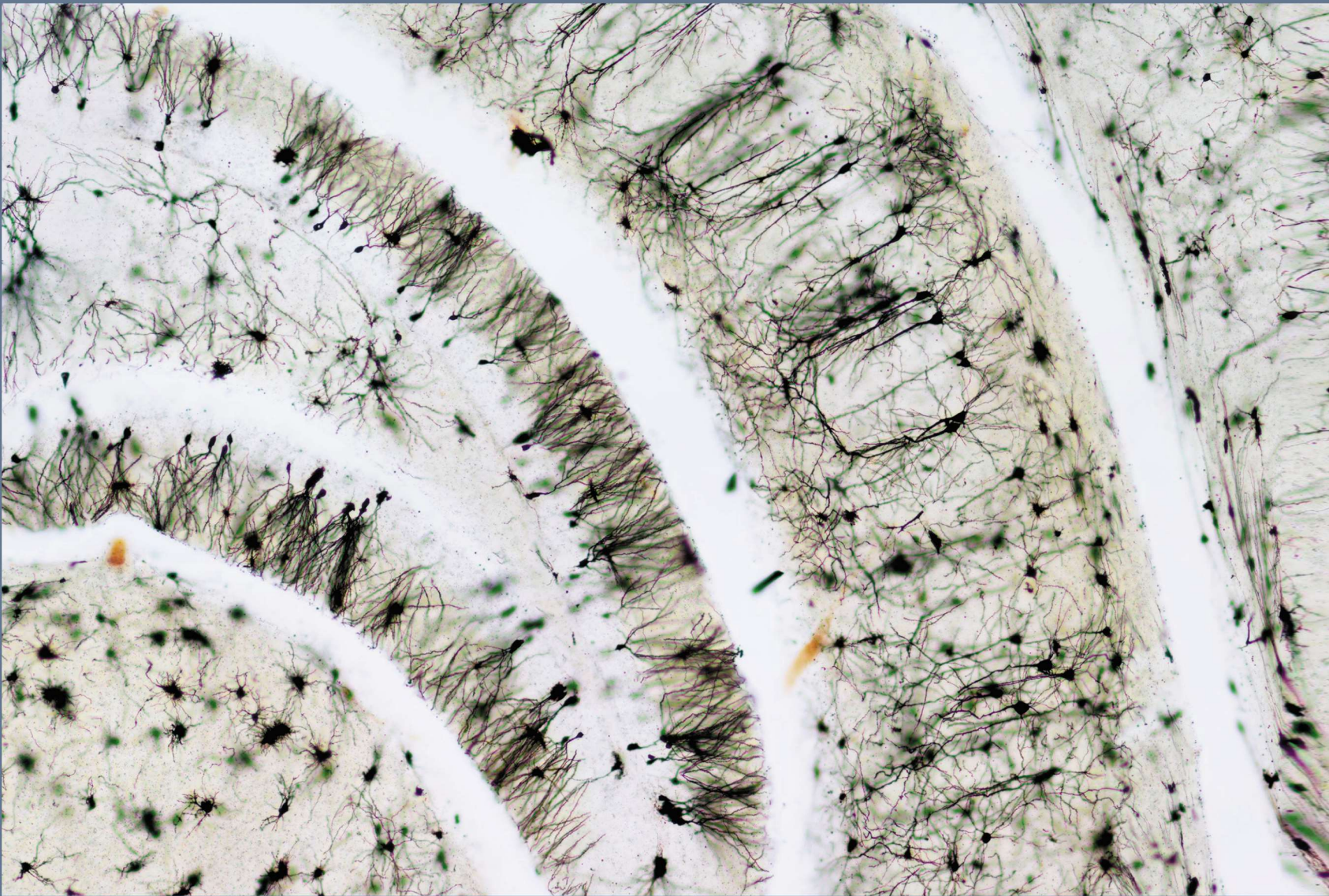


Behavioral Neuroscience

■ NINTH EDITION



S. Marc Breedlove
Neil V. Watson

Behavioral Neuroscience

Ninth Edition

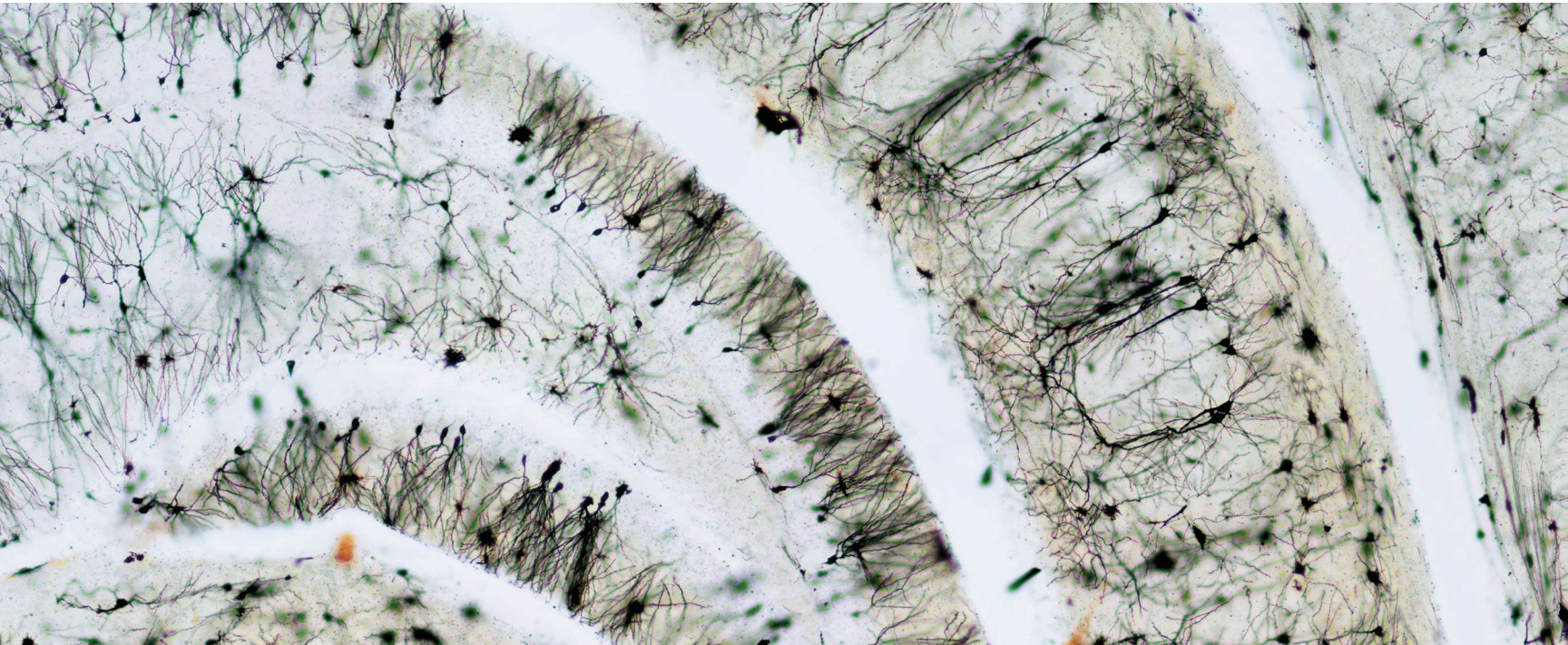
BRAIN, *n.* An apparatus with which we think that we think.

MIND, *n.* A mysterious form of matter secreted by the brain. Its chief activity consists in the endeavor to ascertain its own nature, the futility of the attempt being due to the fact that it has nothing but itself to know itself with.

Ambrose Bierce, 1911 (*The Collected Works of Ambrose Bierce: Volume VII, The Devil's Dictionary*, p. 41, 217)

Behavioral Neuroscience

NINTH EDITION



Courtesy of Dr. Sarah Moghadam, VA Palo Alto Health Care System, Palo Alto, CA and Dr. Ahmad Salehi, Dept. of Psychiatry & Behavioral Sciences, Stanford Medical School

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Behavioral Neuroscience

NINTH EDITION



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Neil V. Watson

About the Cover:

Hippocampal (brain) region. Courtesy of Dr. Sarah Moghadam, VA Palo Alto Health Care System, Palo Alto, CA and Dr. Ahmad Salehi, Dept. of Psychiatry & Behavioral Sciences, Stanford Medical School.

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For Stacey, Collin, and John
S.M.B.

For Scott and Sherry
N.V.W.

