Chapter 3
Brains, Bodies, and Behavior

Every behavior begins with biology. Our behaviors, as well as our thoughts and feelings, are produced by the actions of our brains, nerves, muscles, and glands. In this chapter we will begin our journey into the world of psychology by considering the biological makeup of the human being, including the most remarkable of human organs—the brain. We’ll consider the structure of the brain and also the methods that psychologists use to study the brain and to understand how it works.

We will see that the body is controlled by an information highway known as the nervous system, *a collection of hundreds of billions of specialized and interconnected cells through which messages are sent between the brain and the rest of the body*. The nervous system consists of the central nervous system (CNS), *made up of the brain and the spinal cord*, and the peripheral nervous system (PNS), *the neurons that link the CNS to our skin, muscles, and glands*. And we will see that our behavior is also influenced in large part by the endocrine system, *the chemical regulator of the body that consists of glands that secrete hormones*.

Although this chapter begins at a very low level of explanation, and although the topic of study may seem at first to be far from the everyday behaviors that we all engage in, a full understanding of the biology underlying psychological processes is an important cornerstone of your new understanding of psychology. We will consider throughout the chapter how our biology influences important human behaviors, including our mental and physical health, our reactions to drugs, as well as our aggressive responses and our perceptions of other people. This chapter is particularly important for contemporary psychology because the ability to measure biological aspects of behavior, including the structure and function of the human brain, is progressing rapidly, and understanding the biological foundations of behavior is an increasingly important line of psychological study.
3.1 The Neuron Is the Building Block of the Nervous System

The nervous system is composed of more than 100 billion cells known as neurons. A neuron is a cell in the nervous system whose function it is to receive and transmit information. As you can see in Figure 3.2 "Components of the Neuron", neurons are made up of three major parts: a cell body, or soma, which contains the nucleus of the cell and keeps the cell alive; a branching treelike fiber known as the dendrite, which collects information from other cells and sends the information to the soma; and a long, segmented fiber known as the axon, which transmits information away from the cell body toward other neurons or to the muscles and glands.

Figure 3.2 Components of the Neuron
Some neurons have hundreds or even thousands of dendrites, and these dendrites may themselves be branched to allow the cell to receive information from thousands of other cells. The axons are also specialized, and some, such as those that send messages from the spinal cord to the muscles in the hands or feet, may be very long—even up to several feet in length. To improve the speed of their communication, and to keep their electrical charges from shorting out with other neurons, axons are often surrounded by a myelin sheath. The myelin sheath is a layer of fatty tissue surrounding the axon of a neuron that both acts as an insulator and allows faster transmission of the electrical signal. Axons branch out toward their ends, and at the tip of each branch is a terminal button.

Neurons Communicate Using Electricity and Chemicals

The nervous system operates using an electrochemical process. An electrical charge moves through the neuron itself and chemicals are used to transmit information between neurons. Within the neuron, when a signal is received by the dendrites, is it transmitted to the soma in the form of an electrical signal, and, if the signal is strong enough, it may then be passed on to the axon and then to the terminal buttons. If the signal reaches the terminal buttons, they are signaled to emit chemicals known as neurotransmitters, which communicate with other neurons across the spaces between the cells, known as synapses.

The electrical signal moves through the neuron as a result of changes in the electrical charge of the axon. Normally, the axon remains in the resting potential, a state in which the interior of the neuron contains a greater number of negatively charged ions than does the area outside the cell. When the segment of the axon that is closest to the cell body is stimulated by an electrical signal from the dendrites, and if this electrical signal is strong enough that it passes a certain level or threshold, the cell membrane in this first segment opens its gates, allowing positively charged sodium ions that were previously kept out to enter. This change in electrical charge that occurs in a neuron when a nerve impulse is transmitted is known as the action potential. Once the action
potential occurs, the number of positive ions exceeds the number of negative ions in this segment, and the segment temporarily becomes positively charged.

