The Nervous System

hat part of your brain is involved in language? in memory? in emotions? Neuroscientists used to answer these questions by looking at specific types of brain damage and relating them to specific neurological problems. Now, highly sophisticated machines are peeking inside living human brains—and showing an astonishing level of detail about learning, emotions, and memory. Chief among these harmless techniques is functional magnetic resonance imaging, or fMRI. Regular MRI shows the location of soft tissue; fMRI tracks the movement of glucose through the brain. Because glucose is the basic fuel for the brain, fMRI shows which areas are active at any given moment.

Results from just the past couple of years show how much fMRI can reveal about brain function:

- Before surgery to correct epilepsy, fMRI can locate speech centers, which are often damaged by this surgery. By identifying where in the brain the patient forms words, surgeons can avoid damaging the ability to speak.
- Brain images show differences between the brains of dyslexic children and normal readers. Images made after intensive language treatment show how the brain changes as the children gain language proficiency.
- Men and women use their brains differently, according to fMRI studies from the University of Alberta. "Sometimes males and females would perform the same tasks and show different brain activation, and sometimes they would perform different tasks and show the same brain activation," said PhD student Emily Bell.
- Scientists at the University of Wisconsin showed that brain regions associated with asthma can be activated when patients hear the word "wheeze." The study could lead to new drugs and/or a better appreciation of the brain's role in asthma.



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CHAPTER OUTLINE



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The Nervous System Makes Sense of Everything

LEARNING OBJECTIVES

List the functions of the nervous system.

Describe the main difference between the endocrine system and the nervous system.

ift this book. Turn the page. Scan the words with your eyes and understand them with your brain. All of these conscious movements are directed by the

nervous system. Brush a bothersome hair off your face. Listen to tires crunch the pavement as a car drives past the open window. Smell the flowers outside. All of these sensations are brought to you compliments of the nervous system. Every conscious action that occurs in your body is governed by the nervous system. So are most of the "unconscious" or automatic actions that maintain homeostasis.

When skeletal muscles contract, they do so in response to stimuli from the nervous system. We plan our movement in the brain, and the nervous system transmits that plan to the muscles. At the muscles, the nervous system stimulates contraction but stimulates only those motor units needed for that particular task. In Chapter 6 you learned about neuromuscular junctions. Review FIGURE 6.8 for a quick reminder of this structure.

Although this type of nervous system activity is familiar, the nervous system has numerous other func-

tions, some better understood than others. The nervous system is used to communicate from one end of the body to another. The nervous system receives and integrates stimuli, and formulates an appropriate response. The stimulus can be an external change, such as a shift in temperature or sound, or it can be an internal change, such as a localized decrease in blood pressure or generally increased carbon dioxide levels in the tissues. Whatever the change, the nervous system's job is to immediately detect it and adapt in order to maintain homeostasis.

Often that change will involve the endocrine system, which produces hormones that work in concert with the nervous system. The nervous system usually

initiates immediate short-term responses, using **neurons** (FIGURE 7.1) and **neurotransmitters** to produce amazingly fast results. In contrast, the endocrine system relies on slower chemical interactions of hormones and target cells, which take longer to initiate a response than neural responses but tend to last longer. Your development from infancy to adulthood is

driven by hormones, whereas your startled jump at the sound of a car's backfire is caused by the nervous system.

Neuron FIGURE 7.1

The neuron is the functional unit of the nervous system. These remarkable cells are responsible for carrying sensory information into the brain, formulating a response, and sending that response out to the proper organs.

Neuron A nerve cell that sends and receives electrical signals.

Neurotransmitter A chemical used to transmit a nervous impulse from one cell to the next.

Axon terminal

Axon collateral

AXON

Synaptic end bulb



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The Nervous System is Categorized by $\overline{=}$ **Function and Structure**

LEARNING OBJECTIVES

List the three types of receptors in the afferent nervous system

Outline the major divisions of the nervous system

Explain the differences between the somatic and autonomic divisions of the efferent peripheral nervous system.

Describe the functions of the sympathetic and parasympathetic divisions of the autonomic nervous system

he nervous system has two components: the central nervous system (CNS) and the peripheral nervous system (PNS) (FIGURE 7.2). The distinction is

based mainly on location. The CNS includes the brain and **spinal cord**. It lies encased in the axial skeleton

and is covered by the meninges. The CNS is the main integration center of the body. Sensory information comes into the CNS, where it is analyzed and an appropriate motor response is generated. The motor response is usually directed toward muscular or glandular tissue.



they contain.

Afferent

Sensory impulses moving toward the brain.

Proprioception Stimuli from within

the body giving information on body position and posture.

ferent sensations. Our **special senses** enable us to see, hear, taste, and smell the external world. Our skin has general sensory receptors that inform us about external temperature as well as light touch, pressure, and pain. Within our bodies, visceral receptors monitor proprioception and organ functioning. Stomachaches and sore throats are examples of visceral sensory input. Motor responses are formulated in the CNS and taken to the muscles or glands by the efferent division of the PNS. Here again, the impulses can travel on different pathways. To consciously move skeletal muscle, we plan an activity in the CNS and then direct the muscles to carry it out through motor commands sent

Efferent

Motor impulses moving from the brain to the effector organ.

