Behavioral Neuroscience

Scope and Outlook

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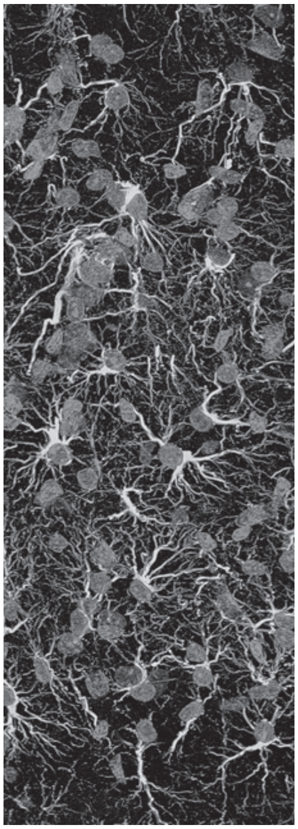

Human or Machine?

In the haunting movie *A.I. Artificial Intelligence*, set late in this century, robots have been developed that imitate humans in a nearly flawless fashion. These humanoid robots, called *Mecha*, fulfill any number of functions, including social interactions where they are programmed to simulate emotional reactions that would be appropriate to the situation. But of course just because Mecha *act* sympathetic, or excited, or happy, displaying the facial and body language of those emotions and saying the words that humans say when they feel them, that doesn't mean that these machines actually *experience* emotions.

A new, advanced model Mecha named David, built to resemble a 10-year-old boy, is programmed to "imprint" upon his adoptive mother, Monica, so that he projects the sort of love and devotion for her that a real boy would display for his mother. Once David has fulfilled his temporary function, his "mother" cannot bring herself to destroy the robot, abandoning him instead. David's subsequent behavior forces the viewer to wonder whether his emotions are simulated or real.

We can't be sure whether David really experiences love or dejection because *A.I.* is, after all, only a movie. But we can reverse the metaphor to ask something else: whether *Monica is actually a machine*. Not a machine made of metal and plastic with a silicon-based computer guiding her behavior, but a machine made of trillions of cells forming flesh and bone, with trillions more cells in her brain that guide her behavior. Those cells in her brain also cause Monica to *experience* love, anguish, and grief as genuinely as any human has ever experienced them. We don't know anything about David or the other Mecha because they don't exist, but modern science has learned a great deal about how Monica's brain—and your brain—works. Our aim in this book is to help you learn what is known so far about how brains work, and how much more we have yet to learn.

In this book we explore the many ways in which the structures and actions of the brain produce mind and behavior. But that is only half of our task. We are also interested in the ways in which behavior and experience in turn modify the structures and actions of the brain. One of the most important lessons we hope to convey is that interactions between brain and behavior are reciprocal. The brain controls behavior and, in turn, behavior and experience alter the brain.

We hope to give an interesting account of the main ideas and research in behavioral neuroscience, which is of great popular as well as scientific interest. Because there are so many strands to tie together, we try to introduce a given piece of information when it makes a difference to the understanding of a subject—especially when it forms part of a story. Most important, we try to communicate our own interest and excitement about the mysteries of mind and body.

