sex cells (the ones present in the ovaries of females and testes of males) in a process called meiosis. Meiosis leads to the

FIGURE 1.6

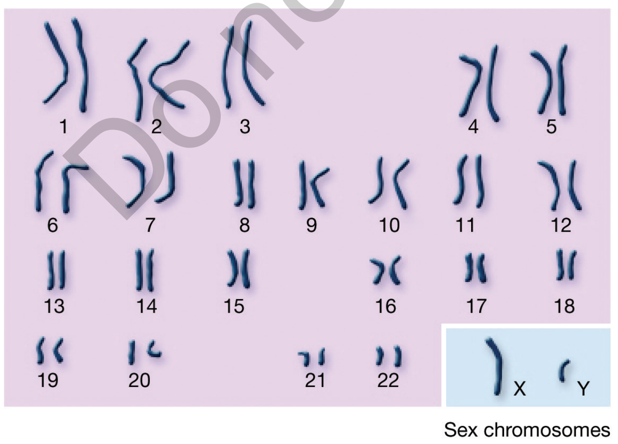
Organisms are made up of cells, each of which contains an identical set of genes.



Carolina Hrejsa/Body Scientific Intl.

FIGURE 1.7

Human karyotype. Humans have 23 pairs of chromosomes, which include 22 pairs of autosomes and one pair of sex chromosomes (X,Y).



U.S. National Library of Medicine

creation of cells having only half of the total number of chromosomes. For example, in humans, out of a total of 46 chromosomes in somatic cells, each sex cell ends up with 23 chromosomes. Therefore, half of the genes you have inherited came from the set of 23 chromosomes provided by your mother and the other half came from the set provided by your father.

Behavioral Genetics

Behavioral genetics is the field of study that seeks to understand how the variation of a trait in a population is related to the variation of genes within that population. As a student of behavioral neuroscience, why should you be interested? Because behavioral geneticists consider how variations in brain function are related to variations of genes within a population.

Behavioral geneticists are interested not only in how genes contribute to behavior but also in how genes interact with environmental factors to produce behavior. Environmental factors include social and cultural factors, child-rearing practices, level of acceptance, social and cultural factors, as well as educational level (Kawamoto & Endo, 2015; Menardo, Balboni, & Cubelli, 2017). For behavioral geneticists, environmental factors also include biological factors such as nutrients, hormones, viruses, and bacteria.

To get a clue about how much of the variation of a trait can be accounted for by genetic variation in a population, behavioral geneticists compute what are known as **heritability estimates**. For example, the heritability estimate for personality was found to be 40%. This means that variation in gene composition accounts for 40% of the variation in personality in the population and that environmental factors account for 60% of the differences (Vukasovic & Bratko, 2015).

Behavioral geneticists are also interested in the heritability estimates of psychological disorders. For example, the heritability of alcohol use disorder was found to be approximately 50% (Verhulst, Neale, & Kendler, 2015). In another study, researchers found that the heritability estimates for minor and major depression are 37% and 46%, respectively (Corfield, Yang, Martin, & Nyholt, 2017).

Epigenetics

Epigenetics is the study of changes in gene expression with no changes in DNA sequences. Epigenetic changes occur naturally. However, they are also triggered by environmental factors and give rise to certain behavioral characteristics (Goldberg, Allis, & Bernstein, 2007). For example, social environment in early life can alter the expression of genes. In a study published in 2004, rat pups who experienced high levels of licking, grooming, and nursing by their mothers had a more moderate response to stress than rat pups that did not experience such high levels of maternal care. The researchers found that higher levels of maternal care created this difference by changing the expression of a gene involved in regulating how the brain is affected by glucocorticoids, which are chemicals released by the adrenal glands in times of stress (Weaver et al., 2004).

You might now wonder whether these epigenetic changes in the expression of genes are passed on to the next generations. The answer to this question is yes. For example, trauma-related epigenetic changes in Holocaust survivors who were imprisoned and tortured in concentration camps during World War II were passed on to their children (Yehuda et al., 2016). Even acquired fears may be inherited. Another study found that male mice trained to fear the smell of cherry blossoms through pairing it with an electric shock had offspring that feared the same smell (Dias & Ressler, 2014).

MODULE SUMMARY

Behavioral neuroscience is the study of brain-behavior relationships. Behavior can be overt, as when actions can be observed directly; or covert, as when behavior cannot be observed directly, such as remembering, reading silently, and dreaming. Behavioral neuroscience includes cognitive neuroscience, affective neuroscience, social neuroscience, and decision neuroscience. Brain-behavior relationships can be studied from different perspectives and at different scales called levels of analysis. These are the molecular, cellular, systems, cognitive, and social levels of analysis.

Genetics is the study of inherited traits and their variations. These inherited traits and characteristics are carried within genes. Genes are located on chromosomes. Humans have 23 pairs of chromosomes: 22 pairs of autosomes and one pair of sex chromosomes. Chromosomes are made of strands of DNA. The set of genes carried by an individual is called the genotype. The inherited traits as a result of the expression of those genes are called the phenotype. However, phenotypes are not determined by genes alone but by the interaction between genes and environmental influences.

Behavioral geneticists are interested in how variations of a trait in a population can be explained by the variation of genes within the same population. They are also known to compute heritability estimates, which estimate the proportion of the variance of a trait that is due to the variation of genes. In epigenetics, researchers are interested in the effect of the environment on the expression of genes. Studies have found that experiences in the early social environment can induce changes in gene expression. In addition, these changes can be passed on to the next generation.

TEST YOURSELF

1.1.1 Explain what the study of brain-behavior relationships consists of.

1.1.2 Describe the main structural aspects of the brain and some of the functions associated with each of the areas you read about.

1.1.3 Name and describe the levels of analysis that constitute the study of brain-behavior relationships.

1.1.4 Briefly explain how phenotypes result from the interactions between genes and environment.

1.2 The Evolution of Brain-Behavior Relationships

Module Contents

Learning Objectives

1.2.1 Explain the concept of natural selection.

1.2.2 Understand the adaptive variations that gave rise to brain-behavior relationships.

1.2.1 NATURAL SELECTION

>> LO 1.2.1 Explain the concept of natural selection.

Key Terms

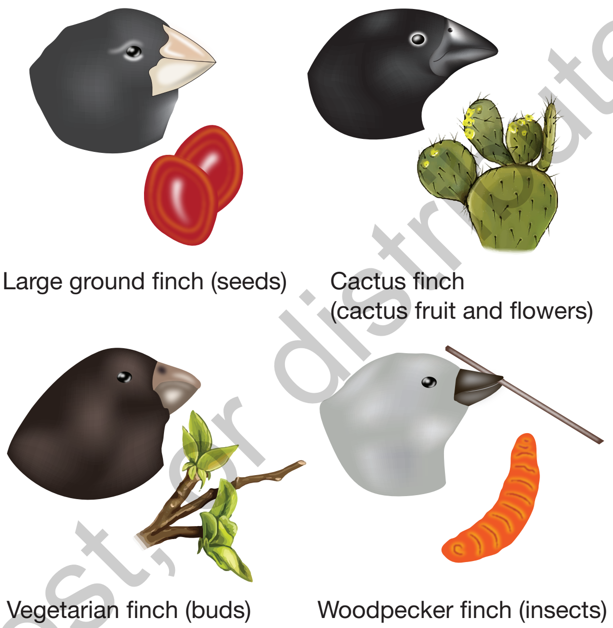
- **Descent with modification:** The idea that current forms of life evolved from preexisting forms.
- **Natural selection:** The process by which evolution can be explained.

Many of life's characteristics are truly striking. Have you ever marveled over the fact that animals are remarkably well adapted to their environments? For example, kangaroo rats can survive in the desert without ever drinking water by extracting moisture from the seeds that they eat (Tracy & Walsberg, 2000); notothenioid fish, which live in the freezing conditions of the Antarctic, produce a protein that acts as an "antifreeze," binding to water crystals in their blood (Cheng & Detrich, 2007); and the amazing cuttlefish changes its color to blend with its surroundings, allowing it to escape predators (Chiao, Chubb, & Hanlon, 2015).

English naturalist Charles Darwin (1809–1882) sought to find a scientific explanation for these adaptations. He proposed that current forms of life evolved from preexisting forms in what is known as **descent with modification**. Much of his amazement was cultivated on his voyage to the Galápagos Islands on the ship *H.M.S. Beagle*. Among many observations, he noted that finches varied considerably in the form of their beaks, and the way in which they used them, from island to island. He found that the form of their beaks seemed to have adapted to the types of food they ate on their respective islands: seeds, flowers, buds, or insects (Figure 1.8).

FIGURE 1.8

Darwin found that different varieties of finches lived on the different islands of the Galápagos. The finches were distinguished by the shapes of their beaks, which were adapted to the types of foods they ate on their respective islands.



Amanda Tomasikiewicz/Body Scientific Intl.

How can species be so well adapted to their environments? Darwin proposed that some of an animal's offspring possess characteristics that will make them more suited to their environment than others, giving them a survival advantage and, therefore, making them more likely to pass on those characteristics to subsequent generations. This process is known as **natural selection** (Darwin, 1859).

Natural selection can be summarized by two observations and inferences made by Darwin:

Observations

1. Members of a population often vary in inherited traits.
2. All species can produce more offspring than the environment can support.

Inferences

1. Some individuals will have inherited traits that will give them a survival advantage and higher

probability of reproducing than individuals that do not have those traits.

2. This survival advantage and higher reproductive probability will lead to the accumulation of those traits in subsequent generations.

1.2.2 NEUROECOLOGY: HOW NATURAL SELECTION ACCOUNTS FOR BRAIN-BEHAVIOR RELATIONSHIPS

>> LO 1.2.2 Understand the adaptive variations that gave rise to brain-behavior relationships.

Key Terms

- **Neuroecology:** The field that studies relationships between the brain and ecologically relevant behaviors and how they may have evolved through natural selection.
- **High vocal center (HVC):** The brain area at the center of a song-learning system in song birds.
- **Exaptation:** The adaptation of a trait that differs from the one it was selected for.

After reading about the adaptations of animals to their environments, you may be left wondering how natural selection can account for brain-behavior relationships. **Neuroecology** is the field of study in which researchers are interested in these types of relationships. For example, neuroecologists study the adaptive variations in the relationships that exist between cognition, sensory, and motor processes, and the brain, with respect to how organisms interact with their environment (Riffell & Rowe, 2016; Sherry, 2006). Neuroecologists have focused on several examples demonstrating that natural selection contributed to brain-behavior relationships in animals.