Somatic division

Division of the nervous system involved in conscious movement.

The two main subdivisions of the nervous system are the central nervous system (CNS) consisting of the brain and spinal cord, and the peripheral nervous system (PNS) consisting of

all nervous tissue outside the CNS. Subdivisions of the peripheral nervous system are the somatic nervous system, the autonomic nervous system, and the enteric nervous system.

The PNS is composed of all the afferent and efferent neurons that extend from the CNS. The neurons of the PNS are arranged in bundles called nerves (FIGURE 7.3). Nerves can be motor, sensory, or mixed, depending on what type of neurons

> Most information going to and from the central nervous system travels through the peripheral nervous system. Information reaches the CNS from the afferent division of the peripheral nervous system. The PNS picks up this information with one of three types of receptors: special senses, general sensory receptors, or visceral receptors. These receptors allow us to experience many dif-

by the **somatic division** of the PNS. This division is sometimes called the voluntary division, because the motor commands are consciously, and therefore voluntarily, controlled. However, the involuntary movement of reflexes is also part of this division. The same motor neurons that stimulate reflexive movements are the ones we use when making a conscious movement.



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THE AUTONOMIC NERVOUS SYSTEM WORKS WHILE YOU SLEEP

Autonomic division Division of the nervous system regulating functions such as blood vessel diameter and stomach activity.

The autonomic division of the PNS is a control system that governs your body's responses to subtle changes in homeostasis with involuntary, unconscious reactions. For example, the CNS continually generates responses to sensory input concerning blood pressure, blood gases, and visceral

functioning. You are not aware of these inputs, nor do you control the motor responses that travel through the autonomic nervous system.

The autonomic nervous system has two subdivisions. The first division, the sympathetic division, includes those nerves that control the body when it is actively moving, burning energy. The sympathetic division is sometimes called the "fight or flight" division, because it is triggered when we feel threatened and must choose to remove ourselves from the danger (flight) or stay and "fight." The parasympathetic division is responsible for digestion, energy storage, and relaxation (TABLE 7.1).

These divisions are nicely separated by the contradictory demands of human life. Sometimes we must conserve energy and rest; other times we must move quickly and expend energy. When competing in an athletic event, or running from an alligator, we must use energy. Conversely, after a feast (alligator steak, anyone?), we must digest the meal and store the energy.

Almost every organ of your body has dual innervation, meaning that it is stimulated and controlled by both the sympathetic and the parasympathetic divisions. The two systems work antagonistically to maintain homeostasis, with only one system stimulating the organ at any given time. Determining which system is in control is easy, based on the organ's activity. If the organ is burning energy, releasing oxygen or glucose into the bloodstream, or otherwise aiding in sharp mental capacity and quick responses, the sympathetic division is working. If the organ's function is conducive to rest and relaxation, you can bet that the parasympathetic division is in control.

The functions of these two divisions are easy to remember. The sympathetic division is sympathetic to your plight. It is active when you need quick energy and rapid movement. The parasympathetic division starts with "P," like potato. When this system is active you are relaxing-acting like a "couch potato."

CONCEPT CHECK

List the differences between the CNS and the PNS.

- What are the functions of the somatic division of the PNS?
- **HOW** can you differentiate between the sympathetic and the parasympathetic divisions of the autonomic nervous system?

Nerve Tissue is Made of Neurons and Glial Cells



Schwann cells

Astrocvtes

Microglia

ervous tissue, one of the four main tissue types, is composed of neurons and supporting cells called **neuroglia** (singular *neuroglion*). The types and functions of

the neuroglia are listed in **TABLE 7.2**. The three classes of neurons are based on function: sensory neurons, motor neurons, and interneurons (FIGURE 7.4). Each type has a distinctive shape, allowing it to be readily identified. Despite their anatomical differences, all neurons have a cell body,

Neuroglia

Supporting and protecting cells found within the nervous system, including cells that provide nutrients, remove debris, and speed impulse transmission.

size and shape, location (CNS or PNS), and function TABLE 7.2						
	Location	Function				
9	PNS	Regulate oxygen, carbon dioxide, nutrient and neurotransmitter levels around ganglia				
	PNS	Surround axons in PNS, causing myelination of axons and faster impulse transmission, aid in repair after injury				
13	CNS	Myelinate CNS neurons, provide structural support				
÷	CNS	Maintain blood brain barrier, regulate nutrient, ion and dissolved gas concentrations, absorb and recycle neurotransmitters, form scar tissue after injury				
ht i	CNS	Clean up cellular debris and pathogens via phagocytosis				
ł	CNS	Line ventricles and central canal of cord, assist in CSF production				

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one axon, and at least one dendrite. The dendrite(s) bring information to the cell body. There can be many dendrites, with the branches providing many avenues for incoming impulses. The single axon routes the nerve impulse from the cell body to another neuron or an effector organ. The axon can have terminal branches, so each time the nerve fires, it can stimulate more than one cell.



Neurons Work Through Action Potentials

LEARNING OBJECTIVES

Differentiate action potential from membrane potential. Describe the types of channels found in neuron membranes.

List the events in an action potential.



