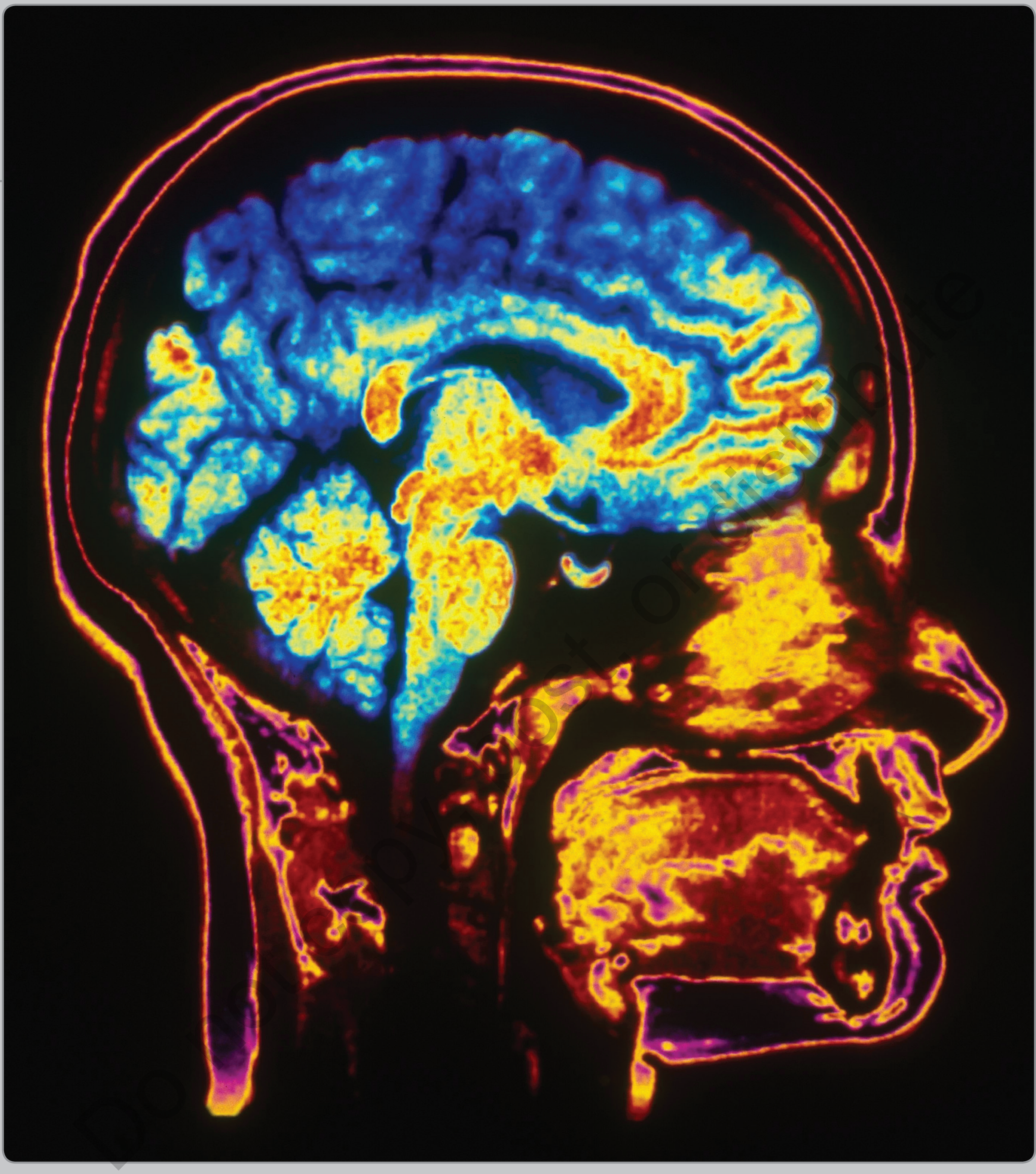


Scott Camazine/Science Source

1 What Is Behavioral Neuroscience?

After reading this chapter, you will be able to

1.1 Define the mind-brain problem in behavioral neuroscience.

1.2 Describe the contributions of philosophers and scientists to the development of behavioral neuroscience as a field of study.

1.3 Identify the role of physiologists in the establishment of modern-day behavioral neuroscience.

1.4 Compare the relative contributions of genes and environment in the development of behavioral characteristics.

1.5 Critique the fixed nature of heredity in shaping behavior.

That device you carry in your pocket is a wonder of modern technology. It represents a very recent step in the evolution of long-distance communications, which began with smoke signals and drum beats and progressed through the telegraph, the wireless radio, and the landline telephone.

Mobile telephones appeared in vehicles in 1956, but a handheld mobile was not commercially available until 1983; dubbed the “brick,” it weighed 1.75 pounds (0.79 kilograms) and cost $3,995 (Figure 1.1). Your 4- or 5-ounce phone operates over a vast cellular network to connect you to your friends and family and an estimated 5 billion people all around the world (there are actually more mobile devices on earth than there are people). Assuming you have a smartphone, you have access to many additional people by way of email, text, and video, as well as more than 1.8 billion websites on the Internet. Your phone also allows you to record memories in the form of notes and images, perform calculations, identify a tune or a flower, find your friends, and determine the best route for your road trip.

The brain has many similarities. An iPhone XR has around 7 trillion transistors (Shankland, 2018). The human brain contains about 80 billion neurons, but each of these in turn connects to thousands of others, forming a network of more than 100 trillion synapses (The Human Memory, 2019) where the brain’s work is done. One computational neuroscientist estimates that the brain’s storage capability rivals that of the Internet; as a psychologist put it, if the brain were a video recorder, it could store 2,500 GB of video information, which would take you about 300 *years* to watch

FIGURE 1.1 Lead Engineer Martin Cooper With the Motorola DynaTAC 8000X.

When the first handheld cellular phone came out in 1984, it cost $4,000 (about $10,000 today), had a battery that took 10 hours to charge, and only had 30 minutes of talk time.

Ted Soqui/Corbis Historical/Getty Images

(Reber, 2010). But storage of memories and information is only one of the brain's many tasks. The brain is organized into specialized subnetworks that orchestrate your body's 650 muscles and 206 bones, generate thought and make decisions, perform calculations, keep track of where you are and help you navigate around your world, tell you when and what to drink and eat, and provide your language capability and range of sensory capabilities. Like the cell phone, the brain has evolved over time and across species, but in this case, as its capability has grown, so has its size. Still, all its amazing power is packed into just 3 pounds of tissue that consumes the same amount of energy as a 20-watt light bulb!

Mobile phones came into their own in the last decade of the 20th century, in terms of both their capabilities—such as built-in cameras, Bluetooth connectivity, and augmented reality—and their popularity, indicated by more sales worldwide in 1998 than for cars and PCs combined. The period was also seminal for the awakening field of neuroscience, so much so that in the United States, it was designated as the Decade of the Brain. Planned as an effort to increase public awareness of the benefits of brain research, the Decade of the Brain was also a celebration of past achievements and a sober look at the future. At the threshold of a new millennium, we understood that we had an obligation to expand the horizons of human knowledge and advance the treatment of neurological diseases, emotional disorders, and addictions that cost the country a trillion dollars per year in care, lost productivity, and crime (Uhl & Grow, 2004). Since then, in the span of your lifetime, we have developed new treatments for depression, identified key genes responsible for the devastation of schizophrenia, developed agents that block addiction to drugs, found ways to slow the memory impairment of Alzheimer's, produced a map of the human genes, and literally peered into the brain itself to watch it work. These achievements seem remarkable for such a brief span of time, but, in fact, they have their roots in a 300-year scientific past and in 22 centuries of thought and inquiry before that. For that reason, we will spend a brief time examining those links to our past.