One of the most often cited examples is that of the relationship between the development of a brain area known as the **high vocal center (HVC)** and song learning in male song birds such as zebra finches and canaries. The HVC is part of a larger system known as the "song system" (Nottebohm, 2005; Nottebohm, Stokes, & Leonard, 1976; Wild, 1997). This system is involved in both song learning and the vocalization of songs. Researchers found that the song system is larger in males than in females and that the size of the HVC and other regions of the song system are enlarged during the spring breeding season. The enlargement of the HVC region in the spring coincides with the production of birdsongs, which are used to attract mates and to ward off rivals. How is this related to natural selection? Females were found to prefer to mate with males that sing at a high rate and that have a large repertoire of songs relative to those that do not. It is not difficult to apply the observations and inferences made by Darwin to this situation (see the previous unit). That is, males with a better developed song system would have been selected for and have greater reproductive success. Consequently, the genes associated with the development of effective song systems were passed on to later generations.

Another often-cited adaptation related to a brain-behavior relationship is that of a number of bird species that store food in hundreds or even thousands of caches (hiding places) over the course of a year. The birds are then able to retrieve the food from the caches, which are widely dispersed in their environment, anywhere from several days to several months after hiding it. This obviously requires an uncanny ability to remember spatial locations. Memory for spatial locations, otherwise known as spatial memory, is dependent on a brain area called the hippocampus (discussed at length in Chapter 12). The hippocampus of food-storing birds was found to be larger (relative to their brain and body size) than the hippocampus of birds that do not store their food. Further, the hippocampus of food-storing birds increases in size during the autumn and winter. This coincides with when food-storing birds cache the most food, due to the rarity of insects and plant seeds during those months (Sherry & Hoshooley, 2010).

However, not every behavior can be said to have arisen through natural selection. For example, the human brain is good at remembering email addresses or learning to use computers even if it obviously did not evolve to do so. For this reason, some researchers think that the brains of our early ancestors evolved general rules to deal with certain tasks that we can now apply to modern-day problems. This is known as **exaptation**, which is the adaptation of a trait that differs from the one it was selected for (Gould & Vrba, 1982; S. B. Klein, Cosmides, Tooby, & Chance, 2002; Sherry & Schacter, 1987). It is also worth noting that, as discussed earlier, changes in an organism's gene expression can be passed on to subsequent generations through epigenetic changes.

MODULE SUMMARY

Animals are remarkably well adapted to their environments. In addition, different species of animals share many life-supporting characteristics. At the same time, an enormous diversity of organisms exists. Charles Darwin sought to find a scientific explanation for those facts. He proposed that current forms of life evolved from preexisting forms in what is known as descent with modification. The mechanism by which he thought this occurred is known as natural selection.

Neuroecology is the field that studies relationships between the brain and ecologically relevant behaviors and how they may have evolved through natural selection. Several examples of such relationships and how they may have been selected for exist, namely, the high vocal center and song learning in song birds and the size of the hippocampus in food-storing birds.

Not all behaviors can be said to have evolved through natural selection. Some behaviors may have evolved to solve ancient problems but are well adapted to solve modern-day problems. The adaptation of a trait for uses that differ from what it was selected for is known as exaptation.

TEST YOURSELF

1.2.1 Explain the concept of natural selection.

1.2.2 Discuss how variations in brain structures evolved to give rise to brain-behavior relationships. Give two examples.

1.3 The Origins of Behavioral Neuroscience

Module Contents

1.3.1 Antiquity
1.3.2 The Mind-Body Problem
1.3.3 Localization of Function

Learning Objectives

1.3.1 Describe some of the views associated with brain function throughout antiquity.

1.3.2 Explain the philosophical roots that underlie the relationship between brain and body.

1.3.3 Understand how the idea that brain functions are localized to specific areas developed.

1.3.1 ANTIQUITY

>> LO 1.3.1 Describe some of the views associated with brain function throughout antiquity.

Key Term

- **Edwin Smith Papyrus:** A medical papyrus that seems to have been written around 1600 B.C.E., during the third dynasty of pharaohs.

The Egyptians

Today we know that the brain is the source of all of our faculties. However, this has not always been the case. In 1862, an archeologist named Edwin Smith (1822–1906) bought an ancient Egyptian papyrus, which became known as the **Edwin Smith Papyrus** (Figure 1.9). The papyrus seems to have been written around 1600 B.C.E., during the third dynasty of pharaohs. Smith kept the papyrus until his death without ever having it translated. The papyrus was eventually translated by another archeologist, James Henry Breasted (1865–1935). Once translated the papyrus revealed itself to be an ancient medical text. In it are descriptions of injuries sustained during building projects and battles.

Some of the injuries described in the papyrus involve head injuries. From the description of the injuries, it is evident that Egyptians knew that brain damage could affect bodily functions ranging from hand-eye coordination problems to paralyzed limbs. However, they thought the heart was the seat of the soul and all of the functions we attribute to the brain today. In fact, so little was thought of the brain that, after death, it was removed through the nostrils with an iron hook and thrown away.

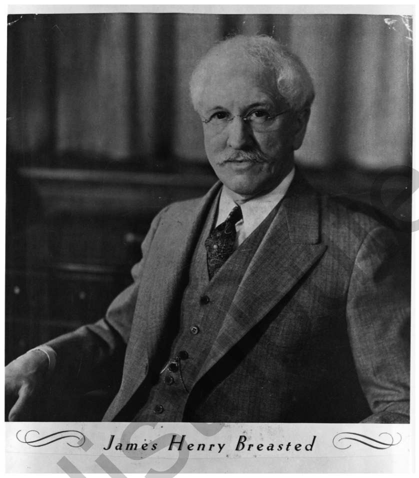
The Greeks

In early Greece there was no room for people's ability to control their own fates. Humans were believed to be created and controlled by gods, much the same way that puppeteers control their puppets. Eventually, the Greeks became more aware of their place in nature and gradually began to think of themselves as free individuals devoid of the tight grip that the gods held on them. People also started to think differently about disease, seeking more naturalistic causes and treatments for them rather than explanations and treatments based on religion.

Central to this change was Hippocrates (460–370 B.C.E.), who treated people according to the laws of nature. Contrary to the Egyptians, Hippocrates firmly believed that the brain, and not the heart, was the seat of all mental

FIGURE 1.9

The Edwin Smith Papyrus (left) and archeologist James Henry Breasted (right), who translated it.

(left) Pictures From History/Newscom; (right) Library of Congress/Corbis Historical/Getty Images

faculties. This was contrary to the belief of the great philosopher Aristotle (384–322 B.C.E.), who thought that the heart was at the center of all faculties. Aristotle believed that the brain served only as a radiator to cool the blood heated by the seething heart (E. Clarke & Stannard, 1963).

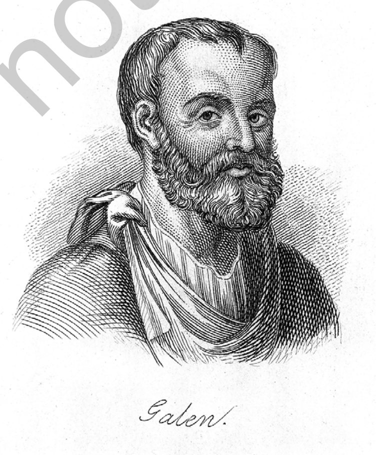
Hippocrates believed that the brain interpreted stimuli from the outside world, giving rise to perception. He identified the brain as the center for consciousness, intelligence, and willpower; and he found the cause of epilepsy to be brain malfunction, rather than divine intervention.

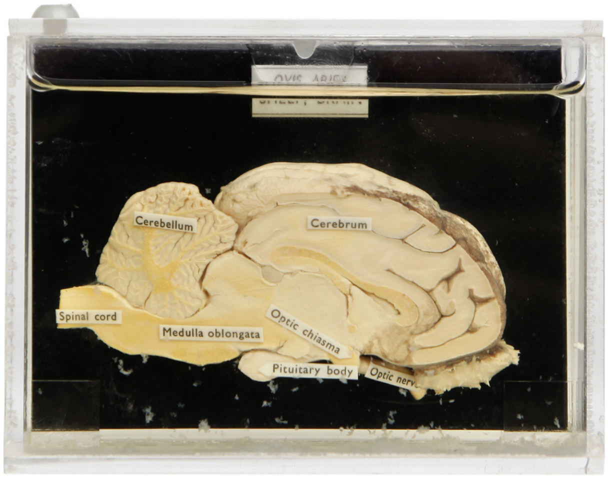
For religious reasons, autopsies were forbidden in Greece in Hippocrates's day. Therefore, it is thought that he learned much about brain-behavior relationships by examining soldiers who sustained head wounds. For example, he noticed that wounds to the head often resulted in convulsions, paralysis, and loss of speech.

Dissections of human cadavers weren't permitted until after Hippocrates's death, with the softening of religious taboos. This allowed Alexandrian anatomists Herophilus of Chalcedon (335–280 B.C.E.) and Erasistratus (304–250 B.C.E.) to perform hundreds of

FIGURE 1.10

Galen (left), who dissected sheep's brains (right), thought that the cerebrum was ideal to pick up sensations, whereas the cerebellum controlled the muscles.





(left) Wellcome Library, London. Wellcome Images via Wikimedia Commons; (right) Gregory Davies/SCIENCE SOURCE such dissections. Herophilus thought that the soul was housed in the fourth ventricle because of the number of motor nerves that leave that area. For his part, Erasistratus attributed the superior intellect of humans to the higher number of circumvolutions (folds) on the cortex compared to other animals. The Greek physician Galen (130–210 C.E.) pointed out that this attribution was wrong, remarking that donkeys possess highly circumvoluted brains but are among the stupidest animals (C. U. Smith, 2010).

Galen practiced in Rome and had a predicament similar to that of Hippocrates. Human autopsies were not permitted in the Rome of his day. Galen then studied the bodies of dead soldiers and of those he encountered by chance. Because the bodies he found were often in a state of decomposition, it was impossible to study soft organs such as the brain. For this reason, Galen turned to dissecting animals. Galen's dissections provided much knowledge about the nervous system. For example, he described the cranial nerves, which go from the brain to the face and upper body. He also differentiated between motor and sensory nerves.