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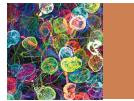
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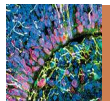
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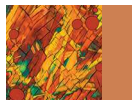
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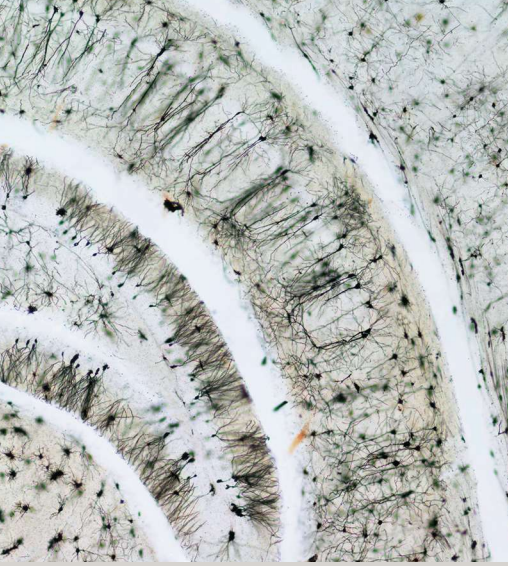
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Courtesy of Dr. Sarah Moghadam, VA Palo Alto Health Care System, Palo Alto, CA and Dr. Ahmad Salehi, Dept. of Psychiatry & Behavioral Sciences, Stanford Medical School

Preface

Twenty-four years ago, a new kind of textbook was published for University courses that were often called “Brain and Behavior.” As the field evolved, the book’s title metamorphosed from *Biological Psychology* to *Behavioral Neuroscience*, but the same drive to provide a definitive and comprehensive survey of the neurosciences lies at the heart of all our efforts. We strive to keep the book up-to-date while keeping a conversational tone to make this wealth of information not just accessible, but fascinating. The biggest change in this new edition is the development of **Learning Objectives** for each segment of the book, with the idea that telegraphing what’s to come will focus readers’ attention and facilitate learning. As you finish each section of text, it would be a good idea to go back and read the associated Learning Objectives to see whether in fact you incorporated the material. If not, a quick review of that text may be in order.

As always, there have been plenty of new findings to add to this edition. In fact, the problem we face is which of the many, many new findings to *leave out*—those that are not quite essential for a survey of the field. We are pretty picky about what we add, and still it seems like a deluge of new information and ideas. Hundreds of new papers are cited in this edition. If that sounds like a lot, let us give you a perspective on how many new papers were omitted. On our newsfeed site (www.biopsychology.com/news/), 1,299 new links were added in 2018 alone. Those are just the findings that were important enough to get the attention of mass media reporters. As we note in Chapter 1, over 40,000 new articles indexed under “neuroscience” appeared that year in PubMed. It would take a thick tome just to list the *titles* of the papers from 2018!

While being very, very selective in sampling this flood of findings, we have made substantial changes in every chapter. For example, in Chapter 3 we have a new figure comparing “kiss and run” synapses with more traditional models of synaptic transmission. Chapter 5 has new material about a hormone secreted from bone that acts on the hypothalamus to reduce appetite. We totally reorganized Chapter 7 for a more streamlined approach and discuss the growing doubts about whether amyloid deposits cause Alzheimer’s. Chapter 9 needed a new figure comparing transduction in the five taste receptors. Chapter 13 talks about yet another factor affecting appetite, glucagon-like peptide 1. Chapter 16 now discusses the logic of pharmacogenomics to treat depression, while Chapter 18 was thoroughly reorganized and includes more about executive function. Honestly, we could go on like this for every chapter. Clearly this is an exciting era in the neurosciences. As Lewis Carroll put it, “We must run as fast as we can just to stay in place!”

We’ve also kept several very popular features from previous editions: **The Cutting Edge** appears in each chapter, where we explore some of the most exciting examples of recent research, and each chapter ends with a **Visual Summary**, where you can see graphic reminders as you review the principle findings that we just presented. These Visual Summaries really shine online, where with just a click you can review figures, animations, and quizzes to help integrate the material. We also continue to open each chapter with a gripping **vignette**, relating someone’s real-life experiences that will be better understood as the content of the chapter unfolds, and we again replaced several of these vignettes as more recent events bring to the surface many of the important issues in behavioral neuroscience. Likewise we’ve retained the marginal glossary that makes it easy to find the definitions that unlock the material, as well as two features to let you burrow in on a particular subject: the online supplements

called **A Step Further** cited throughout the text, and the **Recommended Reading** at the close of each chapter.