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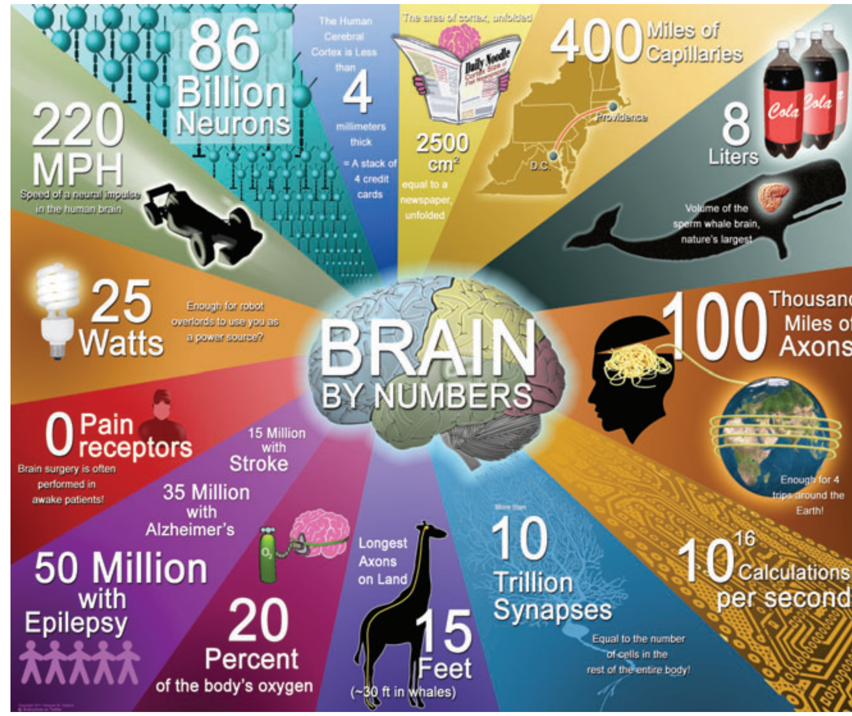


1.1 YOUR BRAIN BY THE NUMBERS The cerebral cortex is the outermost portion of the brain. (© Dwayne Godwin, 2011.)

The Brain Is Full of Surprises

> *I used to think that the brain was the most wonderful organ in my body. Then I realized who was telling me this.*
>
> —Emo Philips
> (American comedian)

Of course we should always consider the source when evaluating an idea, but even so, the brain seems like a very wonderful organ. For one thing, brains produced the entire extent of human knowledge, everything we understand about the universe, however limited that may be. Brains also produced every written description of that hard-won knowledge (including this book you hold in your hands), as well as every work of visual art, from doodles to sweeping murals on the ceiling of the Sistine Chapel.

Most of us have a hard time grasping the idea of a billion of anything, but your head contains an estimated 86 billion nerve cells, or **neurons** (from the Greek word for "nerve" or "cord") (Herculano-Houzel, 2012). Each neuron contacts many other cells at points called *synapses*, so there are *trillions* of those between your ears. A specialized extension of neurons, called an *axon*, is microscopically slender, yet it may be several feet long. We'll learn that axons produce electrical impulses that travel hundreds of miles per hour. **FIGURE 1.1** offers a list of just a few of the things we will learn about the human brain in the course of this book. All this hardware isn't just for show—it allows you to take in all the information in that figure in less than a minute.

What Is Behavioral Neuroscience?

No treaty or trade union agreement defines the boundaries of behavioral neuroscience. The first people to study the relationships between brain and behavior regarded themselves as philosophers, and their findings contributed to the births of biology and psychology. Those disciplines merged in the twentieth century to form *biological psychology*, the field that relates behaviorto bodily processes. With the modern explosion of **neuroscience**, the study of the brain, this research has evolved to the point that **behavioral neuroscience** offers a more accurate description. Whichever name is used, the main goal of this field is to understand the neuroscience underlying behavior and experience.

neuron Also called *nerve cell*. The basic unit of the nervous system.

neuroscience The study of the nervous system.

behavioral neuroscience Also called *biological psychology*. The study of the neural bases of behavior and mental processes.

1.2 WHAT'S IN A NAME? In this graphical representation of the relationships among behavioral neuroscience and other scientific disciplines, fields toward the center of the map are closest to behavioral neuroscience in their history, outlook, aims, and/or methods.

Behavioral neuroscience is a field that includes many players who come from quite different backgrounds: psychologists, biologists, physiologists, engineers, neurologists, psychiatrists, and many others. Thus, there are many career opportunities, in both universities and private industry, for people with interests in this field (Hitt, 2007). **FIGURE 1.2** maps the relations of behavioral neuroscience to these many other disciplines. Clearly, the behavioral neuroscience umbrella opens very wide.

Five Viewpoints Explore the Biology of Behavior

In our pursuit to understand the neuroscience bases of behavior, we use several different perspectives. Because each one yields information that complements the others, the combination of perspectives is especially powerful. We will discuss five major perspectives:

1. *Describing* behavior
2. Studying the *evolution* of behavior
3. Observing the *development* of behavior and its biological characteristics over the life span
4. Studying the biological *mechanisms* of behavior
5. Studying *applications* of behavioral neuroscience—for example, its applications to dysfunctions of human behavior

These perspectives are discussed in the sections that follow, and **TABLE 1.1** on the next page illustrates how each perspective can be applied to three kinds of behavior.