An important aspect of the action potential is that it operates in an all or nothing manner. What this means is that the neuron either fires completely, such that the action potential moves all the way down the axon, or it does not fire at all. Thus neurons can provide more energy to the neurons down the line by firing faster but not by firing more strongly. Furthermore, the neuron is prevented from repeated firing by the presence of a refractory period—a brief time after the firing of the axon in which the axon cannot fire again because the neuron has not yet returned to its resting potential.

**Neurotransmitters: The Body’s Chemical Messengers**

Not only do the neural signals travel via electrical charges within the neuron, but they also travel via chemical transmission between the neurons. Neurons are separated by junction areas known as synapses, areas where the terminal buttons at the end of the axon of one neuron nearly, but don’t quite, touch the dendrites of another. The synapses provide a remarkable function because they allow each axon to communicate with many dendrites in neighboring cells. Because a neuron may have synaptic connections with thousands of other neurons, the communication links among the neurons in the nervous system allow for a highly sophisticated communication system.

When the electrical impulse from the action potential reaches the end of the axon, it signals the terminal buttons to release neurotransmitters into the synapse. A neurotransmitter is a chemical that relays signals across the synapses between neurons. Neurotransmitters travel across the synaptic space between the terminal button of one neuron and the dendrites of other neurons, where they bind to the dendrites in the neighboring neurons. Furthermore, different terminal buttons release different neurotransmitters, and different dendrites are particularly sensitive to different neurotransmitters. The dendrites will admit the neurotransmitters only if they are the right shape to fit in the receptor sites on the receiving neuron. For this reason, the receptor sites and neurotransmitters are often compared to a lock and key (Figure 3.5 "The Synapse").
When the nerve impulse reaches the terminal button, it triggers the release of neurotransmitters into the synapse. The neurotransmitters fit into receptors on the receiving dendrites in the manner of a lock and key.

When neurotransmitters are accepted by the receptors on the receiving neurons their effect may be either excitatory (i.e., they make the cell more likely to fire) or inhibitory (i.e., they make the
cell less likely to fire). Furthermore, if the receiving neuron is able to accept more than one neurotransmitter, then it will be influenced by the excitatory and inhibitory processes of each. If the excitatory effects of the neurotransmitters are greater than the inhibitory influences of the neurotransmitters, the neuron moves closer to its firing threshold, and if it reaches the threshold, the action potential and the process of transferring information through the neuron begins.

Neurotransmitters that are not accepted by the receptor sites must be removed from the synapse in order for the next potential stimulation of the neuron to happen. This process occurs in part through the breaking down of the neurotransmitters by enzymes, and in part through reuptake, a process in which neurotransmitters that are in the synapse are reabsorbed into the transmitting terminal buttons, ready to again be released after the neuron fires.

More than 100 chemical substances produced in the body have been identified as neurotransmitters, and these substances have a wide and profound effect on emotion, cognition, and behavior. Neurotransmitters regulate our appetite, our memory, our emotions, as well as our muscle action and movement. And as you can see in Table 3.1 "The Major Neurotransmitters and Their Functions", some neurotransmitters are also associated with psychological and physical diseases.

Drugs that we might ingest—either for medical reasons or recreationally—can act like neurotransmitters to influence our thoughts, feelings, and behavior. An agonist is a drug that has chemical properties similar to a particular neurotransmitter and thus mimics the effects of the neurotransmitter. When an agonist is ingested, it binds to the receptor sites in the dendrites to excite the neuron, acting as if more of the neurotransmitter had been present. As an example, cocaine is an agonist for the neurotransmitter dopamine. Because dopamine produces feelings of pleasure when it is released by neurons, cocaine creates similar feelings when it is ingested. An antagonist is a drug that reduces or stops the normal effects of a neurotransmitter. When an antagonist is ingested, it binds to the receptor sites in the dendrite, thereby blocking the neurotransmitter. As an example, the poison curare is an antagonist for the neurotransmitter acetylcholine. When the poison enters the brain, it binds to the dendrites, stops communication among the neurons, and usually causes death. Still other drugs work by blocking the reuptake of
the neurotransmitter itself—when reuptake is reduced by the drug, more neurotransmitter remains in the synapse, increasing its action.