You might think that approaching the quarter-century mark we'd be jaded about improving and revising our presentations, but we still love it, perhaps because the dynamic and exciting pace of neuroscience research shows no sign of abating soon. As always, we welcome all feedback, praise or criticism, cuts or additions, from our readers. You can email us directly at behavneuro@gmail.com.

Acknowledgments

We continue to feel so lucky to work with the inestimable team at Sinauer Associates, now a part of Oxford University Press, whose deep skills and generous guidance transform our hundreds of files, thousands of email attachments and sometimes scrambled emails into yet another beautiful book. Again, we feel so grateful to benefit from the experience and exquisite taste of others. In particular, the book could not exist without the contributions of Senior Acquisition Editor Syd Carroll, Production Editor Alison Hornbeck, Production Manager Joan Gemme, Book Designer and Production Specialist Annette Rapier, and Media and Supplements Editor Zan Carter and her crew. We also fondly bid adieu to the recently retired Chris Small, Production Manager for all our previous editions. We hope you're enjoying yourself, Chris, but how could you abandon us!? A cadre of commandos delved deep in the archives to deal with copyrights and permissions, so we salute you Michele Beckta, Mark Siddall, and Tracy Marton. We'd also like to thank our copy editor Lou Doucette, and our longtime art studio, Dragonfly Media, who bring amazing skill and commitment to make us look good.

We must also thank the founder of Sinauer Associates, Andy Sinauer, for his unwavering support over the years, with a touch of sadness upon his retirement. We are so proud to be a part of Andy's tremendous legacy, begun all those years ago with *From Neuron to Brain*, creating gorgeous books that make even the most complex topics accessible and enjoyable.

By this point in the evolution of the book, we have benefited from the wisdom and advice of hundreds of colleagues who have generously served as reviewers of past editions. Although we don't have the space to list them all, we want to acknowledge that in many ways the book you are holding is the product of a whole community of neuroscientists. In this, the Ninth Edition, the following colleagues have provided invaluable critique and commentary:

Susan Bachus, *University of Maryland, Baltimore County*

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Raymond H. Dye, Jr., *Loyola University Chicago*

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Finally, we thank all those tireless colleagues trying to understand the neural basis of behavior, with techniques that would have seemed like sorcery only a few years ago, and who share their hard-won findings with us all.



S. Marc Breedlove



Neil V. Watson

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For the Student

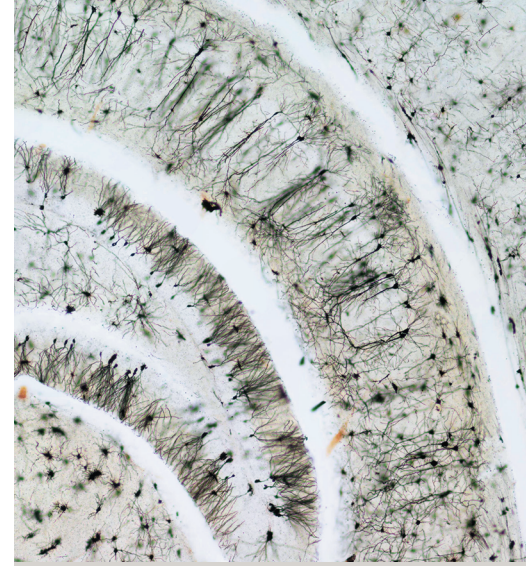
Companion Website (bn9e.com)

The *Behavioral Neuroscience* Companion Website contains a range of study and review resources to help students master the material presented in each chapter of the textbook. Access to the site is included with each new copy of the textbook (see inside front cover). The site includes the following resources:

- *Chapter Outlines* that outline each chapter and link to relevant Study Questions
- *Brain Explorer* that offers an interactive way to explore the brain anatomy discussed in each chapter
- *Activities* that help the student review key structures and processes
- *Animations* and *Videos* that illustrate many of the complex, dynamic concepts and processes of behavioral neuroscience
- *Media Clips* that highlight interesting topics in the chapters (**NEW** for this edition)
- “*A Step Further*” essays that offer expanded coverage of selected topics
- *Visual Summaries* that link to all the Activities, Animations, and Videos, forming a complete review of each chapter
- *Study Questions* that help the student master the full range of material in each chapter
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Courtesy of Dr. Sarah Moghadam, VA Palo Alto Health Care System, Palo Alto, CA and Dr. Ahmad Salehi, Dept. of Psychiatry & Behavioral Sciences, Stanford Medical School

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Introduction

Scope and Outlook

Machine or Human?