The Origins of Behavioral Neuroscience

? What is behavioral neuroscience, and how does it relate to psychology?

The term *neuroscience* identifies the subject matter of the investigation rather than the scientist's training. A neuroscientist may be a biologist, a physiologist, an anatomist, a neurologist, a biochemist, a psychologist, a psychiatrist—or even a computer scientist or a philosopher. Psychologists who work in the area of neuroscience specialize in *behavioral neuroscience*, the branch of psychology that studies the relationships between behavior and the body, particularly the brain. (*Behavioral neuroscience* is the more modern term for *biological psychology*; sometimes the term *biopsychology*, *psychobiology*, or *physiological psychology* is also used.) For psychologists, *behavior* has a very broad meaning, which includes not only overt acts but also internal events such as learning, thinking, and emotion. Behavioral neuroscientists attempt to answer questions such as "What changes in the brain when a person learns?"

"Why does one person develop depression and another, under similar circumstances, becomes anxious, while another seems unaffected?" "What is the physiological explanation for emotions?" "How do we recognize the face of a friend?" "How does the brain's activity result in consciousness?" Behavioral neuroscientists use a variety of research techniques to answer these questions, as you will see in Chapter 4. Whatever their area of study or their strategy for doing research, behavioral neuroscientists try to go beyond the mechanics of how the brain works to focus on the brain's role in behavior.

To really appreciate the impressive accomplishments of today's brain researchers, it is useful, perhaps even necessary, to understand the thinking and the work of their predecessors. Contemporary scientists stand on the shoulders of their intellectual ancestors, who made heroic advances with far less information and technology at their disposal than is available to today's undergraduate student.

Writers have pointed out that psychology has a brief history but a long past. What they mean is that thinkers have struggled with the questions of behavior and experience for more than two millennia, but psychology arose as a separate discipline fairly recently; the date most people accept is 1879, when Wilhelm Wundt (Figure 1.2) established the first psychology laboratory in Leipzig, Germany. But biological psychology would not emerge as a separate science until psychologists offered convincing evidence that the biological approach could answer significant questions about behavior. To do so, they would have to come to terms with an old philosophical question about the nature of the mind. Because the question forms a thread that helps us trace the development of behavioral neuroscience, we will orient our discussion around this issue.

Prescientific Psychology and the Mind-Brain Problem

This issue is usually called "the mind-body problem," but it is phrased differently here to place the emphasis squarely where it belongs—on the brain. The *mind-brain problem* deals with what the mind is and what its relationship is to the brain. There can be no doubt that the brain is essential to our behavior, but does the mind control the brain, or is it the other way around? Alternatively, are the mind and brain the same thing? How these questions are resolved affects how we ask all the other questions of neuroscience.

At the risk of sounding provocative, we argue that there is no such thing as *mind*. It exists only in the sense that, say, weather exists; weather is a concept used to include rain, wind, humidity, and related phenomena. We talk as if there is *a weather* when we say things like "The weather is interfering with my travel plans." But no one really thinks that there is *a weather*. Most, though not all, neuroscientists believe that we should think of the mind in the same way; it is simply the collection of things the brain does, such as thinking, sensing, planning, and feeling. But when we think, sense, plan, and feel, we get the compelling impression that there is *a mind* behind it all, guiding what we do and how we interpret our world. Most neuroscientists say this is just an illusion; the sense of mind is nothing more than an awareness of what the brain is doing. Mind, like weather, is just a concept; it is not a *something*; it does not *do* anything.

This position is known as monism, from the Greek *monos*, meaning "alone" or "single." *Monism* is the idea that the mind and the body consist of the same substance. Idealistic monists believe that everything is nonphysical mind, but most monists take the position that

FIGURE 1.2 Wilhelm Wundt (1832–1920).

Weltrundschau zu Reclams Universum 1902

the body and mind and everything else are physical; this view is called *materialistic monism*. The idea that the mind and the brain are separate is known as *dualism*. For most dualists, the body is material and the mind is nonmaterial. Most dualists also believe that the mind influences behavior by interacting with the brain.

? How do monists and dualists disagree on the mind-brain question?

This question did not originate with modern psychology. Ancient Egyptian texts about life after death support a dualistic perspective before two millennia BCE, and the Greek philosophers were debating it in the fifth century BCE (G. Murphy, 1949), when Democritus proposed that everything in the world was made up of atoms (*atomos*, meaning "indivisible"), his term for the smallest particle possible. Even the soul, which included the mind, was made up of atoms, so it, too, was material. Plato and Aristotle, considered the two greatest intellectuals among the ancient Greeks, continued the argument into the fourth century BCE. Plato was a dualist, whereas his monistic student Aristotle joined the body and soul in his attempt to explain memory, emotions, and reasoning.

Defending either position was not easy. The dualists had to explain how a nonphysical mind could influence a physical body, and monists had the task of explaining how the physical brain could account for mental processes such as perception and conscious experience. But the mind was not observable, and even the vaguest understanding of the nervous system was not achieved until the 1800s, so neither side had much ammunition for the fight.

Descartes and the Physical Model of Behavior

Scientists often resort to the use of models to understand whatever they are studying. A *model* is a proposed mechanism for how something works. Sometimes, a model is in the form of a theory, such as Charles Darwin's explanation that a species developed new capabilities because the capability enhanced the individual's survival and opportunity to reproduce. Other times, a model is a simpler organism, simulation, or system that scientists study in an attempt to understand a more complex one. For example, researchers have used the rat to model everything from learning to Alzheimer's disease in humans, and the computer has often been used to simulate models of cognitive processes. Historically, models tended to follow technological advancements in society, especially in early attempts to understand the nervous system. Though as we discuss in Chapter 2 with respect to human-exclusive processes, models will not duplicate the complexity of the human mind.

? What is a model in science, and how is it useful?

In the 17th century, the French philosopher and physiologist René Descartes (Figure 1.3a) used a hydraulic model to explain the brain's activity (Descartes, 1662/1984). Descartes's choice of a hydraulic model was influenced by his observation of the statues in the royal gardens at St. Germain. When a visitor stepped on certain tiles, the pressure forced water through tubes to the statues and made them move. Using this model, Descartes then reasoned that nerves were also hollow tubes. The fluid they carried was not water but what he called "animal spirits"; these flowed from the brain and inflated the muscles to produce movement. Sensations, memories, and other mental functions were produced as animal spirits flowed through "pores" in the brain. The animal spirits were pumped through the brain by the pineal gland (Figure 1.3b). Descartes's choice of the pineal gland (named because it resembled a pine cone) was based on his conclusion that it was at a perfect location to serve this function. Attached just below the two cerebral hemispheres by its flexible stalk, it appeared capable of bending at different angles to direct the flow of animal spirits into critical areas of the brain. It also was, to Descartes, the only part of the brain that was a single organ and not split into left and right sides (Berhouma, 2013). Thus, for Descartes, the pineal gland became the "seat of the soul," the place where the mind interacted with the body. Although Descartes assigned control to the mind, his unusual emphasis on the physical explanation of behavior foreshadowed the physiological approach that would soon follow.