Some of Galen's many findings made him believe that the brain was the seat of the mind. One of his observations made this obvious to him. He noticed that the nerves associated with the sense organs could all be traced to the brain, not the heart. Galen also related the brain to function after dissecting sheep brains (Figure 1.10). He observed that the front part of the brain, the cerebrum, was fleshy and soft, which would make it ideal to soak up sensations, whereas the back of the brain, the cerebellum, was hard and therefore controlled the muscles (Rocca, 2003). Although his explanations for how perception and movement relate to the brain were wrong, his conclusions were correct. That is, the cerebrum is involved in perceptions and the cerebellum plays an important role in movement.

1.3.2 THE MIND-BODY PROBLEM

>> LO 1.3.2 Explain the philosophical roots that underlie the relationship between brain and body.

Key Terms

- **Mind-body problem:** The age-old philosophical question concerning how the mind, which is immaterial, interacts with the material body.
- **Dualism:** The philosophical position that mind and body are distinct and that they could exist independently of each other.
- **Fluid-mechanical theory:** The idea that movement can be explained by the movement of fluids, called animal spirits, through hollow tubes in the body.

The **mind-body problem** reflects an age-old philosophical question: How does the mind, which is immaterial, interact with the material body? Many positions regarding the relationship between mind and body have been proposed. Here we focus on the position held by philosopher and mathematician René Descartes (1596–1650).

Descartes believed that the mind and the body were distinct and that they could exist independently of each other, a position called **dualism**. Descartes thought that properties of the mind cannot be ascribed to material objects. He included in this category not only stones and plants but also nonhuman animals.

According to what is known as the **fluid-mechanical theory**, Descartes believed that nonhuman animals were mere automata, whose actions can be likened to robots and driven by simple reflexes (Descartes & Schuyl, 1662). These reflexes he explained by the movement of fluids, called animal spirits, through hollow tubes in the body (Figure 1.11).

FIGURE 1.11

Descartes's model of simple reflexes. Putting a foot near a flame causes particles emanating from the flame (A) to pull on the skin on your foot (B). This pulling on the skin stretches a little thread (C). The thread being pulled opens the entrance (*e*) to a pore (*d*). The open pore permits animal fluids to flow into it from a cavity within the brain (F). From the cavity, these animal spirits flow down the tube to the muscles, pulling the foot away from the flame.

Print Collector/Hulton Archive/Getty Images

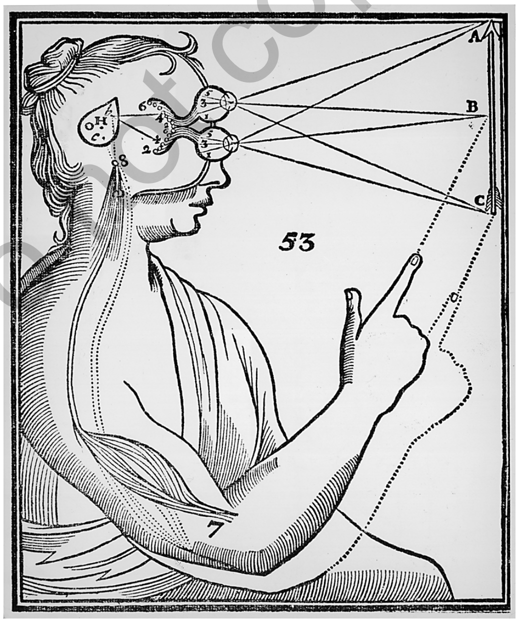
Descartes believed that humans partly functioned this way as well. Contrary to humans, however, he thought that animals, devoid of a mind, could not reason, lacked self-consciousness, and were incapable of language. For Descartes, all of the qualities that we think of as being distinctively human required a God-given soul (or mind), which animals lacked. He thought that the immaterial soul interacted with the pineal gland, which conferred on humans the unique abilities to have free will and to perform voluntary actions.

He thought the pineal gland to be ideal for interacting with the soul because it is a singular structure sitting at the midline of the brain. He also thought that its being suspended, small, and light made it easy to be moved by the immaterial soul. He believed that, in response to sensory experiences and innate ideas, the soul caused the pineal gland to tip, releasing and directing animal spirits through the nerves to control the body (Figure 1.12).

Of course, today's scientists have long since dispensed with the idea of animal spirits and the hollow tubes through which they travel. The pineal gland that Descartes thought was the seat of the soul is now known to produce a chemical called melatonin, which is involved in regulating physiological processes on a 24-hour cycle (known as a circadian rhythm and discussed in more detail in Chapter 9). Descartes's hollow tubes are now known as nerves, and what flows through them are not animal spirits but, rather, electrical impulses called nerve impulses or action potentials, discussed in Chapter 2.

FIGURE 1.12

Descartes's example of how the soul interacted with the body via the pineal gland. When light enters the retina, it triggers the opening of valves behind the eyes, which permits animal spirits to enter tubules connected to the pineal gland. In turn, the pineal gland releases and directs animal spirits to focus the eyes.



Hulton Archive/Getty Images

1.3.3 LOCALIZATION OF FUNCTION

>> LO 1.3.3 Understand how the idea that brain functions are localized to specific areas developed.

Key Terms

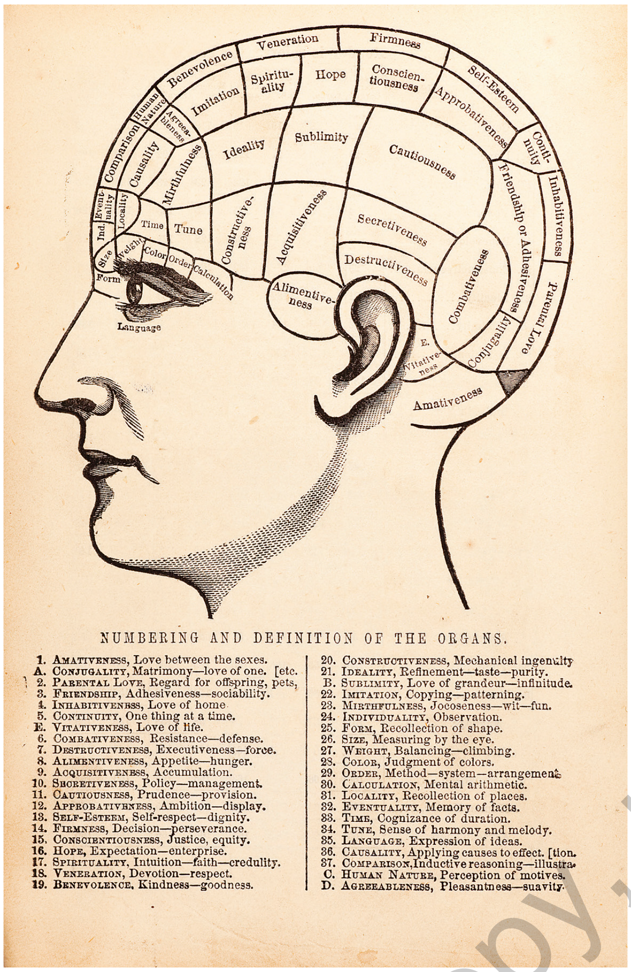
- **Localization of function:** The theory that individual brain areas are dedicated to distinct functions.
- **Phrenology:** The idea that bumps on the skull reflect the size of the underlying brain region, which is associated with a particular faculty.
- **Aphasia:** The loss of an individual's ability to speak.
- **Cerebral dominance:** The idea that the left hemisphere is dominant in the control of speech function.
- **Broca's area:** The area of the third convolution of the left frontal lobe, associated with speech production.
- **Topographical map:** A map, within the brain, that represents different areas of the body in an orderly way.

Modern ideas of brain-behavior relationships began with observations that individual brain areas seemed to be dedicated to distinct functions. This idea became known as the theory of **localization of function**, first proposed in the 1740s by scientist and philosopher Emanuel Swedenborg (1688–1772). However, the best-known early proponent of localization of function was German anatomist Franz Joseph Gall (1758–1828) (Simpson, 2005).

When he was nine years old, Gall noticed that classmates who excelled at memorizing verbal material had large protruding eyes, compared to those who were not as good at doing so. Gall believed that the brain area responsible for verbal memory was enlarged in these students and was located right behind the eyes. Gall then went on to localize myriad other mental functions to particular brain areas, 27 in all. Gall also believed that the bumps on the skull reflected the size of the underlying brain

FIGURE 1.13

A phrenological map showing the areas associated with various faculties.



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region, which was associated with a particular faculty (Figure 1.13). Therefore, he believed that the larger the bump on the skull, the more the faculty represented by the underlying brain area was developed in that individual. Gall studied the patterns of bumps on the skulls of the extremes in society, from people of great talent and intelligence to people considered intellectually challenged and criminals.

Over the years, Gall assessed the skulls of hundreds of people and kept a record of the mental and personality characteristics he concluded they possessed from his assessments. Later, one of Gall's students, Johann Spurzheim (1776–1832), expanded the list of faculties proposed by Gall to 33 and coined the term ***phrenology***, which is Greek for "mental science" or "science of the mind."

Gall's ideas were soon refuted by French physiologist Marie-Jean-Pierre Flourens (1794–1867), who found, by lesioning the cortex of several species of animals, that specific functions were not associated with the brain areas that Gall had assigned to them. He instead found that what affected function in animals was the size of the lesion but not the specific area damaged (J. M. Pearce, 2009).

Localization of Language

Although Gall's theory of relating bumps on the skull to parts of overdeveloped cortex, which represented specific functions, was refuted, the idea of localization of function lived on. It gained momentum when French physician Jean-Baptiste Bouillaud (1796–1881) pointed to the fact that many patients with diseases of the brain displayed motor disturbances, such as paralysis of an arm or a leg. He also noted that loss of speech often accompanied damage to the left frontal lobes (Finger, 2000).

