neuroscience is the multidisciplinary study of the nervous system and its role in behavior. An interesting topic, surely, but neuroscience is a romantic moonwalk? To understand why Kay Jamison chose this analogy, you would need to have watched in astonishment from your backyard on an October night in 1957 as the faint glint of reflected light from Sputnik crossed the North American sky. The American people were stunned and fearful as the Russian
space program left them far behind. But as the implications of this technological coup sank in, the United States set about constructing its own space program and revamping education in science and technology. Less than 4 years later, President Kennedy made his startling commitment to put an American astronaut on the moon by the end of the decade. But the real excitement would come on the evening of July 20, 1969, as you sat glued to your television set watching the Eagle lander settle effortlessly on the moon and the first human step onto the surface of another world (Figure 1.1). For Kay Jamison and the rest of us involved in solving the mysteries of the brain, there is a very meaningful parallel between the excitement of Neil Armstrong’s “giant leap for mankind” and the thrill of exploring the inner space of human thought and emotion.

There is also an inescapable parallel between Kennedy’s commitment of the 1960s to space exploration and Congress’s declaration 30 years later that the 1990s would be known as the Decade of the Brain. Understanding the brain demands the same incredible level of effort, ingenuity, and technological innovation as landing a human on the moon. There were important differences between those two decades, though. President Kennedy acknowledged that no one knew what benefits would arise from space exploration. But as the Decade of the Brain began, we understood that we would not only expand the horizons of human knowledge but also advance the treatment of neurological diseases, emotional disorders, and addictions that cost the United States an estimated trillion dollars a year in care, lost productivity, and crime (Uhl & Grow, 2004).

Another difference was that the moon-landing project was born out of desperation and a sense of failure, while the Decade of the Brain was a celebration of achievements, both past and current. In the past few years, we have developed new treatments for depression, identified key genes responsible for the devastation of Alzheimer’s disease, discovered agents that block addiction to some drugs, learned ways to hold off the memory impairment associated with old age, and produced a map of the human genes.

The United States could not have constructed a space program from scratch in the 1960s; the achievement was built on a long history of scientific research and technological experience. In the same way, the accomplishments of the Decade of the Brain had 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 Biopsychology

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 chemist,
What Is Biopsychology?

Psychologists who work in the area of neuroscience specialize in biological psychology, or biopsychology, the branch of psychology that studies the relationships between behavior and the body, particularly the brain. (Sometimes the term psychobiology or physiological psychology is 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. Biological psychologists attempt to answer questions like “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?” Biological psychologists 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, biological psychologists 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 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 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 subdiscipline 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 biological psychology, 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 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, I will say that there is no such thing as mind. It exists only in the sense that, say, weather exists; weather is a concept we use 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 we don’t really think 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 that 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. Most

In the sciences, we are now uniquely privileged to sit side by side with the giants on whose shoulders we stand.

—Gerald Holton
neuroscientists say this is just an illusion, that the sense of mind is nothing more than the awareness of what our 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 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.

This question did not originate with modern psychology. 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 4th century BCE. Plato was a dualist, while his 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 nerve functioning 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 Darwin’s explanation that a species developed new capabilities because the capability enhanced the individual’s survival. Other times, the model is a simpler organism or system that researchers 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 served as a model of cognitive processes.

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. 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 the 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 was based on his belief 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. Thus, for Descartes, the pineal gland became the “seat of the soul,” the place where the mind interacted with the body. Although Descartes assigned
What Is Biopsychology?

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

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

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

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 the fact that a model or a theory 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 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. (The WWW icon in the margin indicates that you can find a website on this topic in On the Web at the end of the chapter.

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, but instead, \textit{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 you will see in later chapters, his 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.