Descartes lacked an understanding of how the brain and body worked, so he relied on a small amount of anatomical knowledge and a great deal of speculation. His hydraulic model not only represented an important shift in thinking it also illustrates how a model or a theory

FIGURE 1.3 Descartes (1596–1650) and the Hydraulic Model.

Descartes believed that behavior was controlled by animal spirits flowing through the nerves.

iStockphoto.com/traveler1116

Photo 12/Contributor/Getty Images

can lead us astray, at least temporarily. Fortunately, this was the age of the Renaissance, a time not only of artistic expansion and world exploration but also of scientific curiosity. Thinkers began to test their ideas through direct observation and experimental manipulation as the Renaissance gave birth to science. In other words, they adopted the method of *empiricism*, which means that they gathered their information through observation rather than logic, intuition, or other means. Progress was slow, but two critically important principles would emerge as the early scientists ushered in the future.

Helmholtz and the Electrical Brain

In the late 1700s, the Italian physiologist Luigi Galvani showed that he could make a frog's leg muscle twitch by stimulating the attached nerve with electricity, even after the nerve and muscle had been removed from the frog's body. A century later in Germany, Gustav Fritsch and Eduard Hitzig (1870) produced movement in dogs by electrically stimulating their exposed brains. What these scientists showed was that animal spirits were not responsible for movement; instead, the cause was *nerves operated by electricity*! But the German physicist and physiologist Hermann von Helmholtz (Figure 1.4) demonstrated that nerves do not behave like wires conducting electricity. He was able to measure the speed of conduction in nerves, and his calculation of about 90 feet/second (27.4 meters/second) fell far short of the speed of electricity, which travels through wires at the speed of light (186,000 miles/second or 299,000 kilometers/second). It was obvious that researchers were dealing with a biological phenomenon and that the functioning of nerves and of the brain was open to scientific study. Starting from this understanding, Helmholtz's studies of vision and hearing gave "psychologists their first clear idea of what a fully mechanistic 'mind' might look like" (Fancher, 1979, p. 41). As

? What two discoveries furthered the early understanding of the brain?

■ **FIGURE 1.4** Hermann von Helmholtz (1821–1894).

INTERFOTO / Personalities / Alamy Stock Photo

■ **FIGURE 1.5** Paul Broca (1824–1880).

Wikimedia Commons.

you will see in later chapters, Helmholtz's ideas were so insightful that even today we refer to his theories of vision and hearing as a starting point before describing the current ones.

The Localization Issue

The second important principle to come out of this period—localization—emerged over the first half of the 19th century. *Localization* is the idea that specific areas of the brain carry out specific functions. Fritsch and Hitzig's studies with dogs gave objective confirmation to physicians' more casual observations dating as far back as 17th-century BCE Egypt (Breasted, 1930), but it was two medical case studies that really grabbed the attention of the scientific community. In 1848, a railroad construction foreman named Phineas Gage was injured when a dynamite blast drove an iron tamping rod through his skull and the frontal lobes of his brain (see Chapter 3). Amazingly, he survived with little impairment of his intelligence, memory, speech, or movement. But he became irresponsible and profane and was unable to abide by social conventions (H. Damasio, Grabowski, Frank, Galaburda, & Damasio, 1994). Then, in 1861, the French physician Paul Broca (Figure 1.5) performed an autopsy on the brain of a man who had lost the ability to speak after a stroke. The autopsy showed that damage was limited to an area on the left side of his brain now known as Broca's area (Broca, 1861).

By the mid-1880s, additional observations like these had convinced researchers about localization. But a few brain theorists were already taking the principle of localization too far, and we should be on guard lest we make the same mistake. At the end of the 18th century, when interest in the brain's role in behavior was really heating up, the German anatomist Franz Gall had come up with an extreme and controversial theory of brain localization. According to *phrenology*, each of 35 different "faculties" of emotion and intellect—such as combativeness, inhabitiveness (love of home), calculation, and order—was located in a precise area of the brain (Spurzheim, 1908). Gall and his student Spurzheim determined this by feeling bumps on people's skulls and relating any protuberances to the individual's characteristics (Figure 1.6). Others, such as Karl Lashley (1929), took an equally extreme position at the other end of the spectrum; *equipotentiality* is the idea that the brain functions as an undifferentiated whole. According to this view, the extent of damage, not the location, determines how much function is lost.

Obviously, bumps on the skull have nothing to do with the size of the brain structures beneath, and most of the characteristics Gall and Spurzheim identified have no particular meaning at the physiological level. But we also know that the brain is not equipotential. The truth, as is often the case, lies somewhere between these two extremes.

Today's research tells us that functions are as much *distributed* as they are *localized*; behavior results from the interaction of many widespread areas of the brain. In later chapters, you will see examples of cooperative relationships among brain areas in language, visual perception, emotional behavior, motor control, and learning. In fact, you will learn that neuroscientists these days are less likely to ask where a function is located than to ask how the brain integrates activity from several areas into a single experience or behavior. Nevertheless, the localizationists strengthened the monist position by showing that language, emotion, motor control, and so on are controlled by *relatively* specific locations in the brain (Figure 1.7). This meant that the mind ceased being *the explanation* and became *the phenomenon to be explained*.

Understand that the nature and the role of the mind are still debated in some quarters. For example, some neuroscientists believe that brain research will be unable to explain how a material brain can generate conscious experience and that this will spell the final doom of materialism. These nonmaterial neuroscientists interpret the brain changes that occur during behavior therapy as evidence of the mind changing the brain (J. M. Schwartz, Stoessel, Baxter, Martin, & Phelps, 1996; see Chapter 14). Of course, what material neuroscientists see is the brain changing the brain (Gefter, 2008). Neuroscience has been able to explain a great deal of behavior without any reference to a nonmaterial mind, and as you explore the rest of this text, you will begin to see why most brain scientists would describe themselves as material monists.

FIGURE 1.6 A Modern Reproduction of the Phrenologist L. M. Fowler's Map of the Brain.

Phrenologists believed that the psychological characteristics shown here were controlled by the respective brain areas.