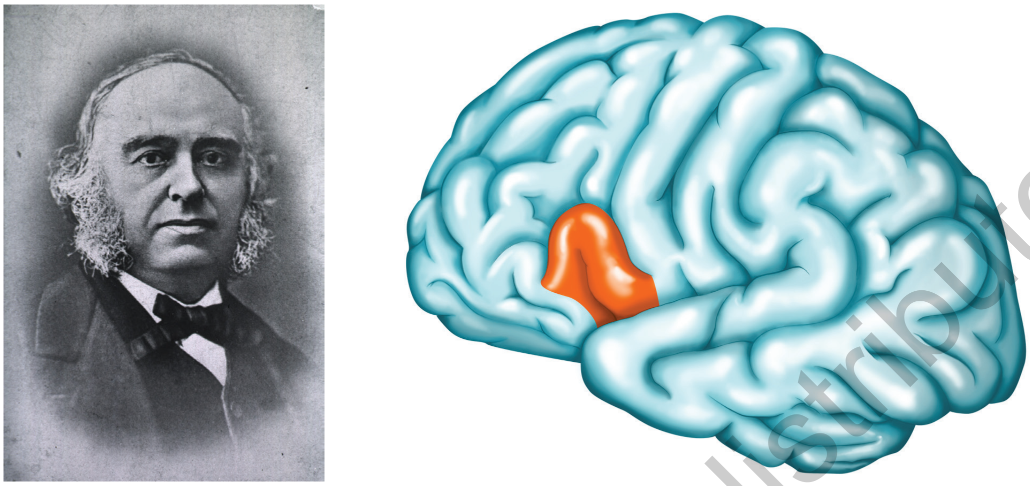
In 1861, Ernest Auburtin (1825–unknown year of death), Bouillaud's son-in-law, reported on several cases in which damage to the frontal lobes resulted in speech impairments. In one of the cases, a patient who attempted suicide by shooting himself in the head found himself with the bone covering the frontal lobes completely blown off, leaving them exposed. His intelligence as well as his speech remained intact. However, as he spoke, pressure applied to his exposed frontal lobes with the back of a large spatula caused his speech to be interrupted mid-word. His speech returned to normal once the pressure applied by the spatula was removed.

Soon after, Auburtin issued the challenge that he would renounce localization of function theory if a case of loss of speech without frontal lobe damage were found. The challenge was taken up by French physician, anatomist, and anthropologist Paul Broca (1824–1880) (Figure 1.14, left). Broca had a patient named Mr. Leborgne, nicknamed "Tan," because this is the sound he made when attempting to give his name. Leborgne had suffered from epilepsy since he was young and lost his ability to speak (a condition called *aphémie* by Broca but later renamed **aphasia**). Broca invited Auburtin to come and examine the patient. Upon his examination, he concluded that Leborgne must have sustained damage to the frontal lobes.

After Leborgne's death, Broca performed an autopsy on him and found that he had progressive damage to his left frontal lobe (in the third convolution). This finding convinced many to accept the up-to-then widely contested localization of function theory. Following Leborgne's autopsy, Broca found several more cases of aphasia, all associated with damage to the left frontal lobe. When damage to only the right frontal lobe was found, the ability to speak was not affected. Broca suggested that the left hemisphere dominated

FIGURE 1.14

Photograph of Paul Broca (left) and the location of Broca's area in the left frontal lobe (right).



(left) U.S. National Library of Medicine; (right) BSIP/Science Source

over the right hemisphere in controlling speech function. This led to the concept known today as **cerebral dominance**. The area in the left frontal lobe that was associated with speech production became known as **Broca's area** (Figure 1.14, right).

Motor Representations in the Cortex

The idea that functions were localized to specific areas of the cortex went well beyond Broca's reported cases of aphasia in patients with damage to the left frontal lobe. For example, British neurologist John Hughlings Jackson (1815–1911) hypothesized that the brain had sensory and motor functions. He based this idea on his observations that, during epileptic seizures, convulsions spread from one part of the body to another in sequential order. From this, he concluded that a representation of the body must exist in the brain (Jackson, 1958).

Jackson's conclusions were confirmed by German anatomist Gustav Fritsch (1838–1927) and psychiatrist Eduard Hitzig (1838–1907). Both independently observed that electrical stimulation of the brain led to the movement of various body parts. As a psychiatrist, Hitzing noticed that electrically stimulating the head in some of his patients produced eye movements. As a battlefield surgeon, Fritsch noticed that while he was dressing an open wound on one side of a soldier's head, the limbs on the opposite side of the body moved (Carlson & Devinsky, 2009).

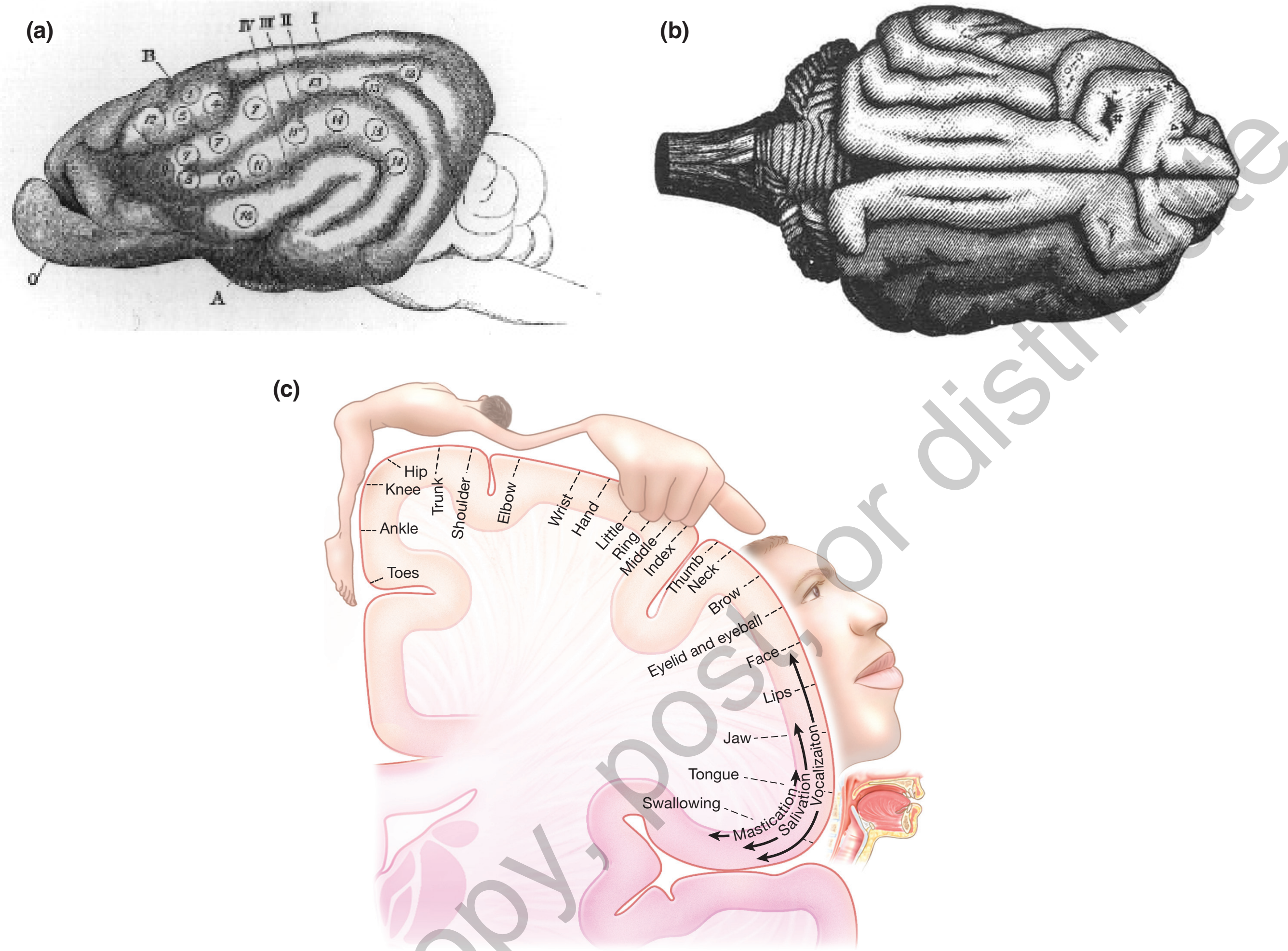
In 1870, Fritsch and Hitzig conducted an experiment to test whether motor functions were localized to particular areas of the cortex. They electrically stimulated the exposed cortex of dogs to see if this would result in movements of the body. The electrical stimulation produced twitching of the muscles on the side opposite from the hemisphere that was stimulated, and stimulation of different parts of the cortex caused different muscles to twitch. They also found that the stimulated cortex formed a **topographical map** of the body, in that different body parts projected to the cortex in an orderly way.

Later, Scottish neurologist David Ferrier (1843–1928) extended Fritsch and Hitzig's finding and the number of areas that can be excited by electrical current. He found that electrically stimulating the cortex of several animals caused them to engage in natural movements such as walking, grabbing, and scratching. He also found that stimulating specific areas of the cortex caused the body to move in ways that imitated that of epileptic patients as described by Jackson (Finger, 2000).

Relatively closer to our times, American Canadian neurosurgeon Wilder Penfield (1891–1976) electrically stimulated the brains of patients undergoing surgery to treat epilepsy. As he was doing so, he asked patients to report what they were experiencing. This was possible because the patients remained awake during surgery. Depending on where he applied the electrical current, Penfield caused specific areas of the body to twitch. However, sometimes the stimulation caused paralysis of parts of the body (Feindel, 1982). Through these experiments, Penfield found that a motor map, similar to the one discovered by Fritsch and Hitzig in dogs, also existed in humans, which became known as the motor homunculus (discussed at greater length in Chapter 8). Figures 1.15a–c show the topographic maps drawn by Fritsch and Hitzing and by Penfield.

FIGURE 1.15

Topographical maps of the brain of dogs by (a) David Ferrier and (b) Fritsch and Hitzig; and (c) topographical map of the human brain discovered by Wilder Penfield.



(a) David Ferrier via Wikimedia Commons; (b) Eduard Hitzig und Gustav Fritsch via Wikimedia Commons; (c) Adapted from *The Cerebral Cortex of Man*, Penfield and Rasmussen. © 1950 Gale, a part of Cengage Learning, Inc.

MODULE SUMMARY

Ideas about the relationships between the brain and behavior have been around since antiquity. Head injuries were described in an ancient Egyptian medical papyrus known as the Edwin Smith Papyrus, written in about 1600 B.C.E. From reading the papyrus it is obvious that the Egyptians of the day knew that brain injury can affect bodily function. However, they thought that the heart and not the brain was the seat of the soul and all of the functions we today attribute to the brain. In contrast, the ancient Greek physician Hippocrates believed that the brain and not the heart was responsible for all mental faculties. Aristotle clung to the view that the heart was at the center of mental faculties and that the brain only served to cool the blood. Galen, a Greek physician who practiced in Rome, noticed that the nerves from the sense organs all led to the brain and not the heart, making it obvious to him that the brain was the seat of the mind. Galen also concluded that the cerebrum processes information from the senses and that the cerebellum controls the muscles.