\textbf{The Localization Issue}

The second important principle to come out of this period—localization—emerged over the first half of the 19th century. \textit{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, Phineas Gage, a railroad construction foreman, was injured when a dynamite blast drove an iron rod through his skull and the frontal lobes of his brain. Amazingly, he survived with no 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 (along with some humorists, as the quote from Mark Twain shows!). But a few brain theorists took the principle of localization too far, and we should be on guard lest we make the same mistake. Near the end of the 18th century, when interest in the brain's role in behavior was really heating up, the German anatomist Franz Gall came up with an extreme and controversial theory of brain localization. According to \textit{phrenology}, each of 35 different "faculties" of emotion and intellect—such as combative ness, 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; \textit{equipotentiality} is the idea that the brain functions as an undifferentiated whole. According to this view, the extent of damage, not the location, is what determines how much function is lost.
We now know that bumps on the skull have nothing to do with the size of the brain structures beneath and that 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 locationists 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 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

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I never could keep a promise. . . . It is likely that such a liberal amount of space was given to the organ which enables me to make promises that the organ which should enable me to keep them was crowded out.

—Mark Twain, in Innocents Abroad

**FIGURE 1.6** A Phrenologist’s Map of the Brain.

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

SOURCE: © Bettmann/CORBIS.

**FIGURE 1.7** Some of the Brain’s Functional Areas.
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 et al., 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.

What is the danger of mind-as-explanation?

How are characteristics inherited?

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 be running into this issue throughout the following 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

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 the mitochondria. Each body cell in a human has 46 chromosomes, arranged in 23 pairs (see Figure 1.8). Each pair is identifiable 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, the female has two X chromosomes, while males typically have an X and a Y chromosome. Notice that the members of a pair of chromosomes are similar, 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 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 8 weeks (in humans), the new organism is referred to as an embryo and from then until birth as a fetus.

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 the double helix (see 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 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. The feature “Application: A Computer Made of DNA” will give you some appreciation of DNA’s complexity and power.

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.

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 one twenty-fifth 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 on the left, note that one parent is homozygous for the type A allele, which means that the two alleles are identical; the other parent is heterozygous, with an allele for type A and one for type O. The allele for type A is dominant and, because every child will receive at least one A allele, all of the children will have type A blood. In other words, although the children have different genotypes (combinations of genes), they have the same phenotype (characteristic). In the second example, where both parents are heterozygous, about one out of four children will receive two recessive alleles and, therefore, will have type O blood.

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.

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.
When some people look at DNA, they are struck by its similarities with a computer. Ehud Shapiro’s lab at the Weizmann Institute in Israel is taking that similarity to its logical conclusion by building computers out of DNA. They are so small that a single drop of water can hold a trillion of them. Basically, a strand of DNA serves as an “input” molecule, which is operated on by two enzymes and a preprogrammed “software” molecule to produce an “output” molecule. All this happens at the binary level, which means that the computer works by manipulating the equivalent of 1s and 0s.

Why would anyone want to make a DNA computer? Shapiro and his colleagues hope to produce DNA “medical kits” that operate inside the body, detecting a variety of diseases and treating them even before symptoms appear. Already, one of their computers can detect and destroy prostate cancer cells and another can detect a form of lung cancer, though only in a test tube so far (Benenson, Gil, Ben-Dor, Adar, & Shapiro, 2004). These computers are simple and perform a single function, but researchers at Stanford have designed a more broadly useful DNA device that mimics a transistor (Bonnet, Yin, Ortiz, Subsoontorn, & Endy, 2013). They were able to string several together to form the kinds of logic circuits used in computers, but the real value of DNA transistors is that they amplify small signals and could improve the ability to detect disease. Another obvious application is data storage; large scientific institutions archive data on magnetic tape, which must be replaced and rewritten every few years. DNA, on the other hand, can be stable for thousands of years if kept in a cool, dry place; by converting the usual binary 1s and 0s to DNA’s four-letter code, U.K. researchers have recorded data at a density equivalent to almost half a million DVDs per gram of DNA (Goldman et al., 2013).

Genes and Behavior

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. Charles Darwin helped establish the idea that behavioral traits can be inherited in humans as well, but the idea fell into
What Is Biopsychology?