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n action potential is a brief change in electrical conditions at a neuron's membrane that occurs when a neural signal arrives; it is what happens when we say a

neuron "fires." What, at the molecular level, allows neurons to carry electrical impulses? How do these oddly shaped cells receive, integrate, and respond to information? The answer begins with the electrical conditions surrounding the neuronal membrane, called the neurolemma. These electrical conditions create a membrane potential across the neurolemma that is exploited when the nerve fires.

(FIGURE 7.5).

A resting neuron, as seen in FIGURE 7.6, has a membrane potential of -70mV. The levels of positive sodium ions and negative chloride ions are higher outside the

Membrane

potential The difference in electrical charge between two sides of a membrane.



Unlike most body cells, neurons can significantly alter their *membrane potential*. The charge difference across the neurolemma alternates between -170 mV and +30 mV during a typical nerve impulse. The cyclic change of charge across the

neuron than inside. Conversely, positive potassium ions are more concentrated inside the neuron than outside. Large, negatively charged proteins trapped in the neuron help to maintain the negative charge across the membrane. In the absence of a selectively permeable membrane, these differences would rapidly disappear as the ions each diffused down their respective concentration gradients. Sodium would diffuse into the cell, potassium would diffuse out, and the negative charges would balance.

This diffusion does not happen, however, because ions cannot simply diffuse through the lipid bilayer of the cell membrane. Instead, they must travel through channel proteins that serve as portals for ion diffusion. Channel proteins can be either passive or active. Passive channels are "leaky" and allow a constant trickle of ions. Active channel proteins allow no ion movement unless stimulated. This means the rate of ion movement across the nerve cell membrane depends on the physical state of the channel proteins, which can vary greatly from moment to moment. This variation in ion concentration across the cell membrane allows neurons to generate action potentials.

termed the nerve impulse, or action potential. Charge differences are controlled by the movement of sodium and potassium ions entering and leaving the neuron.



Neuron and neuromuscular junction FIGURE 7.6

Resting neurons are visually no different from neurons undergoing an action potential. One way to determine the physiological state of a neuron is to measure the resting potential, and another is to look for the release of neurotransmitter. Resting neurons have a membrane potential near -70 mV, and are not actively releasing neurotransmitter.



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GATES AND CHANNELS CONTROL THE FLOW OF IONS

Active channels are often called **gated** channels, because they allow ion transport only under specific environmental conditions. Some gated channels are voltage-gated, opening and closing in response to transmembrane voltage changes. Others are ligand-gated, or chemically regulated, opening and closing when the proper chemical binds to them (FIGURE 7.7). Still others are mechanically regulated, responding to physical distortion of the membrane surface.

At rest, the gated channels are closed. When open, these gates allow ions to cross the membrane in response to their concentration gradients, changing the transmembrane potential and generating a nerve impulse. The steps of an action potential are outlined in FIGURE 7.8.

At the end of the action potential, the transmembrane potential is -90 mV. From the moment the sodium channels open until they reclose, the neuron cannot respond to another action potential. There are two phases to this inactive period. The absolute refractory period lasts from 0.4 to 1.0 milliseconds. During this period, sodium and potassium channels are returning to their original states. The relative refractory period begins when the sodium channels are again in resting condition, and continues until the transmembrane potential stabilizes at -70 mV. The**sodium potassium** exchange pump (Na/KATPase) helps stabilize the cell at the initial ion concentrations by moving three sodium ions out of the cell and two potassium ions into it.

Scientists used to believe Na/K ATPase was needed for the neuron to carry another action potential, but now it seems that it need not operate after every nerve impulse. An enormous number of sodium and potassium ions are on either side of the membrane, and the subtle concentration changes of one action potential do not block impulse transmission. It would take literally thousands of consecutive action potentials to alter the ion concentrations enough to destroy the overall mechanism. The Na / K ATPase merely helps return the local membrane potentials quickly so a second action potential can be generated.



0 +30⊦ 0 m\ when K⁺ gates close.



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ACTION POTENTIALS WORK AT DIFFERENT SPEEDS

Nerves can propagate action potentials at different speeds. Nerve impulses are sent along the axon in wavelike fashion. Impulses always begin at the swollen base of the axon, the axon hillock. These impulses travel along the membrane to the axon terminus, where they stimulate the release of neurotransmitters. Propagation

Myelin White lipids and phospholipids found wrapped around neural processes that aids in faster transmission.

speed can be influenced by the diameter of the axon (thin axons propagate faster) and by the amount of **myelin** on the axon (FIGURE 7.9). When the axon is wrapped in a myelin sheath, action potentials travel in a jumping pattern. The actual movement of sodium and potassium ions oc-



curs only at the nodes, those stretches of naked axon visible between the cells that create the myelin sheath. This allows the action potential to travel much faster, jumping from one node to the next rather than moving steadily down the length of the axon.

In the PNS, the neuroglial cells responsible for myelination are called **Schwann** cells (**FIGURE 7.10**). These cells wrap around the axon, providing a covering of phospholipids. Schwann cells also aid in regeneration of neural axons. If the axon is damaged, the Schwann cells remain in place, providing a tube through which the regenerating axon can grow. In this way, the axon terminus remains in association with the same muscular or glandular cells when it regenerates after being severed.