TABLE 1.1 Five Research Perspectives Applied to Three Kinds of Behavior

RESEARCH PERSPECTIVE	SEXUAL BEHAVIOR	LEARNING AND MEMORY	LANGUAGE AND COMMUNICATION
DESCRIPTION			
Structural	What are the main patterns of reproductive behavior and sex differences in behavior?	In what main ways does behavior change as a consequence of experience—for example, conditioning?	How are the sounds of speech patterned?
Functional	How do specialized patterns of behavior contribute to mating and to care of young?	How do certain behaviors lead to rewards or avoidance of punishment?	What behavior is involved in making statements or asking questions?
EVOLUTION	How does mating depend on hormones in different species?	How do different species compare in kinds and speed of learning?	How did the human speech apparatus evolve?
DEVELOPMENT	How do reproductive and secondary sex characteristics develop over the life span?	How do learning and memory change as we grow older?	What changes in the brain when a child learns to speak?
MECHANISMS	What neural circuits and hormones are involved in reproductive behavior?	What anatomical and chemical changes in the brain hold memories?	What brain regions are particularly involved in language?
APPLICATIONS	Low doses of testosterone restore libido in some postmenopausal women.	Gene therapy and behavioral therapy improve memory in some senile patients.	Speech therapy, in conjunction with amphetamine treatment, speeds language recovery following stroke.

Behavior can be described according to different criteria

Until we describe what we want to study, we cannot accomplish much. Depending on our goals, we may describe behavior in terms of detailed acts or processes, or in terms of results or functions. An analytical description of arm movements might record the successive positions of the limb or the contraction of different muscles. A functional behavioral description, by contrast, would state whether the limb was being used in walking or running, texting or sexting. To be useful for scientific study, a description must be precise and reveal the essential features of the behavior, using accurately defined terms and units.

We compare species to learn how the brain and behavior have evolved

Charles Darwin's theory of evolution through natural selection is central to all modern biology. From this perspective emerge two rather different emphases: (1) the *continuity* of behavior and biological processes among species because of our common ancestry and (2) the species-specific *differences* in behavior and biology that have evolved as adaptations to different environments.

Nature is conservative. Once particular features of the body or behavior evolve, they may be maintained for millions of years and may be seen in animals that otherwise appear very different. For example, the electrical messages used by nerve cells (see Chapter 3) are essentially the same in a jellyfish, a cockroach, and a human being. Some of the chemical compounds that transmit messages through the bloodstream (hormones) are also the same in diverse animals (see Chapter 5). Species share these **conserved** characteristics because the features first arose in a shared ancestor (**BOX 1.1**). But mere similarity of a feature between species does not guarantee that the feature came from a common ancestral species. Similar solutions to a problem may have evolved independently in different classes of animals.