The mind-body problem is an age-old question as to how the mind, which is immaterial, can interact with the material brain. Philosopher and mathematician René Descartes believed that the mind and body were distinct and that they existed independently of each other, a position known as dualism. Descartes believed that simple reflexes could be explained by the movements of fluids through hollow tubes in the body, in what became known as the fluid-mechanical theory. Descartes believed that animals had no soul. Therefore, he believed that all of their behaviors were reflexive. However, he thought that humans were special in that they have a soul. Descartes thought that the soul interacted with the brain in the pineal gland.

Localization of function is the idea that different functions are controlled by specific brain areas. One of the first proponents of this idea was Franz Joseph Gall. Gall believed that the bumps on the skull reflected the abilities for which the underlying cortex was responsible. He thought that the size of a bump related to the extent to which the underlying ability was developed within a person. This practice became known as phrenology. French physician Paul Broca found that many of his patients who suffered from aphasia also had damage to the left frontal lobe. This gave the idea of localization of function a great boost. The idea was bolstered further when Gustav Fritsch and Eduard Hitzig found that electrical stimulation of the cortex of dogs produced twitching in the side of the body opposite to which the stimulation was applied and that the stimulated cortex formed a topographical map of the body. These results were extended by David Ferrier, who found that electrically stimulating the cortex of animals can also cause more complex movements. Wilder Penfield electrically stimulated the brains of patients undergoing surgery to treat epilepsy and found that a motor map, similar to the one discovered by Fritsch and Hitzig in dogs, also existed in humans.

TEST YOURSELF

1.3.1 Discuss the views associated with brain function that prevailed throughout antiquity.

1.3.2 What are some of the philosophical roots that underlie the thinking about the relationship between brain and body?

1.3.3 Trace the history of the idea that brain functions are localized to specific areas.

1.4 Studying Brain-Behavior Relationships Today

Module Contents

1.4.1 Brain-Damaged Patients and Structural Brain Imaging

1.4.2 Lesioning, Stimulating, and Measuring the Brain's Activity

1.4.3 Fields of Study Related to Behavioral Neuroscience

Learning Objectives

1.4.1 Explain how the study of brain-damaged patients can inform neuroscientists about brain-behavior relationships.

1.4.2 Describe how brain-behavior relationships can be inferred by lesioning, stimulating, and measuring the brain's activity.

1.4.3 Define the different fields of study related to behavioral neuroscience.

1.4.1 BRAIN-DAMAGED PATIENTS AND STRUCTURAL BRAIN IMAGING

>> LO 1.4.1 Explain how the study of brain-damaged patients can inform neuroscientists about brain-behavior relationships.

Key Terms

- **Traumatic brain injury:** An injury that results from a blow to the head or from an object penetrating the skull.

- **Structural brain imaging:** Imaging techniques that permit the detection of brain injury.
- **Magnetic resonance imaging (MRI):** A method by which an image of any part of the body can be created with the use of a powerful magnetic field and the emission of a resonant frequency.
- **Computed tomography (CT scan):** A method in which X-ray images are taken from many angles and processed by a computer to produce virtual cross-sections, permitting the examination of structures deep within the brain.

The least invasive way to learn about brain-behavior relationships is to study people who have sustained **traumatic brain injury**. A traumatic brain injury can result from a blow to the head or from an object penetrating the skull (Lunetta, Ohberg, & Sajantila, 2002). Another way in which a person's brain can be damaged is through the progression of neurodegenerative disease such as Alzheimer's disease (Vemuri & Jack, 2010) or Parkinson's disease (Lehericy, Sharman, Dos Santos, Paquin, & Gallea, 2012). The brain can also be damaged by a stroke, in which the flow of blood either to the entire brain or to a specific part of the brain has been cut off.

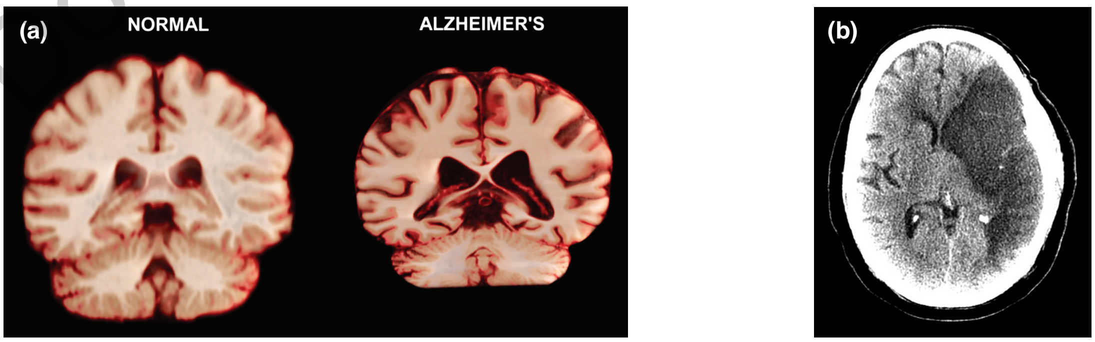
In any case, the changes in behavior or deficits observed in people who have experienced any of these conditions can inform neuroscientists as to which brain areas are likely to be damaged. Also, once the type of brain damage is known, researchers can use this knowledge to predict what types of tasks a person may have difficulties with and design studies to test their predictions. However, the study of brain-damaged patients may not be informative enough to determine the precise location of the brain damage responsible for a given change in behavior or deficit. This is because the brain damage observed in those conditions is often not restricted to any single brain area.

The brain damage caused by these conditions can be observed through **structural brain imaging**. The brain imaging methods most commonly used in these conditions are **magnetic resonance imaging (MRI)** and **computed tomography (CT scan)**. Magnetic resonance imaging is a method by which an image of any part of the body can be created. The area of interest for our purposes is, of course, the brain. An MRI scanner creates an image of the brain by subjecting it to a very powerful magnetic field (the "M" in MRI). This powerful magnetic field induces the nuclei of certain atoms to align. Then, a pulse of radio frequency (the "R" in MRI), which is just right for the nuclei of hydrogen atoms (resonance), is briefly emitted. This pulse alters the alignment of the atoms that resulted from exposure to the magnetic field. The energy from the pulse is absorbed by the nuclei of the atoms. Then the pulse is turned off and the nuclei release that energy and realign with the magnetic field. The release of this energy is detected by the scanner and forms the basis of the image (the "I" in MRI). Remember that MRI does not include the use of X-ray radiation. Figure 1.16a compares MRI scans of a normal brain with that of someone suffering from Alzheimer' disease.

In contrast to MRI, a CT scan makes use of X-ray technology. However, it differs from a regular X-ray examination in that X-ray measurements are taken from many angles. The images are processed by a computer and virtual cross-sections are produced, which permits the examination of structures deep within the brain. A CT scan can also permit the detection of brain damage such as a cerebral infarction, which is an area of dead tissue due to the blockage or narrowing of an artery (Figure 1.16b).

FIGURE 1.16

(a) MRI scans comparing a brain of a normal elderly person (left) with that of a patient suffering from Alzheimer's disease (right). (b) A CT scan of a cerebral infarction due to the blockage or narrowing of an artery.



(a) TheVisualMD/Science Source; (b) Living Art Enterprises, LLC/Science Source

1.4.2 LESIONING, STIMULATING, AND MEASURING THE BRAIN'S ACTIVITY

>> LO 1.4.2 Describe how brain-behavior relationships can be inferred by lesioning, stimulating, and measuring the brain's activity.

Key Terms

- **Manipulation technique:** A technique in which the structure or function of the brain is altered and the resulting effects on behavior are observed.
- **Measurement technique:** A technique in which the brain activity of subjects is measured while they are engaged in some behavioral task with the aim of identifying brain areas that might be involved in its performance.
- **Functional brain imaging:** An imaging technique that permits the measurement of subjects' brain activity while performing a task.
- **Lesioning:** Creating brain damage in experimental animals to determine the functions of particular areas.
- **Deep brain stimulation (DBS):** Inferring the functions of a particular brain area through the administration of a low-voltage electrical current to that area.
- **Transcranial magnetic stimulation (TMS):** Inferring the functions of a particular brain area through the application of a magnetic field over a brain area of interest from the top of the skull.
- **Optogenetics:** The field in which genetics and optics are combined to use light-sensitive molecules to control cellular activity.
- **Functional magnetic resonance imaging (fMRI):** Inferring brain function using MRI technology to image the brain in a way that detects the amount of oxygen used by neurons.
- **Positron emission tomography (PET):** An imaging method in which brain function is inferred by detecting the consumption of glucose by neurons.
- **Electroencephalography (EEG):** A method in which brain function is inferred by detecting differences in the electrical energy emitted from different brain areas.
- **Event-related potentials (ERP):** Small voltage changes, called waveforms, in brain areas responsive to specific events or stimuli.
- **Magnetoencephalography (MEG):** A method in which brain function is inferred by detecting differences in the electromagnetic fields emitted from different brain areas.
- **Intracellular recording:** A method by which tiny electrodes are inserted directly inside neurons to record their electrical activity.
- **Microelectrode:** A tiny electrode used to measure the electrical activity of neurons.
- **Single-unit recording:** A method by which the electrical activity of a single neuron can be recorded.
- **Extracellular recording:** A method by which a microelectrode is inserted into the fluid surrounding neurons to record electrical currents generated by the neurons in the electrode's vicinity.

In addition to studying the behavioral and cognitive deficits suffered by brain-damaged patients with the help of structural brain imaging, there are two main classes of techniques used by behavioral neuroscientists to study brain-behavior relationships. These consist of manipulation and measurement techniques (Huettel, Song, & McCarthy, 2014). With **manipulation techniques**, the structure or function of the brain is altered and the resulting effects on behavior are observed. With **measurement techniques**, the brain activity of subjects is measured while they are engaged in some behavioral task, with the aim of identifying brain areas that might be involved in its performance (Figure 1.17). For this reason, measurement techniques are also known as **functional brain imaging**. In this unit, we will review the most commonly used manipulation and measurement techniques.