Schwann cells are not present in the CNS, where myelin is provided by oligodendrocytes (FIG-**URE 7.11**). These are large cells with branching appendages that touch and protect many axons. If an axon is damaged in the CNS, the oligodendrocyte retreats, leaving no tube or pathway to aid in axonal regrowth. This is partially why damage to the neurons in the CNS is generally not repaired and why spinal-cord injuries are usually permanent.

Although PNS neurons can recover from some damage, neurons in neither the PNS or CNS can regenerate if the cell body is damaged. Axons will regenerate only if they are damaged beyond the axon hillock. As far as we know, new neurons do not form in adult CNS tissue with the exception of one small area of the brain called the hippocampus. Interestingly, depression seems to be linked to the inability to generate new neurons in this area. For the most part, however, when a CNS neuron is damaged beyond repair, it is lost.

SYNAPSES SEPARATE ONE NEURON **FROM ANOTHER**

Action potentials are carried along the neural membrane as a local change in voltage. Ions flow back and forth across the membrane as gated channels open and close, causing the alteration in voltage associated with the action potential. At the terminal bulb, however, the impulse must be transferred to the next neuron in line, and there is no membrane to carry it. Neurons do not





These cells individually wrap and protect the delicate and often extremely long axons of PNS neurons. They secrete compounds that aid in the regeneration of severed neuronal processes, as sometimes happens when we receive a deep wound.

Oligodendrocyte in the brain FIGURE 7.11

physically touch one another; instead they are separated by a gap called a synapse. Neurotransmitters released from the terminal bulb diffuse into the synapse, just as they do at the neuromuscular junction. They traverse this space, called the synaptic cleft, by simple diffusion. Neurotransmitters leave the presynaptic neuron and diffuse toward the postsynaptic neuron, where they settle on receptors and initiate a reaction.

Terminal bulb

The swollen terminal end of the axon that releases neurotransmitters into the synapse.

Presynaptic neuron

The neuron that lies before the synapse, whose axon leads to the synapse.

Postsynaptic neuron

The neuron that begins after passing the synapse, whose dendrites pick up diffusing neurotransmitters.

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NEUROTRANSMITTERS CARRY THE MESSAGE ACROSS THE SYNAPSE

Neurotransmitters are specific chemicals that carry an impulse across a synaptic cleft. We currently have identified and studied more than 45 neurotransmitters, each with a slightly different effect on the postsynaptic neuron (TABLE 7.3). The most common neurotransmitters are **acetylcholine** (ACh) and **norepinephrine** (NE). As described in Chapter 6, ACh stimulates muscle contractions when picked up by receptors on the muscle cell membrane. Once released, it is broken down quite rapidly by the enzyme acetylcholinesterase. ACh is present on the muscle cell and in the synapse for approximately 20 milliseconds.

Norepinephrine (NE) is responsible for the adrenaline rush we experience during tense situations. NE, unlike ACh, is mostly reabsorbed by the presynaptic neuron instead of being broken down. Reabsorption takes longer, so NE can remain effective for 1 to 2 seconds at a time.

GRADED RESPONSES CREATE FINE NEURAL CONTROL

Action potentials are "all or nothing" events, meaning that once the threshold is reached, the nerve will fire completely. Because a single neuron cannot create a partial action potential, we vary the strength of nervous stimulation by changing the number of neurons that are firing.

Graded responses can be obtained by hyperpolarizing or depolarizing individual neural membranes. The hyperpolarized neuron requires a larger stimulus to reach threshold and begin an action potential. The depolarized neuron is the opposite: It requires less of a "kick" to begin an action potential, because its resting potential is closer to the action potential threshold. But once threshold is reached, a neuron generates an action potential that is indistinguishable from any other action potential.

These hyperpolarized and depolarized neurons result from alterations in the resting membrane potential of postsynaptic neurons. Two types of postsynaptic

Neurotransmitters TABLE 7.3 Class Name Location Effects Acetylcholine Acetylcholine Throughout CNS and PNS, neuromuscular Contracts muscle, causes glandular secretions, general parasympathetic functions junctions, parasympathetic division Biogenic amine Hypothalamus, brain stem, cerebellum, Attention, consciousness, control of body Norepinephrine spinal cord, cerebral cortex, and most temperature sympathetic division junctions Epinephrine Thalamus, hypothalamus, midbrain Uncertain **Biogenic** amine spinal cord **Biogenic** amine Hypothalamus, midbrain, limbic system, Regulates subconscious motor functions Dopamine cerebral cortex, retina Hypothalamus, limbic system, cerebellum, Maintains emotional states, moods and body **Biogenic** amine Seratonin spinal cord temperature Biogenic amine Histamine Hypothalamus Sexual arousal, pain threshold, thirst and blood pressure control Amino acid Glutamate Cerebral cortex and brain stem Excitatory, aids in memory and learning GABA Amino acid Cerebral cortex Inhibitory Substance P Pain senses, controls digestive functions Neuropeptide Spinal cord, hypothalamus, digestive tract Stimulates appetite and food intake Neuropeptide Neuropeptide Y Hypothalamus Opiods Endorphins and Thalamus, hypothalamus, brain stem Pain control, behavioral effects

Compounds that affect the nervous system are called psychoactive drugs. Psychoactive drugs, whether legal like alcohol or illegal like marijuana, share one key feature: They affect the synapses where neurons communicate with one another. Psychoactive drugs most often act through one of two essential mechanisms: They may block or activate neural receptors in the synapses, or they may change the concentration of neurotransmitters that naturally occur in the synapses.

sages where none was intended.