<table>
<thead>
<tr>
<th>Neurotransmitter</th>
<th>Description and function</th>
<th>Notes</th>
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<tbody>
<tr>
<td>Acetylcholine (ACh)</td>
<td>A common neurotransmitter used in the spinal cord and motor neurons to stimulate muscle</td>
<td>Alzheimer’s disease is associated with an undersupply of acetylcholine. Nicotine is an agonist that acts like acetylcholine.</td>
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<td>contractions. It’s also used in the brain to regulate memory, sleeping, and dreaming.</td>
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<tr>
<td>Dopamine</td>
<td>Involved in movement, motivation, and emotion. Dopamine produces feelings of pleasure</td>
<td>Schizophrenia is linked to increases in dopamine, whereas Parkinson’s</td>
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<td>when released by the brain’s reward system, and it’s also involved in learning.</td>
<td>disease is linked to reductions in dopamine (and dopamine agonists may</td>
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<td></td>
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<td>be used to treat it).</td>
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<td>Endorphins</td>
<td>Released in response to behaviors such as vigorous exercise, orgasm, and eating spicy</td>
<td>Endorphins are natural pain relievers. They are related to the</td>
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<td></td>
<td>foods.</td>
<td>compounds found in drugs such as opium, morphine, and heroin. The</td>
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<td>release of endorphins creates the runner’s high that is experienced</td>
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<td></td>
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<td>after intense physical exertion.</td>
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<td>GABA (gamma-aminobutyric</td>
<td>The major inhibitory neurotransmitter in the brain.</td>
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<td>acid)</td>
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<td>Glutamate</td>
<td>The most common neurotransmitter, it’s released in more than 90% of the brain’s</td>
<td>A lack of GABA can lead to involuntary motor actions, including</td>
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<td>synapses. Glutamate is found in the food additive MSG (monosodium glutamate).</td>
<td>tremors and seizures. Alcohol stimulates the release of GABA, which</td>
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<td></td>
<td></td>
<td>inhibits the nervous system and makes us feel drunk. Low levels of</td>
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<td></td>
<td></td>
<td>GABA can produce anxiety, and GABA agonists (tranquilizers) are used</td>
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<td></td>
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<td>to reduce anxiety.</td>
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<tr>
<td>Serotonin</td>
<td>Involved in many functions, including mood, appetite, sleep, and aggression.</td>
<td>Low levels of serotonin are associated with depression, and some</td>
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<td>drugs designed to treat depression (known as selective serotonin</td>
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<td></td>
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<td>reuptake inhibitors, or SSRIs) serve to</td>
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The Old Brain: Wired for Survival

The brain stem is the oldest and innermost region of the brain. It’s designed to control the most basic functions of life, including breathing, attention, and motor responses (Figure 3.8 "The Brain Stem and the Thalamus"). The brain stem begins where the spinal cord enters the skull and forms the medulla, the area of the brain stem that controls heart rate and breathing. In many cases the medulla alone is sufficient to maintain life—animals that have the remainder of their brains above the medulla severed are still able to eat, breathe, and even move. The spherical shape above the medulla is the pons, a structure in the brain stem that helps control the movements of the body, playing a particularly important role in balance and walking.

Running through the medulla and the pons is a long, narrow network of neurons known as the reticular formation. The job of the reticular formation is to filter out some of the stimuli that are coming into the brain from the spinal cord and to relay the remainder of the signals to other areas of the brain. The reticular formation also plays important roles in walking, eating, sexual activity, and sleeping. When electrical stimulation is applied to the reticular formation of an animal, it immediately becomes fully awake, and when the reticular formation is severed from the higher brain regions, the animal falls into a deep coma.
The brain stem is an extension of the spinal cord, including the medulla, the pons, the thalamus, and the reticular formation.