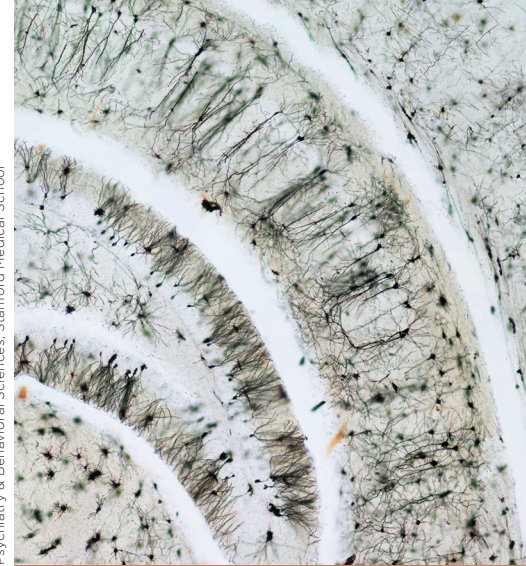
In the near future depicted in the HBO series *Westworld*, people visit a theme park set in the Old West, with steam locomotives, saloons, and brothels, populated with androids, called “hosts,” to entertain humans. The mechanical hosts provide their guests with anything, from casual banter to gunfights, harmless flirting to kinky sex, the only restriction being that the robots are never to harm the humans. The android hosts are so lifelike in appearance and behavior that visitors may have a hard time distinguishing whether someone is a fellow guest or a robot. To make the androids’ simulation of humans complete, they are given backstories, false memories of a life before their appearance for each new batch of guests. Importantly, none of the androids know that they are mechanical beings rather than humans. It’s probably not much of a spoiler to say that several plot lines in the series hinge on androids slowly discovering their true nature, moving from shock and shame that they are mere machines, to openly rebelling from the notion that they are to be used, and abused, as mere playthings for the humans.

We aren’t told too much about how the android “brains” in *Westworld* work, because, of course, such technology remains far outside our grasp, so the writers, reduced to mere speculation, remain rather vague. But apparently the knowledge and personality for any particular android lies in a “control unit,” a golf-ball-size device that can be extracted from the head of one host and implanted into the head of another, interchangeable body. Presumably, if we had enough knowledge and surgical skill, we could remove your brain from your head and connect it up to the head of some other body. Would you still be you? Even if we put your brain into a body of the opposite sex? Come to think of it, are you entirely sure there is a brain in your head, and not one of those control units?

Our aim in this book is to help you learn what is known so far about how brains work, and about how much more we have yet to learn. We will 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 modify the structures and actions of the brain. One of the most important lessons we want 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. Most important, we try to communicate our own interest and excitement about the mysteries of mind and body.

Courtesy of Dr. Sarah Moehadam, VA Palo Alto Health Care System, Palo Alto, CA and Dr. Ahmad Salehi, Dept. of Psychiatry & Behavioral Sciences, Stanford Medical School



1



1.1 The Brain Is Full of Surprises

Learning Objectives

After reading this section, you should be able to:

- 1.1.1 Name the main type of cells found in the brain, and name the connections between them.
- 1.1.2 List the names of some of the many fields of study related to behavioral neuroscience.
- 1.1.3 Describe five different perspectives taken in understanding the biology of behavior.