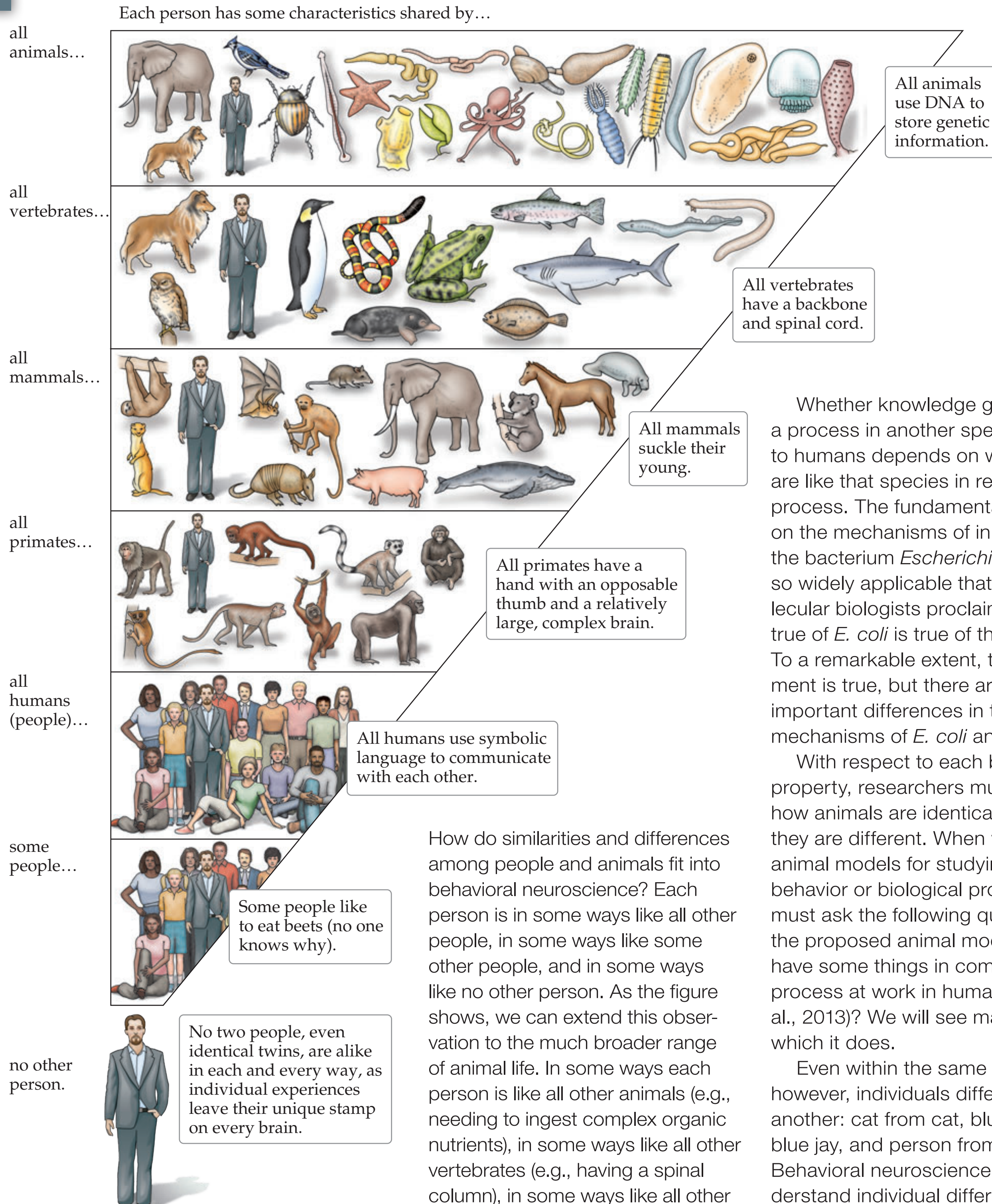
conserved In the context of evolution, referring to a trait that is passed on from a common ancestor to two or more descendant species.

ontogeny The process by which an individual changes in the course of its lifetime—that is, grows up and grows old.

The body and behavior develop over the life span

Ontogeny is the process by which an individual changes in the course of its lifetime—that is, grows up and grows old. Observing the way in which a particular behavior changes during ontogeny may give us clues to its functions and mechanisms. For example, we know that learning ability in monkeys increases over the first years of life. Therefore, we can speculate that prolonged maturation of brain circuits is re-

BOX 1.1 We Are All Alike, and We Are All Different



How do similarities and differences among people and animals fit into behavioral neuroscience? Each person is in some ways like all other people, in some ways like some other people, and in some ways like no other person. As the figure shows, we can extend this observation to the much broader range of animal life. In some ways each person is like all other animals (e.g., needing to ingest complex organic nutrients), in some ways like all other vertebrates (e.g., having a spinal column), in some ways like all other mammals (e.g., nursing our young), and in some ways like all other primates (e.g., having a hand with an opposable thumb and a relatively large, complex brain).