Disfavor as an emphasis on learning as the major influence on behavior became increasingly fashionable. But in the 1960s and 1970s, 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, 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).

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

The Human Genome Project

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

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**FIGURE 1.10 Blood Types in the Offspring of Two Sets of Parents With Type A Blood.**

The circles in the boxes indicate the genotypes of the parents whose genes are indicated on the outside. Because the type A allele is dominant, all four parents have type A blood. On the left, one parent is homozygous for the A allele while the other is heterozygous, with an allele for each blood type. All of their offspring will receive at least one type A allele and will have type A blood, though about half will carry the type O allele. On the right, both parents are heterozygous for A and O. About three fourths of their offspring will receive the type O allele, but only about one fourth—those who receive two type O alleles—will have type O blood.
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 “rough drafts” of the human genome (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 (The 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 much of the non-protein-coding DNA controls the expression of other genes—the translation of their encoded information into the production of proteins, thus controlling their functioning (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.

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 while 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 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. (See the accompanying Application.)
What Is Biopsychology?

What Is Biopsychology?

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 creates considerable resistance to the concept of behavioral genetics. The view is also misleading; a hallmark of genetic influence is 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).

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 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

APPENDICITY

Beyond the Human Genome Project

Now that the human genome has been mapped, logical next steps include figuring out the functions of the genes and the remaining 97% of DNA, and then turning this knowledge into applications that can benefit individual humans. Two general directions of research in pursuit of these goals have been especially newsworthy lately.

When the Human Genome Project ended in 2003, it was replaced by The Encyclopedia of DNA Elements (ENCODE) Project; its purpose is to determine all the functional elements of the human genome and make an initial assessment of what their functions are. The project’s research teams at 32 institutions around the world have so far churned out more than 400 publications (Maher, 2012; Pennisi, 2012); one of their surprising revelations was that 80% of the genome is biochemically active. ENCODE data are already giving researchers new tools for understanding the etiology of a variety of diseases.

The Human Genome and ENCODE projects have catapulted us into a new era of genetic understanding, but some geneticists believe that now it is more efficient to focus on the exome, the complement of exons, or short sequences of DNA that actually direct protein production. The 180,000 exons of the human exome constitute only about 1% of the entire genome, so sequencing them is faster and cheaper, and scientists believe they contain 85% of all disease-causing mutations. Dutch scientists at the annual meeting of the European Society of Human Genetics in 2012 reported that sequencing the exomes of 262 patients detected disease-causing mutations in half of the cases of blindness; 20% of the patients with intellectual disability; 20% of the deafness cases, and 15% to 20% of patients with movement disorders (European Society of Human Genetics, 2012). Lead researcher Marcel Nelen says that most of these patients have had “a long and worrying journey through different doctors and hospitals before they are diagnosed, and exome sequencing can shorten that route.”

Hereditary Destiny or Predisposition?

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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).

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 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). Now, it appears that part of the answer is that we differ more dramatically in which genes are expressed—actually producing proteins—in the brain (Enard, Khaitovich, et al., 2002).

Genes also have varying degrees of effects; some determine the person's characteristics, while 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; 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.

**Heredity, Environment, and Vulnerability**

To assess the relative contributions of heredity and environment, we need to be able to quantify the two influences. *Heredability 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 (Plomin, 1990), 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). The heritability for height is approximately 90% (Plomin, 1990), which makes the values for behavioral characteristics seem modest. On the other hand, 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).

Since 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 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 environments are unusually similar, environmental influence will appear to be lower and heritability higher than typical (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**
threshold. The general concept applies to behavior and abilities as well, though we wouldn't use the term *vulnerability*. 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).

**Concept Check**

- 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.
With 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 raises the question 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 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. 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.

In Perspective

In the first issue of the journal *Nature Neuroscience*, the editors observed that brain science still has a “frontier” feel to it (“From Neurons to Thoughts,” 1998). The excitement Kay Jamison talked about is real and tangible, and the 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, I believe, a coming to terms with the concept of the mind. Evidence of all these influences will be apparent in the following chapters.