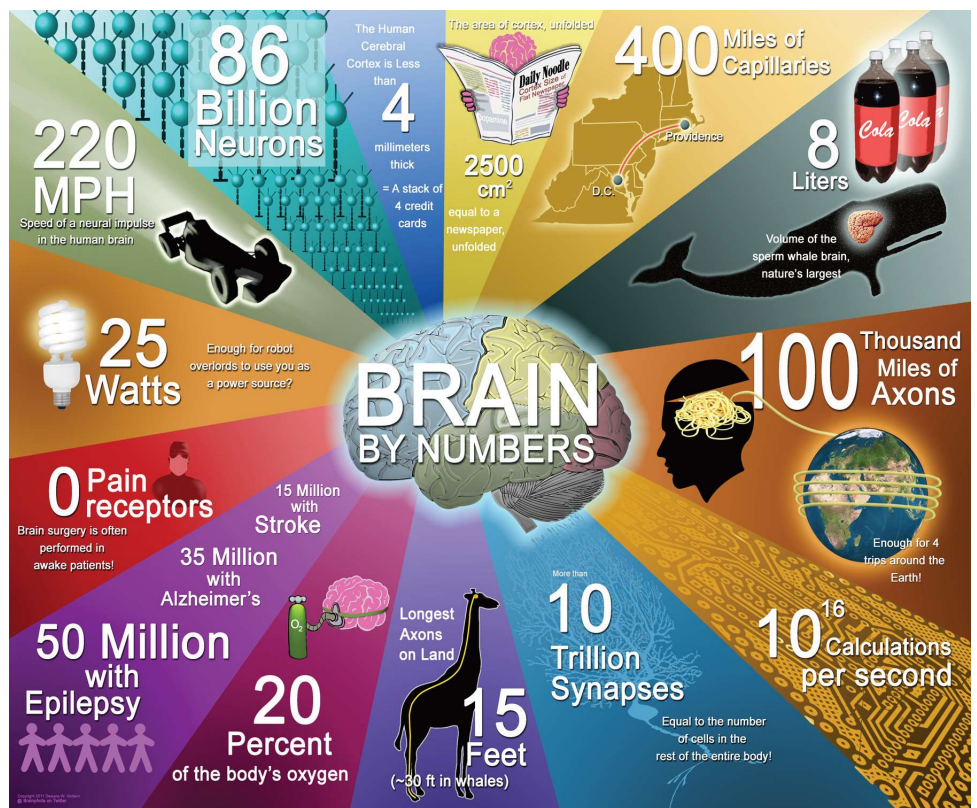
I used to think that the brain was the most wonderful organ in my body. Then I realized who was telling me this.

—Emo Philips
(American comedian)

Of course we should always consider the source when evaluating an idea, but even so, the brain indeed seems like a pretty 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 the sweeping frescos 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

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



1.1 Your Brain by the Numbers The cerebral cortex is the outermost portion of the brain.

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 behavior to 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.

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.

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.

Five viewpoints explore the biology of behavior

In our effort 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. Observing the *development* of behavior and its biological characteristics over the life-span
3. Studying the biological *mechanisms* of behavior
4. Studying *applications* of behavioral neuroscience—for example, its application to dysfunctions of human behavior
5. Studying the *evolution* of behavior

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

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.

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?
ONTOGENY (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.
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?

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 required 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? These are sometimes described as *proximate* questions—questions about the physical interactions that control a particular behavior. How cells in your eye respond differently to light of different wavelengths is a proximate question. On the other hand, why color vision, once it arose, benefited our ancestors is an evolutionary question.

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 translated to address 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).

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

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** on the next page). 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.

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 that reflects shared ancestry and (2) the species-specific *differences* in behavior and biology that have evolved as adaptations to different environments.

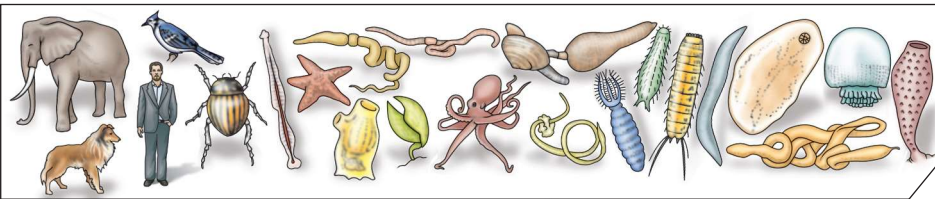
conserved In the context of evolution, referring to a trait that is passed on from a common ancestor to two or more descendant species.

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

We Are All Alike, and We Are All Different

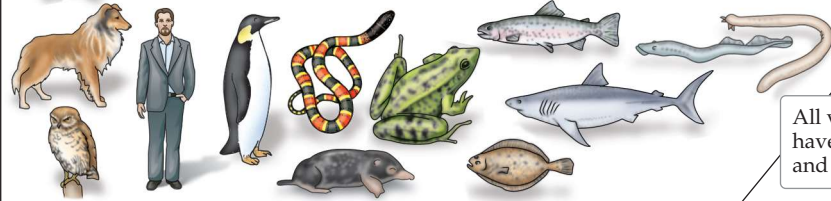
Each person has some characteristics shared by...

all animals...