Manipulation Techniques

Lesions

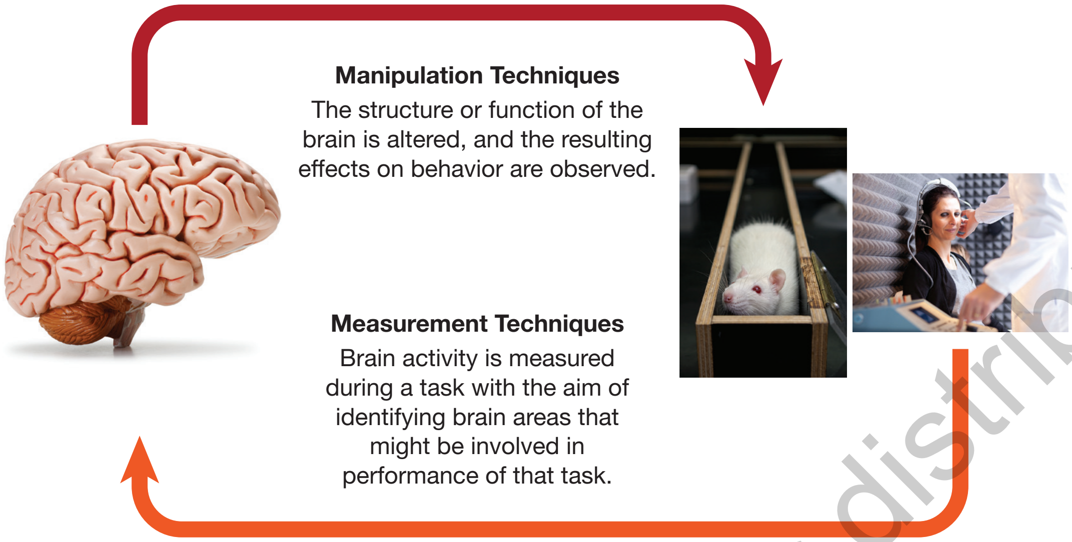
You have just read that studying brain-damaged patients may not inform researchers about specific brain areas responsible for changes in behaviors or deficits. Behavioral neuroscientists can circumvent this problem by **lesioning** specific brain areas in experimental animals and then testing them on various behavioral tasks. Brain lesions can also be induced by administering drugs directly into a brain area of interest or by passing an electrical current through it.

Brain Stimulation

In a procedure called **deep brain stimulation (DBS)**, the functions of a specific brain area can be assessed or enhanced through electrical stimulation. This is done by administering a low-voltage electrical current through electrodes implanted in a brain area or areas of interest. This neurosurgical treatment involves the implantation

FIGURE 1.17

Brain-behavior relationships can be studied using manipulation and measurement techniques.



(Left to right) iStock.com/DNY59; iStock.com/ibreakstock; iStock.com/kaisersosa67

of electrodes in the brain, through the scalp (illustrated in Figure 1.18). The electrodes are connected to a pulse generator implanted below the skin. Clinicians then use a computer that communicates with the device to set the strength and frequency of the stimulation. For example, researchers found that electrically stimulating the temporal cortex, an area important for memory (see Chapter 12), enhanced subjects' ability to recall lists of words, compared to subjects who did not receive the stimulation (Ezzyat et al., 2018; Kucewicz et al., 2018).

DBS can also be administered through electrodes implanted in the subthalamic nucleus (or other brain areas) in the treatment of people with Parkinson's disease, a disorder characterized by shaking, slowness of movement, and rigidity (Mohammed, Bayford, & Demosthenous, 2018; Okun, 2012). DBS is also used to administer electrical stimulation to the ventral striatum in patients who have treatment-resistant obsessive-compulsive disorder (Greenberg et al., 2010). DBS is also being tested for use in the treatment of major depression (Drobisz & Damborska, 2019). Obsessive-compulsive disorder and major depression are discussed further in Chapter 14.

Another way to manipulate brain functioning is through the application of a magnetic field over a brain area of interest from the top of the skull. This method is known as **transcranial magnetic stimulation (TMS)** (illustrated in Figure 1.19). In TMS, electrical current is run through a coil of wires shaped like a figure-eight, which results in the production of a magnetic field. The coil of wires is then placed next to the skull over the brain region scientists are interested in studying. In this way, the magnetic field, produced by the electrified coil, can stimulate or inhibit the neurons in the brain region of interest. Whether neurons are stimulated or inhibited depends on the frequency of the magnetic field. The researchers using TMS can then deduce the importance of a certain brain region to specific tasks by examining the effects that TMS has on the performance of those tasks.

Temporary Inactivation

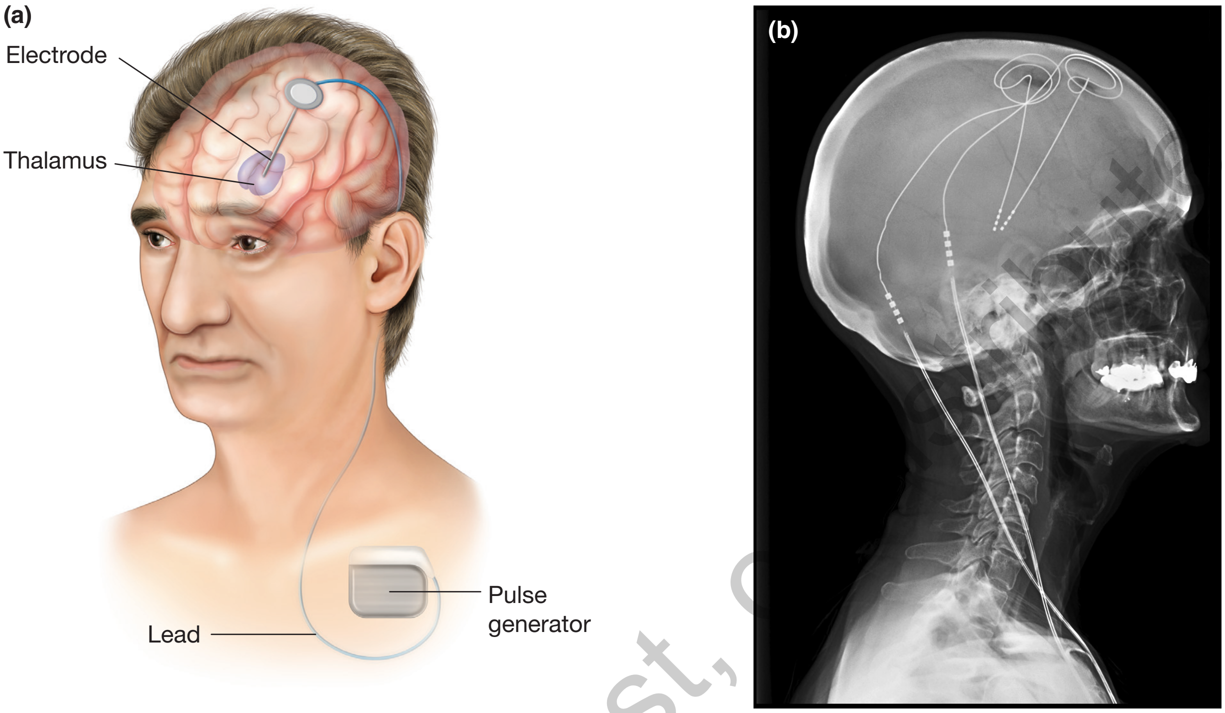
Sometimes neuroscientists want to compare the functions of a brain area when it is functioning normally to when it is not functioning normally. For this purpose, they can inject a drug that temporarily inactivates a specific brain area. Animals can then be tested on behavioral tasks while the brain area is inactivated and tested again once the drug has worn off.

Another way in which the functions of a specific brain area can be tested in animals is by turning neurons on or off using light in a method known as **optogenetics** (see "Applications" at the end of Chapter 2). Optogenetics is the field in which genetics and optics are combined to use light-sensitive molecules to control cellular activity. This may involve making neurons responsive to light by altering their genetic makeup. The use of optogenetics is a relatively new way of manipulating the brain. Similar to temporary inactivation, optogenetics can be used to temporarily activate or deactivate neurons in particular brain areas and then observe the resulting effects on task performance.

Certain organisms, such as bacteria, have cells that contain light-sensitive proteins. Some frequencies of light—for example, blue light—activate their cells. Other frequencies—for example, yellow light—deactivate them.

FIGURE 1.18

(a) Patient set up with a deep brain stimulation (DBS) device. (b) X-ray of the head and neck of a patient fitted with a DBS device.



(a) Amanda Tomasikiewicz/Body Scientific Intl.; (b) Living Art Enterprises/Science Source

FIGURE 1.19

Person receiving transcranial magnetic stimulation (TMS).

Amélie Benoist/SCIENCE SOURCE

To activate or deactivate neurons in experimental animals with lights of different colors, scientists attach the genes for the light-sensitive proteins of these bacteria to harmless viruses. These viruses are then injected into the brain of animals where it is incorporated into the animals' neurons. To activate or deactivate the neurons with light, scientists drill small holes in the skulls of animals, through which they can lower light-emitting diodes (LEDs) of different frequencies into the brain area(s) of interest.

Measurement Techniques

Functional Magnetic Resonance Imaging (fMRI)

As you just read, some of the methods used by neuroscientists involve manipulating the brain in some way and then observing the effects resulting from the manipulation. However, brain-behavior relationships can also be inferred by observing the brain in action. One of the most popular methods to do this is called **functional magnetic resonance imaging (fMRI)**. An fMRI scanner can image the brain with the use of a strong magnetic field and can also detect the amount of oxygen used by neurons. A person's brain can therefore be scanned while the individual performs a behavioral task. The neurons in the brain areas associated with the performance of the given task will consume more oxygen than areas that are least involved in the task. This difference in oxygen consumption by neurons is fed into a computer program and can be visualized by the experimenter (Figure 1.20a).

Positron Emission Tomography

Another popular method of imaging the brain is known as **positron emission tomography (PET)**. A PET scan detects the consumption of glucose by neurons. Participants in a PET study are injected with glucose molecules attached to a radioactive element called an isotope, which decays over time. They are then given a behavioral task while their brain is being scanned. Neurons use glucose for energy. Therefore, the neurons within the brain areas that are activated by the performance of the task consume more glucose, which as we just mentioned is attached to a radioactive isotope. The radioactively tagged glucose goes all over the brain. As the isotope decays, it emits what is known as a positron. When a positron meets an electron, they annihilate each other, which results in the release of energy. More of this energy will be detected in the brain areas associated with the performance of the task, relative to areas that are not. As with fMRI, this information is fed into a computer program and visualized by the experimenter (Figure 1.20b).