Psychoactive drugs affect behavior and judgment, as they alter the functioning of cerebral synapses. Many of these compounds are illegally sold on the black market. Here a policeman guards confiscated drugs obtained during a successful "drug<mark>s</mark> bust."

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enkephalons

Psychoactive Drugs: Getting a Good Reception at the Synapse

In either case, the result is a change in the nature and/or intensity of the message that is passed across the synapse. Psychoactive drugs can subtly change these messages, prevent them entirely, or create false mes-

Many psychoactive drugs affect the neurotransmitter dopamine, which is involved in movement and emotion. Normally, after a neurotransmitter is released in the synapse, it affects a change in the postsynaptic cell and is quickly taken up (removed) from the synapse. Cocaine and amphetamine both inhibit the removal, or "reuptake," of dopamine, so dopamine remains in the synapse, continuing to activate the receptors for an abnormal period. The excess stimulation of dopamine receptors explains the "high" of cocaine and amphetamine.

Neurotransmitter reuptake is also impaired by the "selective serotonin reuptake inhibitors," the SSRI drugs, including Zoloft and Prozac. Many patients with anxiety and depression apparently lack an adequate supply of the neurotransmitter serotonin. SSRI drugs change conditions at the synapse by inhibiting serotonin reuptake, which has the effect of stretching the supply of serotonin and making it more likely that a serotonin signal will transit the synapse.

Surprisingly, the nervous system contains many receptors specifically tuned to associate with compounds found in opiate drugs. The well-studied "mu opiate receptors" can occur on excitatory or inhibitory neurons. Excitatory neurons increase the activity of other neurons; inhibitory neurons slow or stop nerve signals. Opiate drugs like heroin or morphine can activate these receptors. The body produces related compounds called "endogenous opioids" that also activate these receptors. Endogenous

> opioids may account for the feeling of well-being that follows physical exercise and could explain the ability to ignore pain during an emergency.

> The nervous system also contains a great number of receptors for chemicals found in marijuana. These receptors exist in high concentration "around the hippocampus, cortex, olfactory areas, basal ganglia, cerebellum, and spinal cord," according to Roger Pertwee, a cannabis expert at the University of Aberdeen (United Kingdom). "This pattern accounts for the effects of cannabinoids on memory, emotion, cognition, and movement." Cannabinoid receptors are also found in the male and female reproductive systems, and on neurons that cause nausea and vomiting.

The prevalence of receptors for psychoactive drugs helps explain the power of these drugs, and also demonstrates how evolution finds new uses for old molecules. And it might even help treat disease: The discovery of cannabinoid receptors in a part of the eye that controls fluid pressure could eventually lead to drugs to control glaucoma, a blinding disease caused excess pressure inside the eye.

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potential can be developed. Excitatory postsynaptic potentials (EPSPs) cause slight depolarization of the neuron. The membrane potential is already closer to threshold, so a smaller stimulus is needed to begin the action potential. Think of being in a frustrating situation: Maybe you are trying to study for a human biology test while your roommates are listening to music with a driving beat. The longer this goes on, the more frustrated you become. When your roommate asks if you want something to eat, you snap at her. Normally, having to answer this question would not elicit such a reaction, but when you are already angry, it does. This quick reaction to a smaller stimulus mimics an EPSP.

Inhibitory postsynaptic potentials (IPSPs) cause the opposite reaction in the postsynaptic neuron. IPSPs

hyperpolarize the neuron, meaning the membrane potential is further from that needed to generate an action potential, so a larger stimulus is required to begin an action potential. Using the above example, if you were wearing headphones with relaxing music, you could block out the noise, and your roommate would need to tap your shoulder to get your attention. She would need to raise the input level to receive the normal response. Many prescription and recreational drugs affect the events of the synapse, as discussed in the Health, Wellness, and Disease box on page 201. They can alter the potential of the pre- and postsynaptic neurons, affect the diffusion of neurotransmitters, or even mimic the neurotransmitters on the postsynap-

tic neuron. CONCEPT CHECK

> Summarize the steps in an action potential.

Which are the two most common neurotransmitters? **IPSPs differ from EPSPs?**

HOW, in general, do



The Brain and Spinal Cord are Central to the Nervous System

Vhat triggers the

opening of a voltage

regulated channel?

ISt two differences

between Schwann cells

and oligodendrocytes.

LEARNING OBJECTIVES

Describe the anatomy and coverings of the brain. Explain the functions of the various parts of the brain. Explore the anatomy of the spinal cord.

List the steps in a typical reflex



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he human brain occupies approximately 1,165 cubic centimeters and weighs about 1,400 grams. In terms of complexity, nothing that we know of in the universe is even close. Although brains look pretty unexciting from the outside, they conceal an amazing level of detail, all of which emerges from just a few types of cells, specifically and purposefully connected. We'll start our examination of the brain by looking at how it is protected from injury.