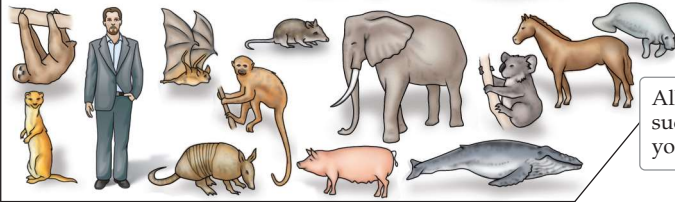
All animals use DNA to store genetic information.

all vertebrates...



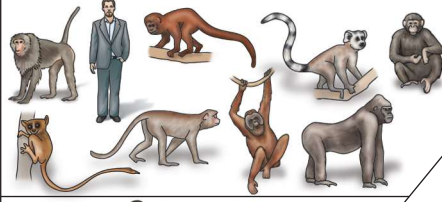
All vertebrates have a backbone and spinal cord.

all mammals...



All mammals suckle their young.

all primates...



All primates have a hand with an opposable thumb and a relatively large, complex brain.

all humans (people)...



All humans use symbolic language to communicate with each other.

some people...



Some people like to eat beetles (no one knows why).

no other person.



No two people, even identical twins, are alike in each and every way, as individual experiences leave their unique stamp on every brain.

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. Each person is in some ways 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.

1.2 Three Approaches Relate Brain and Behavior

Learning Objectives

After reading this section, you should be able to:

- 1.2.1 Differentiate between the independent and dependent variables in scientific experiments.
- 1.2.2 Name the type of research in which a part of the brain is manipulated to observe effects on behavior, and offer examples.
- 1.2.3 Name the type of research in which behavior or experience is manipulated to observe effects on the brain, and offer examples.
- 1.2.4 Describe correlational research about the brain and behavior, and offer examples.
- 1.2.5 Explain why the brain must be capable of changing its structure, and name the term to describe that changeability.

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 light 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.

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.

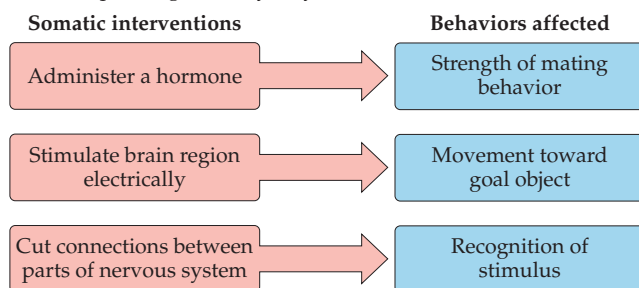
independent variable The factor that is manipulated by an experimenter.

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

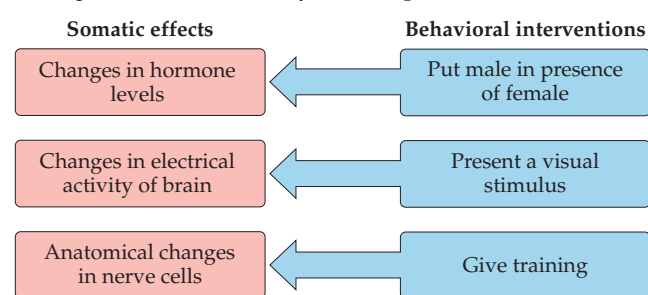
1.3 Three Main Approaches to Studying the Neuroscience of Behavior

(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.

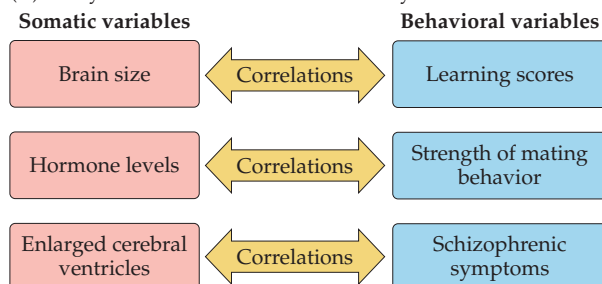
(A) Manipulating the body may affect behavior



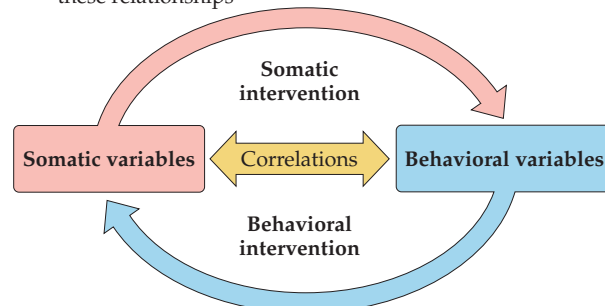
(B) Experience affects the body (including the brain)



(C) Body and behavioral measures covary



(D) Behavioral neuroscience seeks to understand all these relationships



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.