Neuroscience and biopsychology still have 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. Near the end of 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” (quoted 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.

Summary

**The Origins of Biopsychology**

- Biopsychology developed out of physiology and philosophy as early psychologists adopted empiricism.
- Most psychologists and neuroscientists treat 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, would there be anything you could do?

Quiz: Testing Your Understanding

1. How would a monist and a dualist pursue the study of biopsychology 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 have 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 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. schizophrenia.
    c. personality.
    d. height.

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.

**Online Resources**

The following resources are available at edge.sagepub.com/garrett4e. Select your country, click on Student Resources, then Chapter Resources; then select this chapter.

**Chapter Resources**
- Quiz
- Flashcards
- Web links from the text
- Web resources

**On the Web**

The following websites are coordinated with this chapter’s content. (See the numbered WWW icons in the margins.) To access these sites: On the Chapter Resources page, select this chapter and then click on Web links from the text. (Bold items are links.) Also, be sure to look at the other study aids, as well as the Updates from the Author (located above the list of chapters).

1. **Mind and Body** covers the history of the idea from René Descartes to William James. Most pertinent sections are I: 1–5 and II: 1–2.

2. You can search **Online Mendelian Inheritance in Man** by characteristic/disorder (e.g., schizophrenia), chromosomal location (e.g., 1q21–q22), or gene symbol (e.g., SCZD9) to get useful genetic information and summaries of research articles.

3. The Wikipedia article **Exome** includes links to descriptions of several research projects using exome sequencing.

4. The following journals are major sources of neuroscience articles (those that are not open access may require a subscription or university access):
   - *Behavioral Sciences* (open access)
   - *Brain and Behavior* (open access)
   - *Brain, Behavior, and Evolution*
   - *Frontiers in Neuroscience* (open access)
   - *Journal of Neuroscience*
   - *Nature*
   - *Nature Neuroscience*
   - *Nature Reviews Neuroscience*
   - *New Scientist* (for the general reader)
   - *PLoS Biology* (open access)
   - *PLoS Genetics* (open access)
   - *Science*
   - *Scientific American Mind* (for the general reader)
   - *The Scientist* (for the general reader)
   - *Trends in Neurosciences*

**General information sites:**
- **Brain Briefings** (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”)

Chapter Updates and Biopsychology News

For Further Reading


2. “Neuroscience: Breaking Down Scientific Barriers to the Study of Brain and Mind,” by E. R. Kandel and Larry Squire (Science, 2000, 290, 1113–1120), is a briefer treatment of the recent history of neuroscience, with an emphasis on psychological issues; a timeline of events over more than three centuries is included.

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 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.


5. “Tweaking the Genetics of Behavior,” by Dean Hamer (available at http://apbio.savithasastry.com/Units/Unit%208/articles/cle_review_genesandbehavior.pdf), 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

- allele .......................................................... 9
- biopsychology ............................................ 3
- deoxyribonucleic acid (DNA) ................. 9
- dominant .................................................. 9
- dualism ..................................................... 4
- embryo ..................................................... 9
- empiricism ............................................... 5
- equipotentiality ........................................ 6
- expression (of genes) .............................. 12
- fetus .......................................................... 9
- gene .......................................................... 8
- genome .................................................... 12
- genotype .................................................. 9
- heritability ............................................. 14
- heterozygous .......................................... 9
- homozygous ........................................... 9
- Human Genome Project ....................... 12
- localization ............................................ 6
- materialistic monism ............................ 4
- mind-brain problem .............................. 3
- model ...................................................... 4
- monism ..................................................... 4
- natural selection .................................... 13
- nature versus nurture ............................ 8
- neuroscience ........................................ 1
- phenotype ............................................. 9
- phrenology ............................................ 6
- polygenic ................................................. 9
- recessive .................................................. 9
- vulnerability ......................................... 14
- X-linked ................................................... 9
- zygote ..................................................... 9