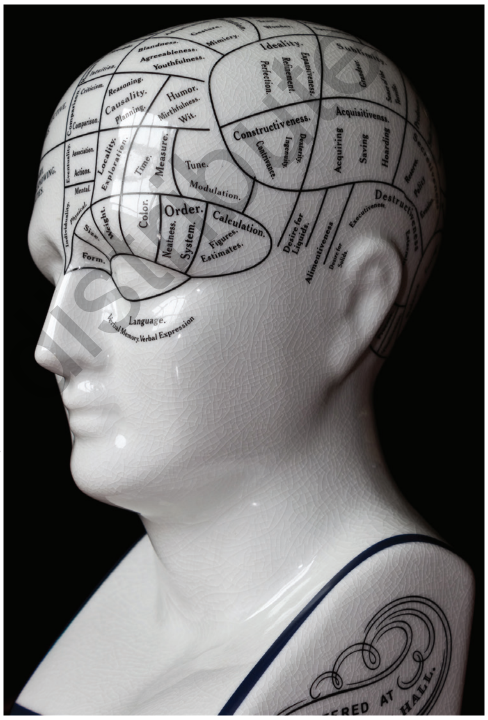


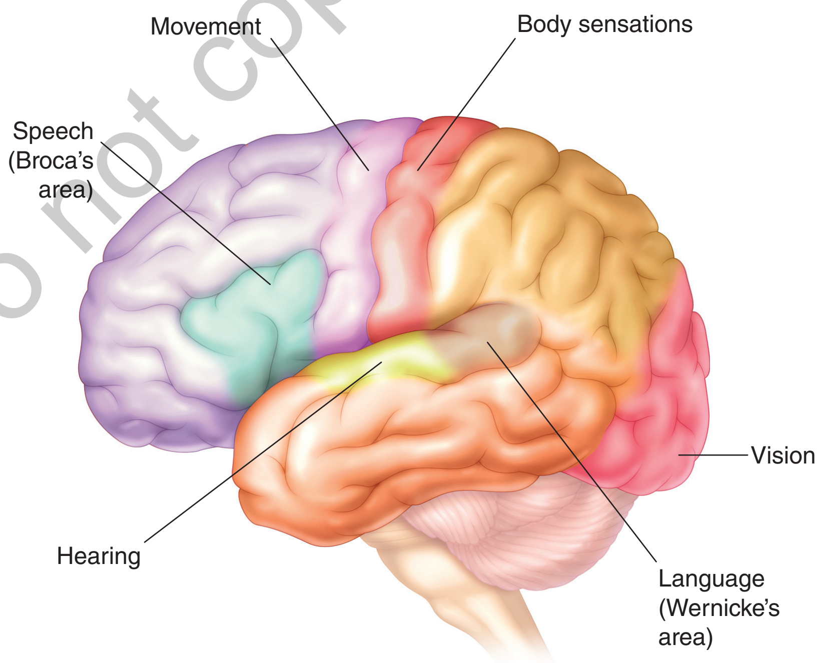
Photo-Jope / Shutterstock Images

CONCEPT CHECK

Take a Minute to Check Your Knowledge and Understanding

- What change in method separated science from philosophy?
- What were the important implications of the discoveries that nerve conduction is electrical and that specific parts of the brain have (more or less) specific functions?
- Where do scientists stand on the localization issue?

FIGURE 1.7 Some of the Brain's Functional Areas.



Nature and Nurture

A second extremely important issue in understanding the biological bases of behavior is the *nature versus nurture* question, or how important heredity is relative to environmental influences in shaping behavior. Like the mind-brain issue, this is one of the more controversial topics in psychology, at least as far as public opinion is concerned. The arguments are based on emotion and values almost as often as they appeal to evidence and reason. For example, some critics complain that attributing behavior to heredity is just a form of excusing actions for which the person or society should be held accountable. A surprising number of behaviors are turning out to have some degree of hereditary influence, so you will encounter this issue again in later chapters. Because there is so much confusion about heredity, we need to be sure you understand what it means to say that a behavior is hereditary before we go any further.

The Genetic Code

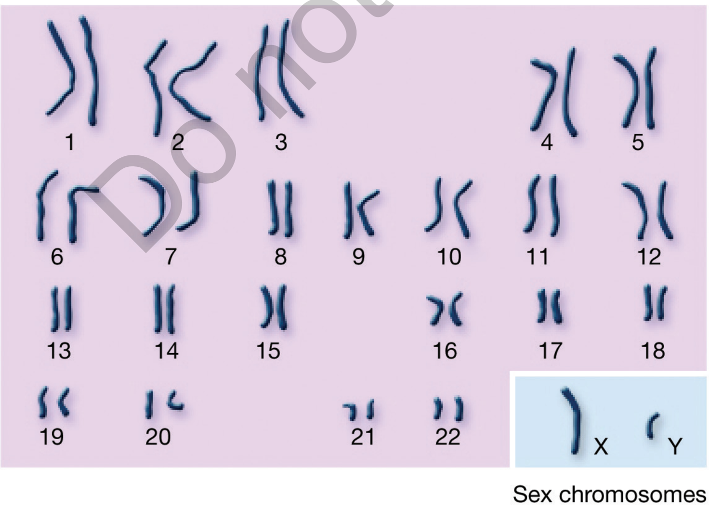
How are characteristics inherited?

The *gene* is the biological unit that directs cellular processes and transmits inherited characteristics. Most genes are found on the chromosomes, which are located in the nucleus of each cell, but there are also a few genes in structures outside the nucleus, called mitochondria. Each body cell in a human has 46 chromosomes, arranged in 23 pairs (Figure 1.8). Each pair is identifiably distinct from every other pair. This is important, because genes for different functions are found on specific chromosomes. The chromosomes are referred to by number, except for the sex chromosomes; in mammals, females have two X chromosomes, while males typically have an X and a Y chromosome. Notice that the members of a pair of chromosomes are similar to each other, again with the exception that the Y chromosome is much shorter than the X chromosome.

Unlike the body cells, the male's sperm cells and the female's ova (egg cells) each have 23 chromosomes. When these sex cells are formed by the division of their parent cells, the pairs of chromosomes separate, so that each daughter cell receives only one chromosome from each pair. When the sperm enters the ovum during fertilization, the chromosomes of the two cells merge to restore the number to 46. The fertilized egg, or *zygote*, then undergoes rapid cell division and development on its way to becoming a functioning organism. For the first eight weeks (in humans), the new organism is referred to as an *embryo*, and from then until birth as a *fetus*.

■ **FIGURE 1.8** A Set of Human Chromosomes.

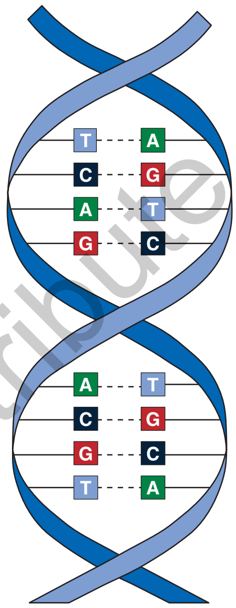
U.S. National Library of Medicine.



The mystery of how genes carry their genetic instructions began to yield to researchers in 1953, when James Watson and Francis Crick published a proposed structure for the deoxyribonucleic acid that genes are made of. *Deoxyribonucleic acid (DNA)* is a double-stranded chain of chemical molecules that looks like a ladder that has been twisted around itself; this is why DNA is often referred to as a *double helix* (Figure 1.9). Each rung of the ladder is composed of two of the four nucleotides adenine, thymine, guanine, and cytosine (A, T, G, C). The order in which these nucleotides appear on the ladder forms the code that carries all our genetic information. The four-letter alphabet these nucleotides provide is adequate to spell out the instructions for every structure and function in your body.

We only partially understand how genes control the development of the body and its activities, as well as how they influence many aspects of behavior. However, we do know that genes exert their influence in a deceptively simple manner: They provide the directions for making proteins. Some of these proteins are used in the construction of the body, and others are enzymes; enzymes act as catalysts, modifying chemical reactions in the body. It is estimated that humans differ among themselves in the sequences of nucleotides that make up our DNA by only about 0.5% (S. Levy et al., 2007); however, you will see throughout this text that this variation leads to enormous differences in development and behavior.

■ **FIGURE 1.9** Structure of a Strand of DNA.