Above the brain stem are other parts of the old brain that also are involved in the processing of behavior and emotions (see Figure 3.9 “The Limbic System”). The thalamus is the egg-shaped structure above the brain stem that applies still more filtering to the sensory information that is coming up from the spinal cord and through the reticular formation, and it relays some of these remaining signals to the higher brain levels (Guillery & Sherman, 2002). The thalamus also receives some of the higher brain’s replies, forwarding them to the medulla and the cerebellum. The thalamus is also important in sleep because it shuts off incoming signals from the senses, allowing us to rest.
Figure 3.9 The Limbic System

This diagram shows the major parts of the limbic system, as well as the pituitary gland, which is controlled by it. The cerebellum (literally, “little brain”) consists of two wrinkled ovals behind the brain stem. It functions to coordinate voluntary movement.

People who have damage to the cerebellum have difficulty walking, keeping their balance, and holding their hands steady. Consuming alcohol influences the cerebellum, which is why people who are drunk have more difficulty walking in a straight line. Also, the cerebellum contributes to emotional responses, helps us discriminate between different sounds and textures, and is important in learning (Bower & Parsons, 2003). [2]
Whereas the primary function of the brain stem is to regulate the most basic aspects of life, including motor functions, the limbic system is largely responsible for memory and emotions, including our responses to reward and punishment. The limbic system is a brain area, located between the brain stem and the two cerebral hemispheres, that governs emotion and memory. It includes the amygdala, the hypothalamus, and the hippocampus.

The amygdala consists of two “almond-shaped” clusters (amygdala comes from the Latin word for “almond”) and is primarily responsible for regulating our perceptions of, and reactions to, aggression and fear. The amygdala has connections to other bodily systems related to fear, including the sympathetic nervous system (which we will see later is important in fear responses), facial responses (which perceive and express emotions), the processing of smells, and the release of neurotransmitters related to stress and aggression (Best, 2009).[3] In one early study, Klüver and Bucy (1939)[4] damaged the amygdala of an aggressive rhesus monkey. They found that the once angry animal immediately became passive and no longer responded to fearful situations with aggressive behavior. Electrical stimulation of the amygdala in other animals also influences aggression. In addition to helping us experience fear, the amygdala also helps us learn from situations that create fear. When we experience events that are dangerous, the amygdala stimulates the brain to remember the details of the situation so that we learn to avoid it in the future (Sigurdsson, Doyère, Cain, & LeDoux, 2007).[5]

Located just under the thalamus (hence its name) the hypothalamus is a brain structure that contains a number of small areas that perform a variety of functions, including the important role of linking the nervous system to the endocrine system via the pituitary gland. Through its many interactions with other parts of the brain, the hypothalamus helps regulate body temperature, hunger, thirst, and sex, and responds to the satisfaction of these needs by creating feelings of pleasure. Olds and Milner (1954)[6] discovered these reward centers accidentally after they had momentarily stimulated the hypothalamus of a rat. The researchers noticed that after being stimulated, the rat continued to move to the exact spot in its cage where the stimulation had occurred, as if it were trying to re-create the circumstances surrounding its original experience. Upon further research into these reward centers, Olds (1958)[7] discovered that animals would do almost anything to re-create enjoyable stimulation, including crossing a painful electrified grid to receive it. In one experiment a rat was given the opportunity to
electrically stimulate its own hypothalamus by pressing a pedal. The rat enjoyed the experience so much that it pressed the pedal more than 7,000 times per hour until it collapsed from sheer exhaustion.

The hippocampus consists of two “horns” that curve back from the amygdala. The hippocampus is important in storing information in long-term memory. If the hippocampus is damaged, a person cannot build new memories, living instead in a strange world where everything he or she experiences just fades away, even while older memories from the time before the damage are untouched.

The Cerebral Cortex Creates Consciousness and Thinking

All animals have adapted to their environments by developing abilities that help them survive. Some animals have hard shells, others run extremely fast, and some have acute hearing. Human beings do not have any of these particular characteristics, but we do have one big advantage over other animals—we are very, very smart.