Electroencephalography

Electroencephalography (EEG), shown in Figure 1.21a, is a method by which the flow of electrical currents produced by the communication between neurons in the brain is detected by electrodes placed on the scalp. The electrodes are placed above all regions of the skull in order to record from various regions of the brain.

When neurons communicate with each other, waves of electrical currents, commonly called brainwaves, are produced. These are picked up by the electrodes. Researchers can then examine the pattern of brain activity while the subject performs a particular task.

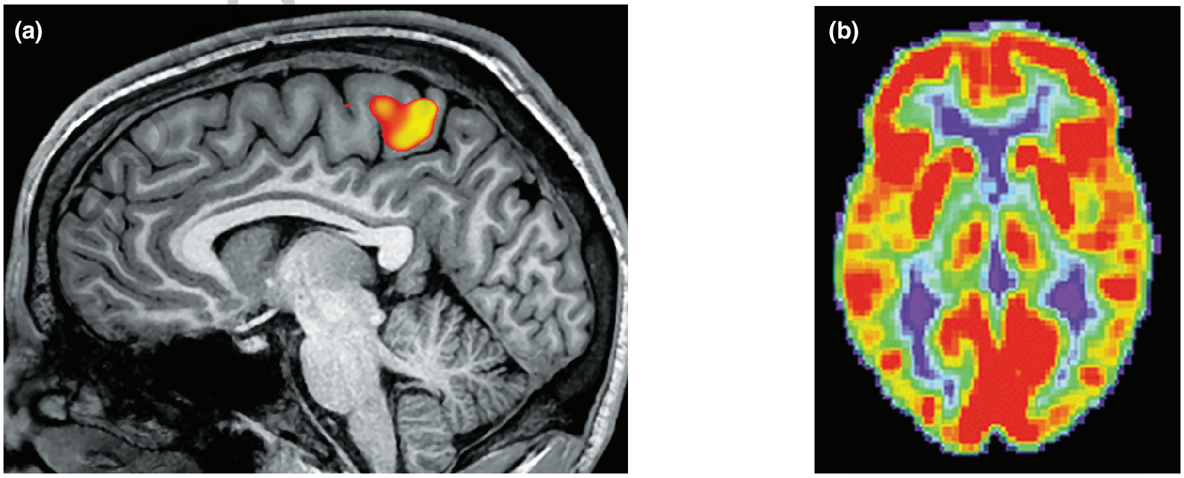
Through this method scientists have also discovered that the brain produces wavelengths of different frequencies and amplitudes, depending on a person's state of consciousness. For example, I presume you are presently alert and awake while reading this text or when you attend classes. Alertness and waking states are associated with high-frequency wavelengths of low amplitude. When you are sleeping, presumably not in class, your brain emits wavelengths of low frequency with high amplitude. However, when you are dreaming, your brain emits wavelengths that look more like the ones emitted while awake, which are of high frequency and low amplitude. Figure 1.21b shows how different types of wavelengths are associated with different stages of sleep (for details about the brainwaves generated in different states of consciousness, see Chapter 9).

EEG is also used to measure what are known as **event-related potentials (ERPs)**. ERPs are small voltage changes, called waveforms. ERPs are detected when many neurons fire in synchrony in response to events in an individual's environment. These events can be part of an individual's external or internal environment. Events can be sensory, cognitive, or motor. Therefore, ERPs can be used to investigate the role of the brain in processing sensory, motor, and cognitive information.

Different types of events trigger different types of waveforms. Studying ERPs permits neuroscientists

FIGURE 1.20

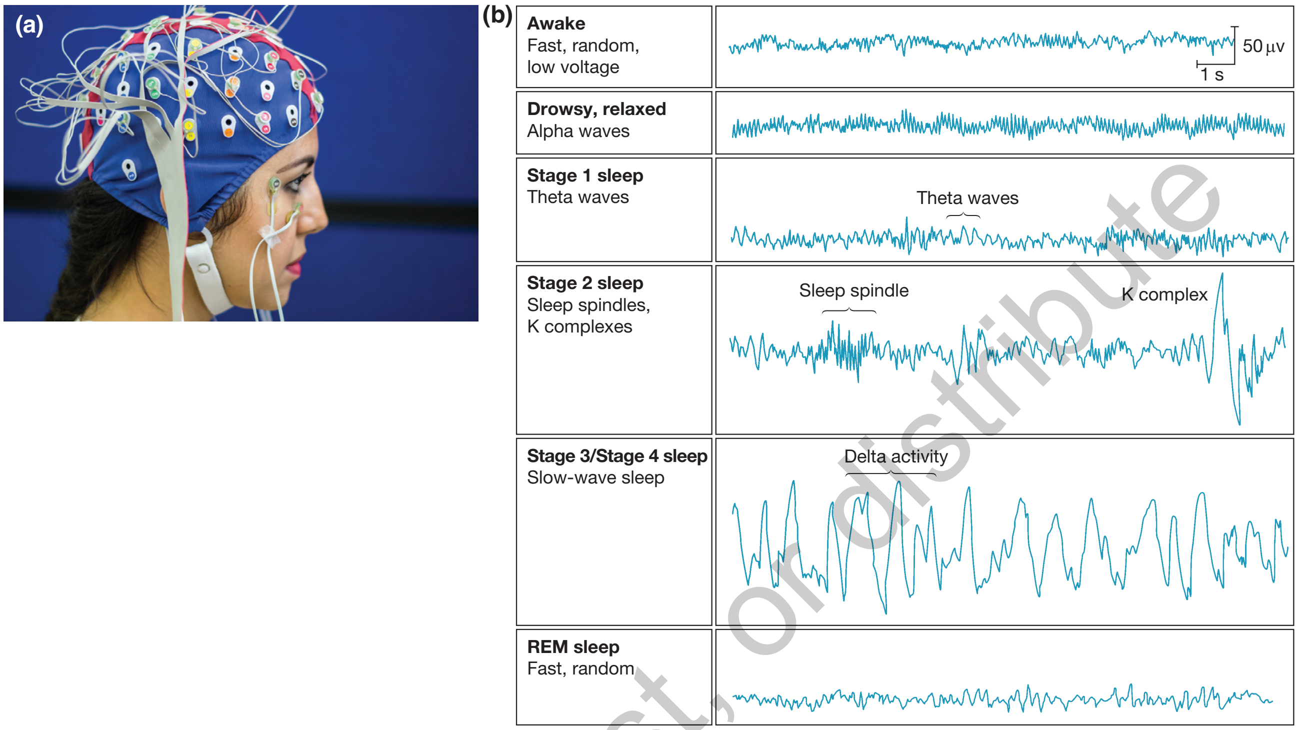
Images of the brain obtained through (a) fMRI and (b) PET scan. The relative activity of brain areas is represented by different colors. Areas of higher activity are represented by warm colors such as red, orange, and yellow, whereas areas of lower activity are represented by blueish and violet colors.



(a) Living Art Enterprises/SCIENCE SOURCE; (b) National Institute of Aging/NIH/SCIENCE SOURCE

FIGURE 1.21

(a) Woman undergoing an EEG. (b) Brain waves measured by EEG are associated with different stages of sleep.



(a) iStock.com/Latsalomao; (b) From *Current Concepts: The Sleep Disorders*, P. Hauri, Kalamazoo, MI: Upjohn, 1982.

to learn about how different brain areas are involved in language, memory, and attentional processes. Neuroscientists may also use ERPs to study abnormal functioning that occurs in various psychiatric disorders such as in schizophrenia, substance abuse, and anxiety disorders (Sur & Sinha, 2009).

ERPs are usually measured from the scalp (scalp ERP). However, on rare occasions an electrode can be inserted directly within a brain structure (intracranial ERP). This type of ERP is rare and is usually done to assess the electrical activity in a particular brain area before brain surgery.

A similar method known as **magnetoencephalography (MEG)** measures the magnetic fields produced by communicating neurons, instead of the electrical fields measured by EEG. The advantage of MEG over EEG is that intervening tissue has very little effect on the clarity of the magnetic signal compared to the electrical signal. Wherever electrical current is present, there is also a magnetic field. Therefore, the source of the signal detected by MEG is the same as in EEG.

However, the signals generated by magnetic fields are very weak. For this reason, they are easily interfered with by magnetic fields generated by computers, elevators, and other electrical machines or instruments present in the environment. Therefore, MEG recordings have to be done in a special room that blocks out environmental magnetic fields.

Electrophysiological Measurements

Neuroscientists are sometimes interested in measuring the electrical activity of individual neurons. This is done through **intracellular recording**, which involves inserting a tiny metal wire called a **microelectrode** directly inside a neuron to measure the current that flows through it. This method is often referred to as **single-unit recording**. Electrodes may also be placed in the fluid outside of neurons and the electrical activity generated around the tip of the microelectrode is measured. This method is known as **extracellular recording**.

1.4.3 FIELDS OF STUDY RELATED TO BEHAVIORAL NEUROSCIENCE

>> **LO 1.4.3 Define the different fields of study related to behavioral neuroscience.**

Key Terms

- **Neuroanatomy:** The scientific study of the structures and organization of the nervous system.

- **Neurochemistry:** The scientific study of how chemicals in the brain are synthesized and involved in brain function.
- **Neuroendocrinology:** The scientific study of how hormones, which are chemicals that control important bodily functions, interact with the nervous system.
- **Neuropathology:** The scientific study of the changes in the brain that occur when it becomes diseased.
- **Neuropharmacology:** The scientific study of how drugs and other agents already inside the brain affect the function of cells.
- **Neuropsychopharmacology:** The scientific study of how drugs produce psychotropic effects.
- **Neurophysiology:** The scientific study of brain function by using various methods to stimulate, measure, or record the activity of individual brain cells or entire brain areas.
- **Neuropsychology:** The scientific study of how psychological functions are localized in certain brain areas.

The study of behavioral neuroscience draws from and influences the study of many related areas. One of these areas is **neuroanatomy**. Neuroanatomy is the study of the structure and organization of the nervous system. The study of neuroanatomy results in a greater understanding of how the brain functions, how it is shaped by environmental influences, and how it changes throughout development (Lerch et al., 2017).

Whereas neuroanatomists are interested in charting the nervous system's structure and organization, neuroscientists who study **neurochemistry** are interested in how chemicals in the brain are synthesized and involved in brain function. Findings from the study of neurochemistry can inform neuroscientists on many brain processes, such as those involved in learning (Hakim & Keay, 2018) and in the development of disorders (Rajagopal, Huang, Michael, Kwon, & Meltzer, 2018).