Because all but two of the chromosomes are paired, most genes are as well; a gene on one chromosome is paired with a gene for the same function on the other chromosome. The exception is that the shorter Y chromosome has only 1/25th as many genes as the X chromosome. Although paired genes have the same type of function, their effects often differ; these different versions of a gene are called *alleles*. In some cases, the effects of the two alleles blend to produce a result; for example, a person with the allele for type A blood on one chromosome and the allele for type B blood on the other will have type AB blood.

In other cases, one allele of a gene may be dominant over the other. A *dominant* allele will produce its effect regardless of which allele it is paired with on the other chromosome; a *recessive* allele will have an influence only when it is paired with the same allele. Figure 1.10 illustrates this point. In the example, note that one parent is *heterozygous* for the blood type B allele, which means that the two alleles are different; the other parent is heterozygous for the blood type A allele. The A and B alleles are dominant over the o allele; as a result, each blood type (A, B, AB, or O) has an equal chance (one in four) of occurring in an offspring. Individuals with the same *phenotype* (an observable characteristic such as blood type B) may differ by *genotype* (combinations of alleles such as B and B or B and o). You can see in the figure that type A and B parents have a one in four chance of having a child with different blood types, one of which will be *homozygous* (receiving two identical alleles) for the recessive o allele.

In the case of unpaired genes on the X chromosome, a recessive gene alone is adequate to produce an effect because it is not opposed by a dominant gene. A characteristic produced by an unpaired gene on the X chromosome is referred to as *X-linked*. With such a large discrepancy in the number of genes on the X and Y chromosomes, you can understand the potential for effects from X linkage. One example is that males are eight times more likely than females to have a deficiency in red-green color vision. See Chapter 10 for more on this deficiency.

? Why do males more often show characteristics that are caused by recessive genes?

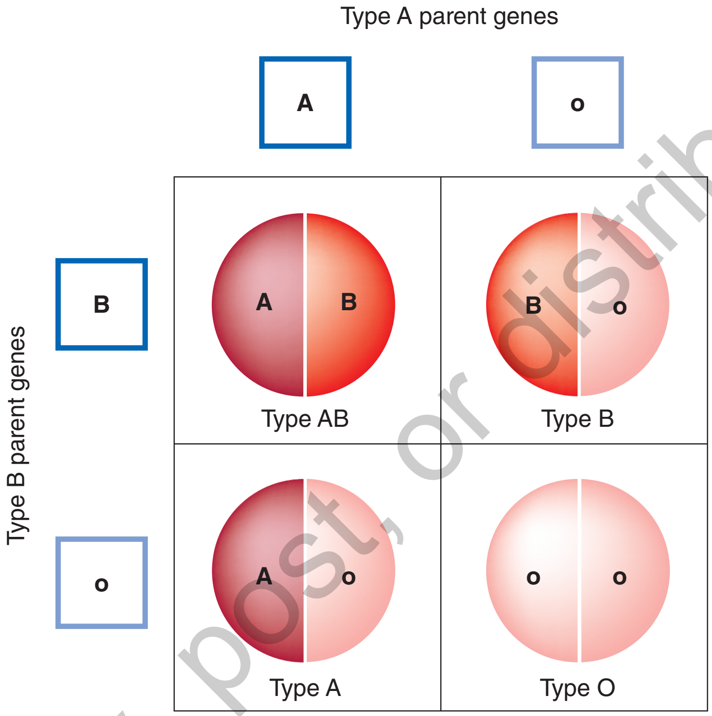
Some characteristics—such as blood type and the degenerative brain disorder Huntington's disease—result from a single pair of genes, but many characteristics are determined by several genes; they are *polygenic*. Height is polygenic, and most behavioral characteristics such as intelligence and psychological disorders are also controlled by a large number of genes.

We have known from ancient times that animals could be bred for desirable behavioral characteristics, such as hunting ability or a mild temperament that made them suitable as pets. Darwin helped establish the idea that behavioral traits can be inherited in humans as well, but the idea fell into disfavor as an emphasis on learning as the major influence on behavior became increasingly fashionable. In the 1960s and 1970s, however, the tide of strict environmentalism began to ebb, and the perspective shifted toward a balanced view of the roles of nature and nurture (Plomin, Owen, & McGuffin, 1994). By 1992, the American Psychological Association was able to identify genetics as one of the themes that best represent the present and the future of psychology (Plomin & McClearn, 1993).

Of the behavioral traits that fall under genetic influence, intelligence is the most investigated. Most of the behavioral disorders, including alcoholism and drug addiction,

■ **FIGURE 1.10** Blood Types in the Offspring of Heterozygous Parents.

The small boxes indicate the genes of the two parents; because A and B alleles are dominant over the o allele, the parents' blood types are A and B, respectively. Each offspring receives one allele from each parent; the circles show the four possible combinations of alleles (genotypes) in the offspring, each of which has an equal chance of occurring. The text under the circles indicates the blood types (phenotypes) of the offspring. Note that type O blood occurs only when the child receives two recessive o alleles.



schizophrenia, major mood disorders, and anxiety, are partially hereditary as well (McGue & Bouchard, 1998). The same can be said for some personality characteristics (T. J. Bouchard, 1994) and sexual orientation (J. M. Bailey & Pillard, 1991; J. M. Bailey, Pillard, Neale, & Agyei, 1993; Kirk, Bailey, Dunne, & Martin, 2000).

? What are some of the inheritable behaviors?

However, you should exercise caution in thinking about these genetic effects. Genes do not provide a script or instructions for behavior. They control the production of proteins; the proteins in turn affect the development of brain structures, the production of neurotransmitters and the receptors that respond to them, and the functioning of the glandular system. We will offer specific examples in later chapters, where we will discuss this topic in more depth.

The Human Genome Project

? What is the Human Genome Project, and how successful has it been?

After geneticists have determined that a behavior is influenced by genes, the next step is to discover which genes are involved. The various techniques for identifying genes boil down to determining whether people who share a particular characteristic also share a particular gene or genes that other people don't have. This task is extremely difficult if the researchers don't know where to look, because the amount of DNA is so great. However, the gene search received a tremendous boost in 1990, when a consortium of geneticists at 20 laboratories around the world began a project to identify all the genes in our chromosomes, or the human *genome*.

The goal of the *Human Genome Project* was to map the location of all the genes on the human chromosomes and to determine the genes' codes—that is, the order of bases within each gene. In 2000—just 10 years after the project began—the project group and a private organization simultaneously announced they had produced "rough drafts" (International Human Genome Sequencing Consortium, 2001; Venter et al., 2001); within another 5 years, the entire human genome had been sequenced (Gregory et al., 2006).

But when it comes to gene functioning, there is still more mystery than enlightenment. Only 21,000 of our genes—just 3% of our DNA—have turned out to be protein encoding (ENCODE Project Consortium, 2012). The lowly roundworm has 19,735 protein-coding genes (Hillier, Coulson, & Murray, 2005), so, clearly, the number of genes is not correlated with behavioral complexity. However, the amount of noncoding DNA—which we used to call "junk DNA"—*does* correlate with behavioral complexity (Andolfatto, 2005; Siepel et al., 2005). So what is important about "junk" DNA? Some of it is, in fact, nonfunctional, remnants left behind during evolution. But 80% of the non-protein-coding DNA is biochemically active. Much of it controls the functioning of other genes by altering *gene expression*—the translation of encoded information into the production of proteins (Pennacchio et al., 2006). For example, when a stretch of noncoding DNA known as *HACNS1*—which is unique to humans—is inserted into a mouse embryo, it turns on genes in the "forearm" and "thumb" (Figure 1.11; Prabhakar et al., 2008). DNA taken from the same area in chimpanzees and rhesus monkeys does not have that effect. The researchers speculate that the genes that *HACNS1* turns on led to the evolutionarily important dexterity of the human thumb.