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.

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.
- 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 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)



Go to Media Clip 1.1
Neuroplasticity
bn9e.com/mc1.1

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. 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.

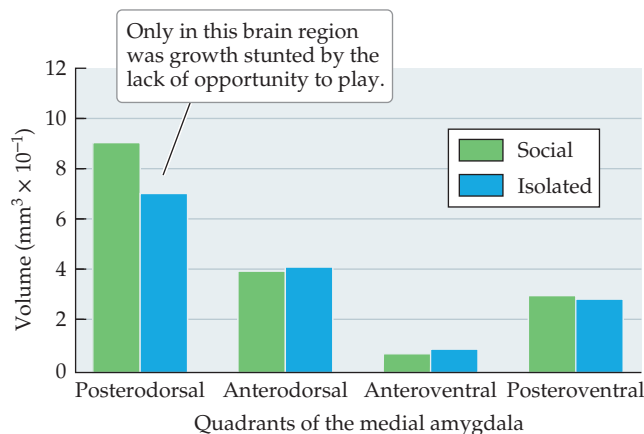
Behavioral neuroscience and social psychology are related

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, teach 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 other's butts). Examination of these animals as adults found only one brain difference between the groups: a region of the brain known to process odors was smaller in the isolated males than in the males raised with playmates (FIGURE 1.4). Was it the lack of play (N. S. Gordon et al., 2003), the lack of odors to investigate, or the stress of isolation that made the region smaller? Whatever the mechanism, social experience affects this brain structure. In Chapter 17 we'll see more examples of social experience altering the brain.

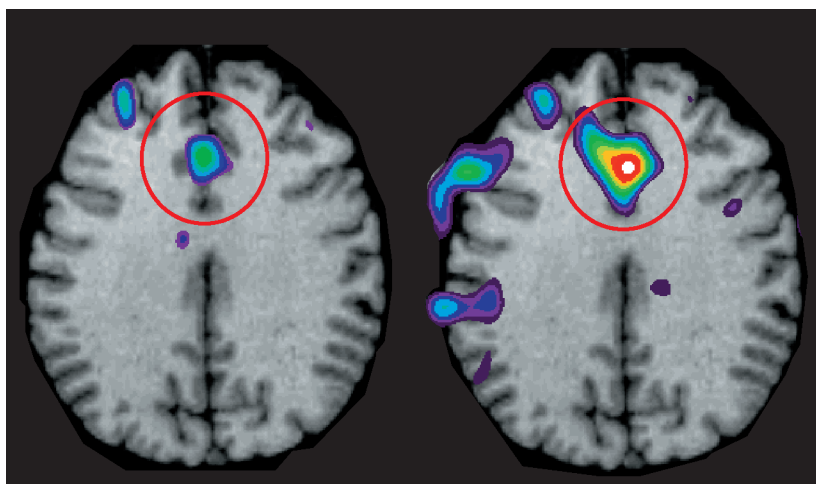
Here's an example of how social influences can affect human brain function. When people were asked to put a hand into moderately hot water (47°C), part of the brain became active, presumably because of the discomfort involved (Rainville et al., 1997). But people who were led to believe the water would be *very* hot had a more activated brain than did those led to believe the discomfort would be minimal (FIGURE 1.5), even though the water was the same temperature for everyone. The socially induced psychological expectation affected the magnitude of the brain response,

1.5 Pictures of Pain People told to expect only mild discomfort from putting a hand into 47°C water (left) showed less activation in a particular brain region (the anterior cingulate cortex) than did people expecting more discomfort (right) from water of the very same temperature. Areas of high activation are indicated by orange, red, and white.



1.4 The Role of Play in Brain Development

A brain region involved in processing odors (the posterodorsal portion of the medial amygdala) was smaller in male rats housed individually than in males housed together and allowed to play. Other nearby regions were identical in the two groups. (After B. M. Cooke et al., 2000. *Behav Brain Res* 117: 107–113.)



From P. Rainville, 1998. Presented at INABIS '98, 5th Internet World Congress on Biomedical Sciences at McMaster University, Canada, Dec 7-16th. Available at <http://www.mcmaster.ca/inbis98/wood/rainville0419/index.html>