In the field known as **neuroendocrinology**, neuroscientists are interested in how hormones, which are chemicals that control important bodily functions, interact with the nervous system. The study of neuroendocrinology can inform neuroscientists on the basis of many types of behaviors, including those involved in feeding (Edwards & Abizaid, 2017) and reproduction (Mani & Oyola, 2012).

Neuroscientists who study **neuropathology** are mostly interested in the changes in the brain that occur when it becomes diseased. For example, the study of neuropathology provides valuable insight into the processes involved in Alzheimer's disease (Mostafavi et al., 2018) and Parkinson's disease (Dickson, 2018).

Neuropharmacology is the field in which neuroscientists study how drugs and other agents affect the functioning of neurons. One of the aims of neuropharmacology is to discover drugs that may one day be used in the treatment of neurological and psychological disorders (Yeung, Tzvetkov, & Atanasov, 2018). Neuropharmacologists may also be interested in how drugs can act as environmental risk factors in the development of psychological disorders. For example, it was found that exposure to cannabis and stress during adolescence may increase the probability that someone will suffer from excessive anxiety, characterized by exaggerated fears (Saravia et al., 2019).

In **neuropsychopharmacology**, neuroscientists study how drugs produce psychotropic effects, that is, how they affect a person's mind, emotions, and behavior through their actions in the brain. For example, it was found that the drug lysergic-acid diethylamide (LSD) and other drugs produce visual hallucinations (seeing things that are not really there) by increasing the activity of the brain chemical called serotonin (Kraehenmann et al., 2017), which you will learn about in Chapter 3, and by increasing the excitation of a variety of brain areas related to vision (Kometer & Vollenweider, 2018).

In the study of **neurophysiology**, neuroscientists may also be interested in learning about brain function by using various methods to stimulate, measure, or record the activity of individual brain cells or entire brain areas. For example, several studies have shown that exercise has positive effects on mood and cognition. Neurophysiological studies have provided evidence for the neurobiological basis of these effects by showing that exercise increases activity in relevant brain areas (Basso & Suzuki, 2017).

Finally, some neuroscientists are interested in studying how psychological functions are localized in certain brain areas. Such is the field of **neuropsychology**. Neuropsychologists can learn about the localization of functions by creating damage to specific brain areas in experimental animals and testing them on a task relevant to the function of interest. Neuropsychologists also acquire knowledge about brain function by studying people who have suffered brain damage. Neuropsychologists can also relate activity in certain brain areas, measured by various imaging methods, to specific functions. For example, it was found that people with damage to a part of the brain called the prefrontal cortex are impaired in understanding the emotions of others (A. Perry et al., 2017).

Who Is Interested in Findings From Behavioral Neuroscience?

The fields of study just described are considered to be subfields of neuroscience. However, people in other fields of study and professions that do not necessarily engage in neuroscience research may be interested in the findings that emanate from behavioral neuroscience. This includes neurologists, who are trained to diagnose and treat disorders of the nervous system; psychiatrists, who are trained to diagnose and treat mental disorders; and neurosurgeons, who are trained to perform surgery on the nervous system. The list also includes psychologists, professors, various health practitioners, and many more.

Graduates from university programs in behavioral neuroscience or neuroscience in general can find employment in a variety of more or less related fields. Lists of these fields can be found on the websites of various universities. For example, the following link is to the Careers in Neuroscience website of Princeton University: https://pni.princeton.edu/undergraduate-concentration/careers-neuroscience.

MODULE SUMMARY

Today, brain-behavior relationships are studied in many different ways. For example, patients who have suffered brain damage through various ways can be studied and the kind and extent of their brain damage can be related to impairments in behavioral tasks. The extent of the brain damage can be assessed by imaging methods such as magnetic resonance imaging and computed tomography. Scientists can find out whether a given brain area is related to some behavioral function by lesioning specific brain areas of experimental animals and then testing them on behavioral tasks to see if the lesion caused any kind of impairment in function. The same areas can also be stimulated to see whether any change in behavior can be observed. The brain can be stimulated in several ways. These include electrical brain stimulation and transcranial magnetic stimulation. Neurons in specific brain areas can also be turned off temporarily by the administration of drugs that can inactivate them. Furthermore, neurons can be turned either on or off by genetically altering them to make them responsive to light in what is known as optogenetics.

Brain activity can be related to behavior through methods that permit neuroscientists to observe the extent to which brain areas are used in the performance of behavioral tasks. These include functional magnetic resonance imaging, electroencephalography, and magnetoencephalography. Finally, neuroscientists can also record the electrical activity of individual neurons by inserting a tiny electrode either inside individual neurons to measure their electrical activity or in the fluid in which neurons bathe to measure the electrical current flowing near the electrode. This activity is related to the behavior being performed by the animal at the time of recording.

Fields of study related to behavioral neuroscience include neuroanatomy, neurochemistry, neuroendocrinology, neuropathology, neuropharmacology, neuropsychopharmacology, neurophysiology, and neuropsychology. Finally, many practitioners, who do not necessarily engage in research, may also be interested in findings from the study of behavioral neuroscience. These include neurologists, psychiatrists, neurosurgeons, professors, and various health practitioners.

TEST YOURSELF

1.4.1 Explain how the study of brain-damaged patients informs neuroscientists about brain-behavior relationships.

1.4.2 How are brain-behavior relationships inferred by lesioning, stimulating, and measuring the brain's activity?

1.4.3 Name and differentiate between the areas related to behavioral neuroscience.

APPLICATIONS

Brain Imaging as a Lie Detector: Not So Fast!

You have probably seen it in many movies and television series. A crime suspect is hooked up to devices measuring blood pressure, pulse, and skin conductivity. The purpose is to determine whether the individual is lying. This procedure is known as the polygraph test. The polygraph test does not directly measure whether someone is lying but, rather, measures the physiological reactions triggered when someone fails to tell the truth. Although the polygraph is great for enhancing movie drama, its results are inadmissible in the courtroom as evidence of someone's guilt. This is because of problems

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associated with interpreting the results of a polygraph test. That is, no pattern of physiological reactions is known to be associated exclusively with lying. For example, heightened physiological reactions may not necessarily be indicative of a lie but may instead indicate that the person is simply nervous about the test. In contrast, a lack of reaction may be due to a subject's being exceptionally calm while lying. Within this context, the question arose as to whether more valid physical correlates of lying could be developed.

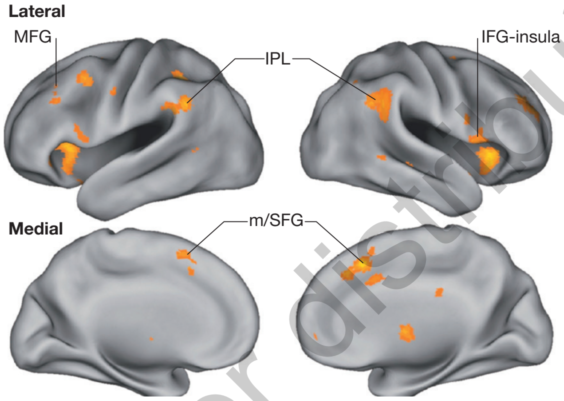
Enter functional magnetic resonance imaging (fMRI). Functional magnetic resonance imaging is used in both research and medicine to observe how brain activity is related to cognitive and behavioral function. It does so by measuring the amount of oxygen taken up by neurons while an individual performs a task. Neurons in brain areas most solicited by the task consume more oxygen than other areas, which is detected by the scanner and taken as evidence that the area is involved in the performance of the task.

Among many other questions related to brain-behavior relationships, some neuroscientists are trying to determine whether fMRI can be used to detect whether someone is lying and whether fMRI can become a superior method to the polygraph. If so, will the results obtained through fMRI ever become admissible evidence in a court of law? Before this happens, much more evidence will be needed regarding the validity and reliability of findings relating fMRI results to lying. That is, do the results truly reflect lying and not some other cognitive functions, and can the results be reliably replicated? So far neuroscientists have no evidence that either of these conditions has been met.

The quest to find out whether fMRI can be used as a lie detector began in the early 2000s when psychiatrist Daniel D. Langleben and colleagues (2002) administered the guilty knowledge test (GKT) to subjects while their brains were being imaged by fMRI. The GKT involves asking participants to answer no in response to questions to which both the participant and the experimenter know the answer to be yes. Langleben's hypothesis was that because lying requires an individual to inhibit giving a truthful response, areas of the brain associated with response inhibition, namely, the prefrontal and cingulate cortex, should be activated when an individual is lying. The study confirmed Langleben's hypothesis in that there was a significant difference in the pattern of brain areas activated in participants when telling the truth and when being deceitful. Since that time, several studies using fMRI have identified brain areas that are consistently activated when someone is lying. As shown in Figure 1.22, these include the lateral areas such as the medial frontal gyrus (MFG), inferior parietal lobule (IPL), and the insula in the inferior frontal gyrus

FIGURE 1.22

Is this the brain of a liar? Results of a study in which fMRI was used to detect deception. Areas in orange are consistently activated across studies when lying.



Farah, M.J., et al. (2014). Functional MRI-based lie detection: scientific and societal challenges. *Nature Reviews Neuroscience* 15: 123–131. With permission from Springer Nature.

(IFG-insula). They also include medial areas of the brain such as the medial and superior frontal gyrus (m/SFG) (Farah, Hutchinson, Phelps, & Wagner, 2014).

However, the results of those studies must be interpreted with caution because many other factors could have contributed to the brain activation observed in individuals while they were lying. These include memory and attentional processes related to the experimental setup and procedures used in the studies. For example, in one study, simply getting the instructions to lie increased brain activity. In another study, subjects were asked to pretend to steal objects, hide them, and lie about having taken them, leading to the possibility that brain activity may reflect memory for objects in addition to activation related to deception (Gamer, Klimecki, Bauermann, Stoeter, & Vossel, 2012).

In addition to these possible confounds, neuroscientists have come up with several hurdles that would need to be dealt with. For example, questions still remain as to whether laboratory conditions under which these fMRI studies are conducted reflect real-life situations, in which individuals are asked questions about real-life moral violations, the answers to which could result in them going to jail. Another question has to do with whether patterns of results while being deceptive generalize to different populations, such as those defined by age group, profession, or the presence of mental illness.

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