FIGURE 1.11 Human Junk DNA Turns on Genes in a Mouse Embryo's Paw.

To determine where the DNA was having an effect, it was paired with a gene that produces a blue protein when activated. The blue area indicates that *HACNS1* is targeting genes in the area analogous to the human thumb.

From "Human-specific Gain of Function in a Developmental Enhancer," by S. Prabhakar et al, *Science*, 321, p. 1348. Reprinted with permission from AAAS.

A second question is what the genes do. The gene map doesn't answer that question, but it does make it easier to find the genes responsible for a particular disorder or behavior. For example, when geneticists were searching for the gene that causes Huntington's disease in the early 1980s, they found that most of the affected individuals in a large extended family shared a couple of previously identified genes with known locations on chromosome 4, whereas the disease-free family members didn't. This meant that the Huntington's gene was on chromosome 4 and near these two *marker* genes (Gusella et al., 1983). Actually finding the Huntington's gene still took another 10 years; now the gene map is dramatically reducing the time required to identify genes.

Identifying the genes and their functions will improve our understanding of human behavior and psychological as well as medical disorders. We will be able to treat disorders genetically, counsel vulnerable individuals about preventive measures, and determine whether a patient will benefit from a drug or have an adverse reaction, thus eliminating delays from trying one treatment after another.

Heredity: Destiny or Predisposition?

To many people, the idea that several, if not most, of their behavioral characteristics are hereditary implies that they are clones of their parents and their future is engraved in stone by their genes. This is neither a popular nor a comfortable view, and it creates considerable resistance to the concept of behavioral genetics. The view is also misleading; a hallmark of genetic influence is actually *diversity*.

GENES AND INDIVIDUALITY

Although family members do tend to be similar to each other, children share only half of their genes with each of their parents or with each other. A sex cell receives a random half of the parent's chromosomes; as a result, a parent can produce 2^{23}, or 8 million, different combinations of chromosomes. Add to this the uncertainty of which sperm will unite with which egg, and the number of genetic combinations that can be passed on to offspring rises to 60 or 70 trillion! So sexual reproduction increases individuality in spite of the inheritability of traits. This variability powers what Darwin (Figure 1.12) called *natural selection*, which means that those whose genes endow them with more adaptive capabilities are more likely to survive and transmit their genes to more offspring (Darwin, 1859).

? Do genes lock a person into a particular outcome in life?

The effects of the genes themselves are not rigid; they can be variable over time and circumstances. Genes are turned on and turned off, or their activity is upregulated and downregulated, so that they produce more or less of their proteins or different proteins at different times. If the activity of genes were constant, there would be no smoothly flowing sequence of developmental changes from conception to adulthood. A large number of genes change their functioning late in life, apparently accounting for many of the changes common to aging (Ly, Lockhart, Lerner, & Schultz, 2000), as well as the onset of diseases such as Alzheimer's (Breitner, Folstein, & Murphy, 1986). The functioning of some genes is even controlled by experience, which explains some of the changes in the brain that constitute learning (C. H. Bailey, Bartsch, & Kandel, 1996). For the past quarter century, researchers have puzzled over why humans are so different from chimpanzees, our closest relatives, considering that 95% to 98% of our DNA sequences are identical (R. J. Britten, 2002; M.-C. King & Wilson, 1975). Part of the answer appears to be that we differ more dramatically in which genes are *expressed*—actually producing proteins—in the brain (Enard et al., 2002).

Genes also have varying degrees of effects. Some determine the person's characteristics, whereas others only influence them. A person with the mutant form of the *huntingtin* gene *will* develop Huntington's disease, but most behavioral traits depend on many genes. For instance, a single gene will account for only a slight increase in intelligence or in the risk for schizophrenia. The idea of risk raises the issue of vulnerability and returns us to our original question, the relative importance of heredity and environment.

FIGURE 1.12 Charles Darwin (1809–1882).

From Origins, Richard Leakey and Roger Lewin.

HEREDITY, ENVIRONMENT, AND VULNERABILITY

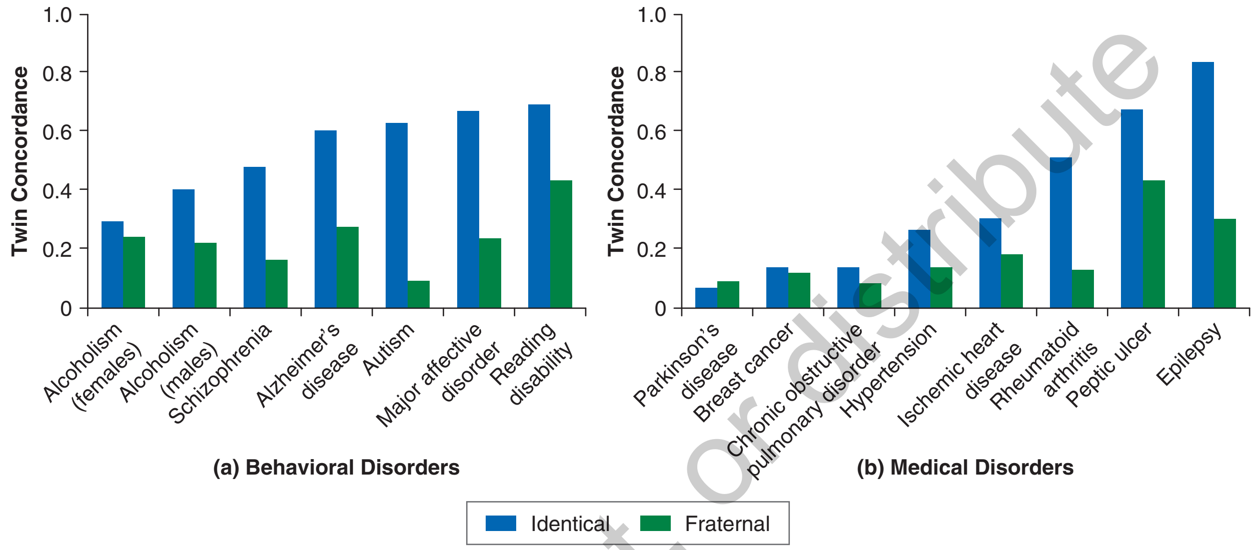
To assess the relative contributions of heredity and environment, we need to be able to quantify the two influences. *Heritability* is the percentage of the variation in a characteristic that can be attributed to genetic factors. There are various ways of estimating heritability of a characteristic. One technique involves a comparison of how often identical twins share the characteristic with how often fraternal twins share the characteristic. The reason for this comparison is that identical twins develop from a single egg and therefore have the same genes, while fraternal twins develop from separate eggs and share just 50% of their genes, like nontwin siblings. Heritability estimates are around 50% for intelligence (Devlin, Daniels, & Roeder, 1997), which means that about half of the population's differences in intelligence are due to heredity. Heritability has been estimated at 60% to 90% for schizophrenia (Tsuang, Gilbertson, & Faraone, 1991) and 40% to 50% for personality characteristics and occupational interests (Plomin et al., 1994). By way of comparison, the genetic influence on behavioral characteristics is typically stronger than it is for common medical disorders, as Figure 1.13 shows (Plomin et al., 1994).