THE MENINGES AND CEREBROSPINAL FLUID PROTECT AND NOURISH THE **CENTRAL NERVOUS SYSTEM**

The axial skeleton provides bony protection for the CNS. The meninges and cerebrospinal fluid (CSF), in turn, protect the CNS from the axial skeleton, provid-

Cerebrospinal fluid (CSF)

A liquid similar to blood, but with less dissolved material and no blood cells, that maintains uniform pressure within the brain and spinal cord.

The outer covering of the meninges, called dura mater, is a tough connective tissue layer immediately beneath the skull. Below the dura mater is the arachnoid. This layer is thin and fragile, and looks like a spider web. Cerebrospinal fluid flows between the strands of the arachnoid. The inner layer of the meninges is called **pia mater**. This extremely thin layer is attached to the neurons and cannot be peeled off without damaging them.

Meningitis, an inflammation of these three layers of connective tissue, is extremely difficult to treat because the environment of the brain is isolated and controlled precisely. Medications cannot be easily introduced into this environment. Additionally, meningitis can be life threatening because the swollen membranes compress the neurons of the brain and spinal cord. Meningitis can be viral or bacterial. Although a new vaccine shows promise in controlling outbreaks, viral meningitis has no cure. Physicians merely treat the symptoms and hope that the patient is strong enough to recover after the virus runs its course. Bacterial meningitis causes other concerns. Normal doses of an-

ing a soft lining and cushion that nourishes and protects the delicate neural structures. The meninges are a series of three connective tissue coverings found between the nervous tissue and the bone, surrounding and protecting the brain and spinal cord (FIG-**URE 7.12**). The cerebrospinal fluid within the meninges nourishes the neurons and absorbs shock.

tibiotic are ineffective because they seldom if ever get from the blood to the cerbrospinal fluid of the brain and on to reach the meninges. It is difficult to prescribe the proper amount of antibiotics-too little will not reach the infection, and too much can kill the patient.

Cerebrospinal fluid (CSF) provides a constant environment for the central nervous system, as well as a cushion in which the organs float. Every time you move your head, your brain floats within the cranium. When you lift your head from your pillow in the morning, the brain sloshes toward the occipital bone. Because fluid is noncompressible, the layer of CSF around the brain prevents the fragile surface of the brain from striking the cranium. Otherwise, the delicate outer portion of the brain would bang against the bones every time you moved your head, destroying neural connections and ultimately the tissue itself.



Meninges FIGURE 7.12

The meninges lie directly under the skull, between the bone and the brain. Here you can see the skin on the left of the head. The sequential layers visible from left to right are then the periosteum of the skull bones, the bone itself, the dura mater, the arachnoid, and the pia mater lying directly on top of the gyri and sulci of the brain.

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VENTRICLES MA

The brain may look like a solid mass of nervous tissue, but nothing could be further from the truth. Four rather large cavities in the brain are filled with CSF. These cavities (**FIGURE 7.13**) are literally holes in your head, but we call them **ventricles**.

CSF is continuously produced and absorbed, creating a constant flow. If drainage back to the blood and the heart gets blocked, CSF builds up within the brain, adding a watery fluid under the skull that is rightly named hydrocephaly ("water head"). In infants whose skull bones have not yet fused, hydrocephaly forces the entire cranial cavity to expand at the fontanels. Once the skull has ossified, there are no fontanels, and hydrocephaly compresses the neurons of the cortex, effectively shutting down parts of the brain. This can be corrected by surgically implanting a shunt to drain the excess fluid.

CSF formation helps maintain the **blood-brain barrier**, which permits only certain ions and nutrients to cross the vessels of the choroid plexus, resulting in a controlled environment for CNS neurons. Bacteria and viruses thus have difficulty entering the brain. Unfortunately, when bacteria do enter, they are difficult to treat, because the blood-brain barrier also keeps most antibiotics out.

Each ventricle contains a choroid plexus, which forms CSF. CSF flows throughout the central nervous system, starting in the ventricles and flowing down toward the spinal cord. It flows down the central canal of the spinal cord, then up the outside of the cord and around the outside of the brain. CSF is absorbed into the bloodstream in the subarachnoid space.

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VENTRICLES MAKE CEREBROSPINAL

CSF formation and flow FIGURE 7.13

THE BRAIN HAS FOUR MAIN PARTS

A first glance at the brain shows four major parts: the brain stem, the diencephalon and midbrain, the cerebellum, and the cerebrum. Although the entire brain is basically involved in the integration of sensory input and motor responses, each section has slightly different roles.

THE BRAIN STEM IS AN ANCIENT ROOT OF LIFE

The brain stem contains vital centers that regulate heart rate, breathing, and blood pressure (FIGURE 7.14). It is the portion of the brain closest, anatomically and physiologically, to the spinal cord. The **medulla oblongata** and the **pons** make up the brain stem.