You might think that we should be able to determine the intelligence of an animal by looking at the ratio of the animal’s brain weight to the weight of its entire body. But this does not really work. The elephant’s brain is one thousandth of its weight, but the whale’s brain is only one ten-thousandth of its body weight. On the other hand, although the human brain is one 60th of its body weight, the mouse’s brain represents one fortieth of its body weight. Despite these comparisons, elephants do not seem 10 times smarter than whales, and humans definitely seem smarter than mice.

The key to the advanced intelligence of humans is not found in the size of our brains. What sets humans apart from other animals is our larger cerebral cortex—the outer bark-like layer of our brain that allows us to so successfully use language, acquire complex skills, create tools, and live in social groups (Gibson, 2002).[^8] In humans, the cerebral cortex is wrinkled and folded, rather than smooth as it is in most other animals. This creates a much greater surface area and size, and allows increased capacities for learning, remembering, and thinking. The folding of the cerebral cortex is referred to as corticalization.

[^8]: Gibson, 2002.
Although the cortex is only about one tenth of an inch thick, it makes up more than 80% of the brain’s weight. The cortex contains about 20 billion nerve cells and 300 trillion synaptic connections (de Courten-Myers, 1999). Supporting all these neurons are billions more glial cells (glia), *cells that surround and link to the neurons, protecting them, providing them with nutrients, and absorbing unused neurotransmitters*. The glia come in different forms and have different functions. For instance, the myelin sheath surrounding the axon of many neurons is a type of glial cell. The glia are essential partners of neurons, without which the neurons could not survive or function (Miller, 2005).

The cerebral cortex is divided into two *hemispheres*, and each hemisphere is divided into four *lobes*, each separated by folds known as *fissures*. If we look at the cortex starting at the front of the brain and moving over the top (see Figure 3.10 "The Two Hemispheres"), we see first the frontal lobe (behind the forehead), *which is responsible primarily for thinking, planning, memory, and judgment*. Following the frontal lobe is the parietal lobe, *which extends from the middle to the back of the skull and which is responsible primarily for processing information about touch*. Then comes the occipital lobe, *at the very back of the skull, which processes visual information*. Finally, in front of the occipital lobe (pretty much between the ears) is the temporal lobe, *responsible primarily for hearing and language*.

*Figure 3.10 The Two Hemispheres*
The brain is divided into two hemispheres (left and right), each of which has four lobes (temporal, frontal, occipital, and parietal). Furthermore, there are specific cortical areas that control different processes.

**Functions of the Cortex**

When the German physiologists Gustav Fritsch and Eduard Hitzig (1870/2009)\(^{[11]}\) applied mild electric stimulation to different parts of a dog’s cortex, they discovered that they could make different parts of the dog’s body move. Furthermore, they discovered an important and unexpected principle of brain activity. They found that stimulating the right side of the brain produced movement in the left side of the dog’s body, and vice versa. This finding follows from a general principle about how the brain is structured, called *contralateral control*. The brain is wired such that in most cases the left hemisphere receives sensations from and controls the right side of the body, and vice versa.

Fritsch and Hitzig also found that the movement that followed the brain stimulation only occurred when they stimulated a specific arch-shaped region that runs across the top of the brain from ear to ear, just at the front of the parietal lobe (see Figure 3.11 "The Sensory Cortex and the Motor Cortex"). Fritsch and Hitzig had discovered the motor cortex, the part of the cortex that controls and executes movements of the body by sending signals to the cerebellum and the spinal cord. More recent research has mapped the motor cortex even more fully, by providing mild electronic stimulation to different areas of the motor cortex in fully conscious patients while observing their bodily responses (because the brain has no sensory receptors, these patients feel no pain). As you can see in Figure 3.11 "The Sensory Cortex and the Motor Cortex", this research has revealed that the motor cortex is specialized for providing control over the body, in the sense that the parts of the body that require more precise and finer movements, such as the face and the hands, also are allotted the greatest amount of cortical space.
The portion of the sensory and motor cortex devoted to receiving messages that control specific regions of the body is determined by the amount of fine movement that area is capable of performing. Thus the hand and fingers have as much area in the cerebral cortex as does the entire trunk of the body.