Because about half of the differences in behavioral characteristics among people are attributable to heredity, approximately half are due to environmental influences. Keep in mind that heritability is not an

FIGURE 1.13 Twin Studies of Behavioral and Medical Disorders.

The concordance of (a) behavioral disorders and (b) medical disorders in identical and fraternal twins. Concordance is the proportion of twin pairs in which both twins have the disorder. Note the greater concordance in identical twins and the generally higher concordance for behavioral disorders than for medical disorders.

From "The Genetic Basis of Complex Human Behavior," by R. Plomin, M. J. Owen, and P. McGuffin, *Science*, 264, p. 1734. © 1994 American Association for the Advancement of Science. Reprinted with permission from AAAS.



absolute measure but tells us the proportion of variability that is due to genetic influence; the measure depends on the environmental circumstances of the group we're looking at as much as its genetic characteristics. For example, adoption studies tend to overestimate the heritability of intelligence, because adopting parents are disproportionately from the middle class. Because the children's adoptive environments are unusually similar, environmental influence will be lower and heritability higher than in the general population (McGue & Bouchard, 1998). Similarly, heritability will appear to be lower if we look only at a group of closely related individuals.

Researchers caution us that "we inherit dispositions, not destinies" (R. J. Rose, 1995, p. 648). This is because the influence of genes is only partial. This idea is formalized in the vulnerability model, which has been applied to disorders such as schizophrenia (Zubin & Spring, 1977). *Vulnerability* means that genes contribute a predisposition for a disorder, which may or may not exceed the threshold required to produce the disorder; environmental challenges such as neglect or emotional trauma may combine with a person's hereditary susceptibility to exceed that threshold. The general concept applies to behavior and abilities as well, though we wouldn't use the term *vulnerability* in those contexts. For example, the combination of genes a person receives determines a broad range for the person's potential intelligence; environmental influences then will determine where in that range the person's capability will fall. Psychologists no longer talk about heredity versus environment, as if the two are competing with each other for importance. Both are required, and they work together to make us what we are. As an earlier psychologist put it, "to ask whether heredity or environment is more important to life is like asking whether fuel or oxygen is more necessary for making a fire" (Woodworth, 1941, p. 1).

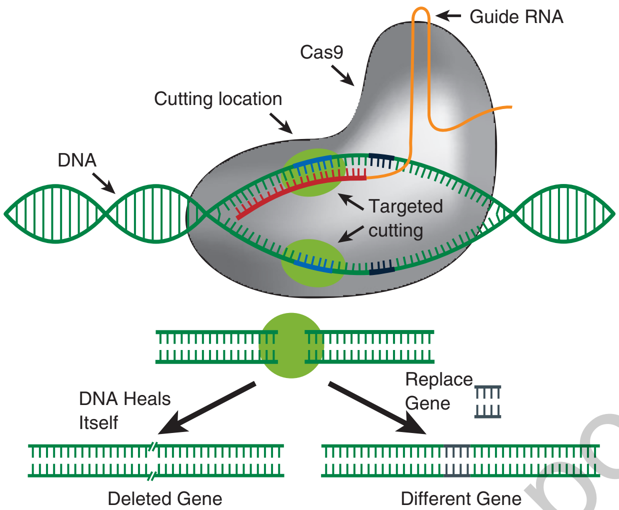
? What do we mean by "genetic predisposition"?

With an increasing understanding of genetics, we are now in the position to change our very being. This kind of capability carries with it a tremendous responsibility. The knowledge of our genetic makeup and the ready availability of genetic testing through companies such as AncestryDNA and 23andMe raise the question of whether it is better for a person to know about a risk that may never materialize, such as susceptibility to Alzheimer's disease.

In addition, many people worry that the ability to do genetic testing on our unborn children means that some parents will choose to abort a fetus because it has genes for a trait they consider undesirable (see A Further Look for more about genetic editing of fetal genes). Our ability to plumb the depths of the brain and of the genome is increasing faster than our grasp of either its implications or how to resolve the ethical questions that will arise. We will consider some of the ethical issues of genetic research in Chapter 4.

A FURTHER LOOK

CRISPR: A New Tool to Edit Genes



As we gain an increased understanding of the role, timing, and location of gene actions through efforts such as the Human Genome Project, it is only a matter of time before we will be routinely replacing defective genes in humans with healthy, functioning ones. Replacing or repairing a gene requires three key procedures at the DNA level: (1) identifying key genetic sequences that indicate the start and end of the defective DNA, (2) developing enzymes that can remove the DNA from the genome while leaving the rest of the genetic material intact, and, in some cases, (3) inserting an alternative form of DNA into the genome.

CRISPR stands for *clustered regularly interspaced short palindromic repeats*, which were discovered in bacteria. These repeats are fragments of previous viral infections that the bacterial cell uses to recognize and destroy similar invading viruses. Scientists employ various CRISPR-associated (Cas) proteins, which use an RNA sequence generated by the scientist as a guide to recognize DNA to be removed; the enzyme then acts like molecular scissors, cutting the ends of the DNA. The cell then patches the break or inserts replacement DNA carried by the Cas enzyme. This technology has the power to revolutionize our understanding of the genetic effects on physiology, behavior, and cognition, as well as to treat genetic diseases.

Though CRISPR is still in its infancy, its early successes have raised fears that this technique will eventually be used for editing human traits and creating designer babies. This fear was heightened in November 2018, when the Chinese scientist He Jiankui admitted that he had edited the genomes of two female embryos in an attempt to make them immune to HIV infection (Marchione, 2018). HIV viruses require the CCR5 receptor to enter white blood cells, and Dr. He was trying to replace the normal receptor gene with the gene for the CCR5 delta 32 receptor, which is HIV resistant. Although the technique was unsuccessful (the girls have one normal and one resistant gene, leaving them susceptible to HIV infection), the use of CRISPR technology on human embryos was universally condemned, and Dr. He was sentenced to 3 years in jail (Normile, 2019).

CONCEPT CHECK

Take a Minute to Check Your Knowledge and Understanding

- Why is it inappropriate to ask whether heredity or environment is more important for behavior?
- When we say that a person inherits a certain personality characteristic, what do we really mean?

- Explain how two parents who have the same characteristic produce children who are different from them in that characteristic. Use appropriate terminology.
- Explain how genes influence behavior.

In Perspective

In the first issue of the journal *Nature Neuroscience*, the editors observed that brain science still has a "frontier" feel to it. The excitement of exploration is real and tangible, and the discoveries and accomplishments are remarkable for such a young discipline. The successes come from many sources: the genius of our intellectual ancestors, the development of new technologies, the adoption of empiricism, and, we believe, a coming to terms with the concept of the mind. Evidence of all these influences will be apparent in the following chapters.

Behavioral neuroscience still has a long way to go. For all our successes, we do not fully understand what causes schizophrenia, exactly how the brain is changed by learning, or why some people are more intelligent than others. The 1990s was declared the Decade of the Brain; Torsten Wiesel (whose landmark research in vision you will read about later) scoffed at the idea of dedicating a decade to the brain as "foolish. . . . We need at least a century, maybe even a millennium" (as cited in Horgan, 1999, p. 18). As you read the rest of this book, keep in mind that you are on the threshold of that century's journey, that millennium of discovery.