Whether knowledge gained about a process in another species applies to humans depends on whether we are like that species in regard to that process. The fundamental research on the mechanisms of inheritance in the bacterium *Escherichia coli* proved so widely applicable that some molecular biologists proclaimed, "What is true of *E. coli* is true of the elephant." To a remarkable extent, that statement is true, but there are also some important differences in the genetic mechanisms of *E. coli* and mammals.

With respect to each biological property, researchers must determine how animals are identical and how they are different. When we seek animal models for studying human behavior or biological processes, we must ask the following question: Does the proposed animal model really have some things in common with the process at work in humans (Seok et al., 2013)? We will see many cases in which it does.

Even within the same species, however, individuals differ from one another: cat from cat, blue jay from blue jay, and person from person. Behavioral neuroscience seeks to understand individual differences as well as similarities. Therefore, the way in which each person is able to process information and store the memories of these experiences is another part of our story.

quired for complex learning tasks. In rodents, the ability to form long-term memories lags somewhat behind the maturation of learning ability. So, young rodents learn well but forget more quickly than older ones, suggesting that learning and memory involve different processes. Studying the development of reproductive capacity and of differences in behavior between the sexes, along with changes in body structures and processes, throws light on body mechanisms underlying sexual behaviors.

Biological mechanisms underlie all behavior

To learn about the mechanisms of an individual's behavior, we study how his or her *present* body works. To understand the underlying mechanisms of behavior, we must regard the organism (with all due respect) as a "machine," made up of billions of neurons. We must ask, How is this thing constructed to be able to do all that?

Our major aim in behavioral neuroscience is to examine body mechanisms that make particular behaviors possible. In the case of learning and memory, for example, we would like to know the sequence of electrical and biochemical processes that occur when we learn something and retrieve it from memory. What parts of the nervous system are involved in that process? In the case of reproductive behavior, we also want to understand the neuronal and hormonal processes that underlie mating behaviors.

Research can be applied to human problems

Like other sciences, behavioral neuroscience is also dedicated to improving the human condition. Numerous human diseases involve malfunctioning of the brain. Many of these are already being alleviated as a result of research in the neurosciences, and the prospects for continuing advances are good. Attempts to apply knowledge also benefit basic research. For example, the study of memory disorders in humans has pushed investigators to extend our knowledge of the brain regions involved in different kinds of memory (see Chapter 17).

Three Approaches Relate Brain and Behavior

Behavioral neuroscientists use three approaches to understand the relationship between brain and behavior: somatic intervention, behavioral intervention, and correlation. In the most common approach, **somatic intervention** (**FIGURE 1.3A**), we alter a structure or function of the brain or body to see how this alteration changes behavior. Here, somatic intervention is the **independent variable**, and the behavioral effect is the **dependent variable**; that is, the resulting behavior depends on how the brain has been altered. For example, in response to mild electrical stimulation of one part of her brain, not only did one patient laugh, but she found whatever she happened to be looking at amusing (Fried et al., 1998).

In later chapters we describe many kinds of somatic intervention with both humans and other animals, as in the following examples:

- A hormone is administered to some animals but not to others; various behaviors of the two groups are later compared.
- A part of the brain is stimulated electrically, or by use of lasers to stimulate only a particular class of neurons, and behavioral effects are observed.
- A connection between two parts of the nervous system is cut, and changes in behavior are measured.

The approach opposite to somatic intervention is psychological or **behavioral intervention** (**FIGURE 1.3B**). In this approach, the scientist intervenes in the behavior or experience of an organism and looks for resulting changes in body structure or function. Here, behavior is the independent variable, and change in the body is the dependent variable. Among the examples that we will consider in later chapters are the following:

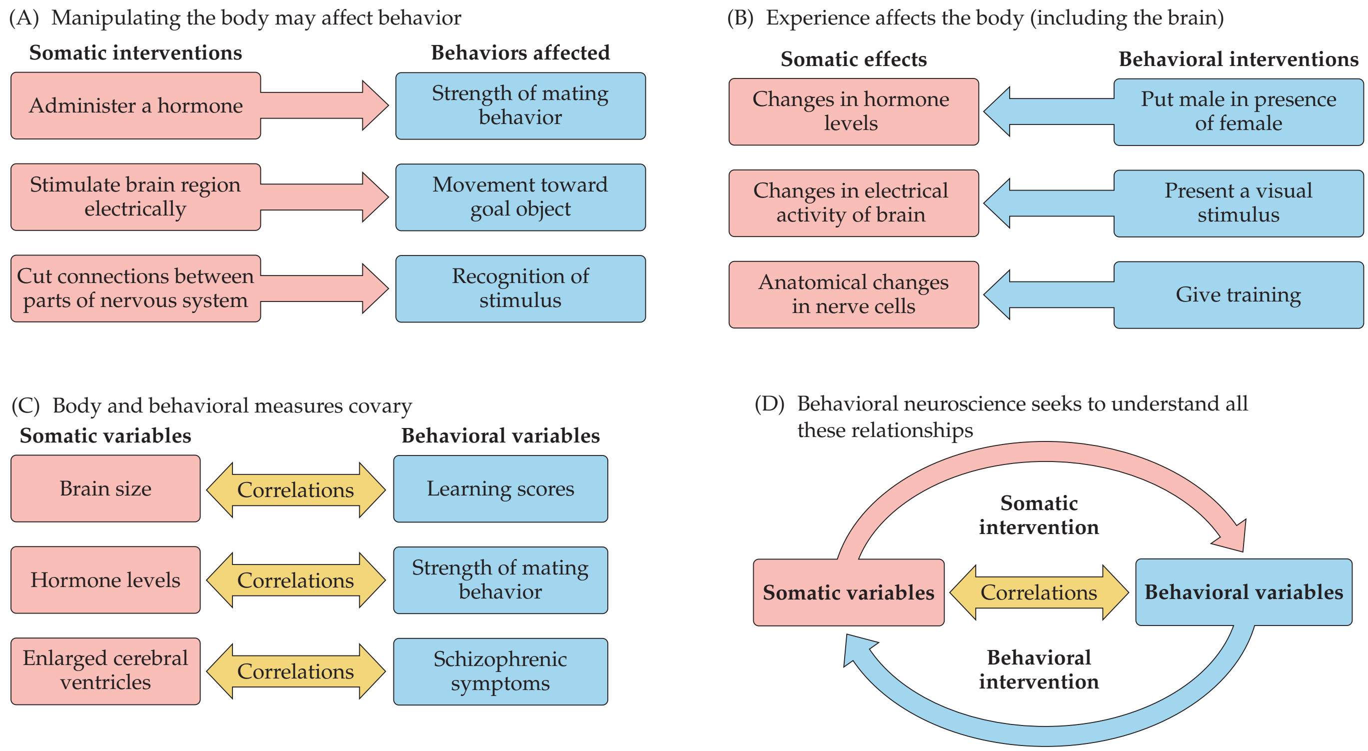
- Putting two adults of opposite sex together may lead to increased secretion of certain hormones.

somatic intervention An approach to finding relations between body variables and behavioral variables that involves manipulating body structure or function and looking for resultant changes in behavior.

independent variable The factor that is manipulated by an experimenter.

dependent variable The factor that an experimenter measures to monitor a change in response to manipulation of an independent variable.

behavioral intervention An approach to finding relations between body variables and behavioral variables that involves intervening in the behavior of an organism and looking for resultant changes in body structure or function.



1.3 THREE MAIN APPROACHES TO STUDYING THE NEUROSCIENCE OF BEHAVIOR (A) In *somatic intervention*, investigators change the body structure or chemistry of an animal in some way and observe and measure any resulting behavioral effects. (B) Conversely, in *behavioral intervention*, researchers change an animal's behavior or its environment and try to ascertain whether the change results in physiological or anatomical changes. (C) Measurements of both kinds of variables allow researchers to arrive at *correlations* between somatic changes and behavioral changes. (D) Each approach enriches and informs the others.

- Exposing a person or animal to a visual stimulus provokes changes in electrical activity and blood flow in parts of the brain.
- Training of animals in a maze is accompanied by electrical, biochemical, and anatomical changes in parts of their brains.