The medulla oblongata contains the vital centers of the brain stem associated with heart rate, respiratory function, and blood pressure. These centers, found in many animals, indicate that the medulla oblongata evolved in ancient times. Here also are reflex centers for sneezing, coughing, hiccupping, and swallowing. Motor impulses generated in the higher centers

of the brain travel through the medulla oblongata on their way to the PNS.

You may have heard that the right side of the brain controls the left side of the body and vice versa. This is basically true, because 80 percent of the motor information from the right side of the brain enters the medulla oblongata and crosses to the left side before leaving the CNS. The crossing of these tracts is visible on the anterior surface of the medulla oblongata. The structures that can be seen crossing over one another are the pyramids (descending motor tracts), and the technical

Medulla oblongata

Portion of the brain stem immediately adjacent to the spinal cord, associated with heart rate, breathing controls, and blood presure.

Pons The area superior to the medulla oblongata, involved in transfer of information as well as respiratory reflexes

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tone, posture, and balance; and fine-tuning conscious and unconscious movements directed by the cerebrum. Although we walk without thinking, the process requires exact coordination. That smooth gait, with its leg lifts and counterbalancing arm swings, is directed by the cerebellum.

One job of the cerebellum is to understand where the limbs are located, using proprioception. This sensory skill allows you to lift your legs and move them forward without glancing at them, because your brain knows where your feet are at all times. The nervous pathways associated with proprioception run from the muscles and joints to the cerebellum.

The cerebellum is also important in learning motor skills. Riding a bike, learning to swim, or even learning new information through repeatedly writing notes are all examples of cerebellar learning. New research indicates that the cerebellum may also play a role in sensory integration by receiving input from sensory neurons and directing it to inner portions of the cerebrum. Abnormal cerebellar anatomy has been detected in autistic children, suggesting a link between cerebellar function and autism.

THE DIENCEPHALON IS **A RELAY CENTER**

The diencephalon includes the central portion of the brain and functions mainly as a relay center for sensory information from the body and motor responses from the cerebrum (FIGURE 7.17). Within this portion of the brain, conscious and unconscious sensory information and motor commands are integrated. Centers for visual and auditory startle reflexes are located here.

The auditory reflex causes you to "jump" when you hear a car backfire. The visual reflex can also cause you to jump when you are focused on reading or studying and something flits by your peripheral vision. If you jump and rapidly turn your head to catch that fleeting vision, you've had a visual reflex.

The thalamus and hypothalamus are also located in the diencephalon. The thalamus is a relay station for most incoming sensory information. Stimuli are sent from the thalamus to the appropriate portions of the cerebrum. The limbic system, which is responsible for our emotions, communicates with the anterior portion of the thalamus. This communication forms a physical link between incoming sensory information and emotions.

The hypothalamus is, as the name implies, below the thalamus. It secretes hormones that control the anterior pituitary gland, monitor water balance, and







stimulate smooth muscle contraction. The hypothalamus also regulates our circadian rhythm, body temperature, heart rate, and blood pressure.

THE CEREBRUM IS A CENTRAL **PROCESSING CENTER**

The **cerebrum** is the largest portion of the brain (**FIG-LRE 7.18**). It is here that information is processed and integrated, and appropriate responses are generated. The cerebrum contacts all other parts of the brain, and is our center for higher thought processes. It is here that we learn, remember, and plan activities. Learning is the subject of many research studies, and we are only beginning to understand how the brain learns and remembers facts. (See "I wonder. . . What happens when we learn?")

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What Happens When We Learn?

Understanding learning is one of the toughest challenges in neuroscience. Brains are sometimes compared to computers, but whereas it's easy to point to where a hard drive stores certain information, that is seldom possible in the brain. The brain stores information here and there, in complex, threadlike networks of neurons. Our learned ability to speak, for example, is stored separately from our memory of last year's birthday party. And both are stored separately from our ability to paddle a canoe or whistle a song.

Learning is a type of memory, and memory occurs in three phases. Immediate memory prevents us from being bewildered by maintaining information in our consciousness so that we know, for example, where we are. Shortterm memory helps us carry out tasks-keeping a conversation going, say, or remembering why we are writing a letter. Although much of our short-term memory is quickly erased, some of it gets adopted in long-term memory. This memory can survive for life, or it can fade, but it is what many people mean when they say "memory." Scientists believe these three types of memory may exist in different parts of the brain.

Several types of change occur when the brain remembers something, but we call them all "neural plasticity," meaning changes in the brain that alter its ability to do something. The neural plasticity associated with learning has several components. For example, during learning, specific proteins are synthesized in the brain (we know this is true because when we block protein synthesis, we block learning). Synapses change in neural pathways so that impulses can travel through them faster and more easily, a change we call potentiation. When we learn to ride a bike, for example, the neural pathways that tell us to steer to avoid falling are potentiated. The next time we ride, these reactions happen faster, and take less conscious effort, until they eventually are triggered automatically whenever we ride a bike.

Neural plasticity also changes the dendrites, the neural processes that bring impulses to the cell body. Recent studies teaching skills to rats and looking specifically at the rat hippocampus show that certain ion channels in the membrane at the dendrites become more numerous after just 10 minutes of training.