CHAPTER SUMMARY

THE ORIGINS OF BEHAVIORAL NEUROSCIENCE

- Behavioral neuroscience (or biopsychology) developed out of physiology and philosophy as early psychologists adopted empiricism.
- Most psychologists and neuroscientists treat the mind as a product of the brain, believing that mental activity can be explained in terms of the brain's functions.
- Localization describes brain functioning better than equipotentiality, but a brain process is more likely to be carried out by a network of structures than by a single structure.

NATURE AND NURTURE

- We are learning that a number of behaviors are genetically influenced. One does not inherit a behavior itself, but genes influence structure and function in the brain and body in a way that influences behavior.
- Behavior is a product of both genes and environment. In many cases, genes produce a predisposition, and environment further determines the outcome.
- With the knowledge of the genome map, we stand on the threshold of unbelievable opportunity for identifying causes of behavior and diseases, but we face daunting ethical challenges as well.

STUDY RESOURCES

FOR FURTHER THOUGHT

- Why, in the view of most neuroscientists, is materialistic monism the more productive approach for understanding the functions of the mind? What will be the best test of the correctness of this approach?

- Scientists were working just as hard on the problems of the brain a half century ago as they are now. Why were the dramatic discoveries of recent years not made then?
- What are the implications of knowing what all the genes do and of being able to do a scan that will reveal which genes an individual has?
- If you were told that you had a gene that made it 50% likely that you would develop a certain disease later in life, what could you do with that knowledge?

TEST YOUR UNDERSTANDING

1. How would a monist and a dualist pursue the study of behavioral neuroscience differently?
2. What was the impact of the early electrical stimulation studies and the evidence that specific parts of the brain were responsible for specific behaviors?
3. The allele for type B blood is, like the one for type A, dominant over the allele for type O. Make a matrix like the one in Figure 1.10 to show the genotypes and phenotypes of the offspring of an AO parent and a BO parent.
4. A person has a gene that is linked with a disease but does not have the disease. We mentioned three reasons why this could occur; describe two of them.
5. Discuss the interaction between heredity and environment in influencing behavior, including the concept of vulnerability.

SELECT THE BEST ANSWER:

1. The idea that the mind and brain are both physical is known as
   a. idealistic monism.
   b. materialistic monism.
   c. idealistic dualism.
   d. materialistic dualism.
2. A model is
   a. an organism or a system used to understand a more complex one.
   b. a hypothesis about the outcome of a study.
   c. an analogy, not intended to be entirely realistic.
   d. a plan for investigating a phenomenon.
3. Descartes's most important contribution was in
   a. increasing knowledge of brain anatomy.
   b. suggesting the physical control of behavior.
   c. emphasizing the importance of nerves.
   d. explaining how movement is produced.
4. Helmholtz showed that
   a. nerves are not like electrical wires because they conduct too slowly.
   b. nerves operate electrically.
   c. nerves do not conduct animal spirits.
   d. language, emotion, movement, and so on depend on the activity of nerves.
5. In the mid-1800s, studies of brain-damaged patients convinced researchers that
   a. the brain's activity was electrical.
   b. the mind was not located in the brain.
   c. behaviors originated in specific parts of the brain.
   d. the pineal gland could not serve the role Descartes described.
6. Localization means that
   a. specific functions are found in specific parts of the brain.
   b. the most sophisticated functions are located in the highest parts of the brain.
   c. any part of the brain can take over other functions after damage.
   d. brain functions are located in widespread networks.
7. X-linked characteristics affect males more than females because
   a. the X chromosome is shorter than the Y chromosome.
   b. unlike males, females have only one X chromosome.
   c. the responsible gene is not paired with another gene on the Y chromosome.
   d. the male internal environment exaggerates effects of the genes.

8. Two parents are heterozygous for a dominant characteristic. They can produce a child with the recessive characteristic
   a. if the child receives a dominant gene and a recessive gene.
   b. if the child receives two recessive genes.
   c. if the child receives two dominant genes.
   d. under no circumstance.
9. The Human Genome Project has
   a. counted the number of human genes.
   b. made a map of the human genes.
   c. determined the functions of most genes.
   d. cloned most of the human genes.
10. Heritability is greatest for
   a. intelligence.
   b. occupational interest.
   c. personality.
   d. schizophrenia.
11. If we all had identical genes, the estimated heritability for a characteristic would be
   a. 0%.
   b. 50%.
   c. 100%.
   d. impossible to determine.

Answers:
1. b, 2. a, 3. b, 4. a, 5. c, 6. a, 7. c, 8. b, 9. b, 10. d, 11. a.

FOR MORE INFORMATION

The following journals are major sources of neuroscience articles (those that are not *open* access may require a subscription or university access). These may be of use to you as you progress through the textbook and your scholarly pursuits in behavioral neuroscience:

Brain and Behavior (open access)

Brain, Behavior, and Evolution

Frontiers in Neuroscience (open access; also see related journals under “18 Sections”)

Journal of Neuroscience

Nature

Nature Neuroscience

Nature Reviews Neuroscience

New Scientist (for the general reader)

PLoS Biology and *PLoS Genetics* (open access)

Scientific American Mind (for the general reader)

The Scientist (for the general reader)

Trends in Neurosciences

General information sites:

BrainFacts (various topics in neuroscience)

Brain in the News (neuroscience news from media sources)

The Human Brain (a collection of brain-related articles published in the magazine *New Scientist*)

Neuroguide (a small but growing offering of resources)

Science Daily (latest developments in science; see “Mind & Brain” and “Health & Medicine”)

FOR FURTHER READING

1. “The Emergence of Modern Neuroscience: Some Implications for Neurology and Psychiatry,” by W. Maxwell Cowan, Donald H. Harter, and Eric R. Kandel (*Annual Review of Neuroscience*, 2000, *23*, 343–391), describes the emergence of neuroscience as a separate discipline in the 1950s and 1960s and describes some of its important accomplishments in understanding disorders.
2. Neuroscientist Michael Gazzaniga calls Mitchell Glickstein’s *Neuroscience: A Historical Introduction* (MIT Press, 2014) “authoritative, highly readable, wonderfully illustrated, and just plain interesting.”
3. *The Scientific American Brave New Brain*, by Judith Horstman (Jossey-Bass, 2010), describes how today’s scientific breakthroughs will in the future help the blind see and help the deaf hear, allow our brains to repair and improve themselves, help us postpone the mental ravages of aging, and give the paralyzed control of prosthetic devices and machinery through brain waves.
4. *Behavioral Genetics*, by Valerie Knopik, Jenae Neiderhiser, John DeFries, and Robert Plomin (Worth, 2017, 7th ed.), is a textbook on that topic; another

text, *Evolutionary Psychology*, by William Ray (SAGE, 2013), takes a neuroscience approach to the evolution of behavior.

5. "Tweaking the Genetics of Behavior," by Dean Hamer (*Scientific American*, April 1999, 62–67), is a fanciful but thought-provoking story about a female couple in 2050 who have decided to have a child cloned and the decisions available to them for determining their baby's sex and her physical and psychological characteristics through genetic manipulation.

KEY TERMS