The third approach to brain-behavior relations, **correlation** (**FIGURE 1.3C**), consists of finding the extent to which a given body measure varies with a given behavioral measure. Later we will examine the following questions, among others:

- Are people with large brains more intelligent than people with smaller brains (a topic we'll take up later in this chapter)?
- Are individual differences in sexual behavior correlated with levels of certain hormones in the individuals?
- Is the severity of schizophrenia correlated with the magnitude of changes in brain structure?

Such correlations should not be taken as proof of causal relationship. For one thing, even if a causal relation exists, the correlation does not reveal its direction—that is, which variable is independent and which is dependent. For another, two factors might be correlated only because a third, unknown factor affects the two factors measured. If you and your study partner get similar scores on an exam, that's not because your performance *caused* her to get the score she did, or vice versa. What a correlation does suggest is that the two variables are linked in some way—directly or indirectly. Such a correlation often stimulates investigators to formulate hypotheses and to test them by somatic or behavioral intervention. Only by moving on to such

correlation The covariation of two measures.

neuroplasticity Also called *neural plasticity*. The ability of the nervous system to change in response to experience or the environment.

intervention approaches can we establish whether one variable is *causing* changes in the other.

Combining these three approaches yields the circle diagram of **FIGURE 1.3D**, incorporating the basic approaches to studying relationships between bodily processes and behavior. It also emphasizes the theme that the relations between brain and behavior are reciprocal: each affects the other in an ongoing cycle of bodily and behavioral interactions. We will see examples of this reciprocal relationship throughout the book.

Neuroplasticity: Behavior Can Change the Brain

The idea that there is a reciprocal relationship between brain and behavior has embedded within it a concept that is, for most people, startling. When we say that behavior and experience affect the brain, we mean that they, literally, physically alter the brain. The brain of a child growing up in a French-speaking household assembles itself into a configuration different from that of the brain of a child who hears only English. That's why the first child, as an adult, understands French effortlessly while the second does not. In this case we cannot tell you what the structural differences are exactly, but we do know one part of the brain that is being altered by these different experiences (see Chapter 19).

Numerous examples, almost all in animal subjects, show that experience can affect the number or size of neurons, or the number or size of connections between neurons. This ability of the brain, both in development and in adulthood, to be changed by the environment and by experience is called **neuroplasticity** (or *neural plasticity*, or simply *plasticity*).

Today when we hear the word *plastic*, we think of the class of materials found in so many modern products. But originally, *plastic* meant "flexible, malleable" (from the Greek *plassein*, "to mold or form"), and the modern materials were named *plastics* because they can be molded into nearly any shape. In 1890, William James (1842–1910) described plasticity as the possession of a structure weak enough to yield to an influence but strong enough not to yield all at once.

In the ensuing years, research has shown that the brain is even more plastic, more yielding, than James suspected. For example, parts of neurons known as *dendritic spines* (see Chapter 2) appear to be in constant motion, changing shape in the course of seconds (H. Fischer et al., 1998). We will see many examples in which experience alters the structure and/or function of the brain: In Chapter 5, you'll read that hearing a baby cry causes the mother's brain to secrete a hormone. In Chapter 7, we'll see that visual experience in kittens directs the formation of connections in the brain. In Chapter 12, we'll discuss how a mother rat's grooming of her pups affects the survival of spinal cord neurons. And Chapter 17 talks about how a sea slug learning a task changes the connections between two particular neurons.

Behavioral neuroscience and social psychology are related

The plasticity of the human brain has a remarkable consequence: other individuals can affect the physical structure of your brain! Indeed, the whole point of coming to a lecture hall is to have the instructor use words and figures to alter your brain so that you can retrieve that information in the future (in other words, she is teaching you something). Many of these alterations in your brain last only until you take an exam, but every once in a while the instructor may tell you something that you'll remember for the rest of your life. Most aspects of our social behavior are learned—from the language we speak to the clothes we wear and the kinds of food we eat—so the mechanisms of learning and memory (see Chapter 17) are important for understanding social behavior.

For an example from an animal model, consider the fact that rats spend a lot of time investigating the smells around them, including those coming from other rats. Cooke et al. (2000) took young male rats, just weaned from their mother, and raised them in two different ways: either alone in separate cages, or with other males in group cages so they could engage in play (including a lot of sniffing of each