Just as the motor cortex sends out messages to the specific parts of the body, the somatosensory cortex, an area just behind and parallel to the motor cortex at the back of the frontal lobe, receives information from the skin’s sensory receptors and the movements of different body parts. Again, the more sensitive the body region, the more area is dedicated to it in the sensory cortex. Our sensitive lips, for example, occupy a large area in the sensory cortex, as do our fingers and genitals.

Other areas of the cortex process other types of sensory information. The visual cortex is the area located in the occipital lobe (at the very back of the brain) that processes visual information. If

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you were stimulated in the visual cortex, you would see flashes of light or color, and perhaps you remember having had the experience of “seeing stars” when you were hit in, or fell on, the back of your head. The temporal lobe, located on the lower side of each hemisphere, contains the auditory cortex, which is responsible for hearing and language. The temporal lobe also processes some visual information, providing us with the ability to name the objects around us (Martin, 2007). \[12\]

As you can see in Figure 3.11 "The Sensory Cortex and the Motor Cortex”, the motor and sensory areas of the cortex account for a relatively small part of the total cortex. The remainder of the cortex is made up of association areas in which sensory and motor information is combined and associated with our stored knowledge. These association areas are the places in the brain that are responsible for most of the things that make human beings seem human. The association areas are involved in higher mental functions, such as learning, thinking, planning, judging, moral reflecting, figuring, and spatial reasoning.

**The Brain Is Flexible: Neuroplasticity**

The control of some specific bodily functions, such as movement, vision, and hearing, is performed in specified areas of the cortex, and if these areas are damaged, the individual will likely lose the ability to perform the corresponding function. For instance, if an infant suffers damage to facial recognition areas in the temporal lobe, it is likely that he or she will never be able to recognize faces (Farah, Rabinowitz, Quinn, & Liu, 2000). \[13\] On the other hand, the brain is not divided up in an entirely rigid way. The brain’s neurons have a remarkable capacity to reorganize and extend themselves to carry out particular functions in response to the needs of the organism, and to repair damage. As a result, the brain constantly creates new neural communication routes and rewires existing ones. Neuroplasticity refers to the brain’s ability to change its structure and function in response to experience or damage. Neuroplasticity enables us to learn and remember new things and adjust to new experiences.

Our brains are the most “plastic” when we are young children, as it is during this time that we learn the most about our environment. On the other hand, neuroplasticity continues to be observed even in adults (Kolb & Fantie, 1989). \[14\] The principles of neuroplasticity help us
understand how our brains develop to reflect our experiences. For instance, accomplished musicians have a larger auditory cortex compared with the general population (Bengtsson et al., 2005) and also require less neural activity to move their fingers over the keys than do novices (Münte, Altenmüller, & Jäncke, 2002). These observations reflect the changes in the brain that follow our experiences.

Plasticity is also observed when there is damage to the brain or to parts of the body that are represented in the motor and sensory cortexes. When a tumor in the left hemisphere of the brain impairs language, the right hemisphere will begin to compensate to help the person recover the ability to speak (Thiel et al., 2006). And if a person loses a finger, the area of the sensory cortex that previously received information from the missing finger will begin to receive input from adjacent fingers, causing the remaining digits to become more sensitive to touch (Fox, 1984).

Although neurons cannot repair or regenerate themselves as skin or blood vessels can, new evidence suggests that the brain can engage in neurogenesis, the forming of new neurons (Van Praag, Zhao, Gage, & Gazzaniga, 2004). These new neurons originate deep in the brain and may then migrate to other brain areas where they form new connections with other neurons (Gould, 2007). This leaves open the possibility that someday scientists might be able to “rebuild” damaged brains by creating drugs that help grow neurons.