Learning does not exist in a vacuum; the brain's ability to learn is related to what else is going on. Lab studies show that fight-or-flight

conditions drastically reduce the ability to learn. People with post-traumatic stress disorder have difficulty learning, probably because of high levels of stress hormones. Emotional stress may even cause amnesia, which can destroy our memory of who we are, without harming the skill of tying a shoe.

Memory and learning play a critical role at both ends of life. Learning to swim, play guitar, or distinguish the peripheral from the central nervous system are all things we may learn while young. In our final years, diseases like Alzheimer's can undo the learning of a lifetime, leaving us bewildered and frustrated over simple tasks we used to accomplish with ease. One final point in our "scratch-the-surface" overview of learning: The topic remains a black hole of neuroscience. Expect to learn a lot more about learning in the years to come.



Association areas help us identify objects we have already seen, recognize familiar faces and voices, and remember winter holidavs from a whiff of fresh-baked cookies.

Central sulcus ~

POSTERIOR

The surface of the cerebrum has creases or sulci that separate individual raised portions called gyri. The surface of the cerebrum is composed of gray matter, whereas the interior is white. Gray matter is mainly cell bodies and nonmyelinated neural

Sulci (sulcus) Shallow grooves on the surface of the brain.

Gyri (gyrus) Depressions separating individual sulci.

Cortex Thin outer layer of any organ.



Cerebrum with lobes and general functions of lobes indicated FIGURE 7.18

processes-in other words, naked axons and dendrites. In the gray matter, connections are made as axons meet dendrites. The cerebral **cortex** is entirely gray matter, folded to provide a larger surface area for these neural connections. It contains literally billions of cell bodies responsible for sensations, voluntary movements, and thought.

The white matter inside the cerebrum contains myelinated axons that carry information to the spinal cord or other areas of the brain. Myelinated axons are covered in lipids, giving this tissue its characteristic white appearance and allowing for faster impulse transmission. Information is passed from one area of the brain to another via tracts of white matter.

THE CEREBRAL HEMISPHERES ARE HOMES OF LOGIC AND ARTISTRY

The cerebrum has two distinct hemispheres that are quite similar anatomically. Both hemispheres are divided into lobes with general functions assigned to each. For example, the occipital lobe is where vision is interpreted, and the frontal lobe is involved in conscious thought processes. The cortex of each lobe has motor areas, sensory areas, and association areas that integrate new information with stored memories. The primary motor area, in the frontal lobe, just in front of the central sulcus, formulates voluntary motor commands. Each portion of the body is represented in the



primary motor area. The more control we have over movements of a particular body part, the larger the section of the primary motor area devoted to it, as seen in the homunculus diagram (FIGURE 7.19).

Sensory information from the skin and skeletal muscles is received in the primary somatosensory area of the cortex, just behind the primary motor area. As with the primary motor area, sensations from each body part go to a specific segment of this gyrus. The larger the segment of primary somatosensory area devoted to the body part, the more sensory receptors are found in that part. Interestingly, when any of the nerves along these sensory pathways are stimulated, the brain interprets the sensation as coming from the organ at the distal end of the pathway, regardless of the source of the

stimulation. This causes referred pain, which also occurs when we interpret a painful stimulus from an internal organ as pain in our skin or surface organs. This may happen because the visceral sensory pathways often join with or cross cutaneous sensory pathways in the spinal cord. When the pain stimulus reaches the brain, it is interpreted as coming from the skin, which is the usual site of injury. A typical example is the pain of appendicitis. Although the appendix lies in the lower right abdomen, appendicitis pain is usually described as right behind the umbilicus, or belly button.

A few specialized motor actions are governed by areas outside the primary motor area. The formation of words, for example, is organized in Broca's area, on the left frontal lobe.



The left and right cerebral hemispheres are distinct in some important ways. In most people, the right hemisphere analyzes sensory input, recognizes faces, and functions in spatial relationships. Emotional interpretation of conversation is a function of the right hemisphere. When you hear someone say "that's just great," your right hemisphere determines whether the speaker was actually impressed or speaking sarcastically. The left hemisphere usually includes the general language interpretation and speech centers, and it controls writing and speaking. The left hemisphere is more active during mathematical calculations, categorizing items, and making logical decisions, leading some to call it the "dominant" or "categorical" hemisphere.

Special senses

The five senses of the body: hearing, vision, taste, smell, and touch.

temporal lobe. We even have a primary taste area in the parietal lobes that permits us to differentiate the taste of chocolate from coffee. No word yet on how that works with mocha java...

ASSOCIATION AREAS LINK THINGS TOGETHER

Association areas of the cerebral cortex integrate and example, the somatosensory association area processes sensory information from the skin and muscles. The vidoes the same thing with new auditory information. Although we can assign functions to each part

coordinate information from many sources. For sual association area associates new visual information with stored visual images. The auditory association area of the brain, the various parts do not function alone. The brain is a network of incomprehensible complex-

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Special senses (see Chapter 8) are integrated in specific areas of the cerebral cortex. For example, the entire occipital lobe is devoted to visual interpretation. Auditory interpretation occurs in the primary auditory area of the ity. Stimuli are integrated throughout the cortex, and responses are generated from many areas. The left and right sides of the brain connect through the transverse tracts of the corpus callosum, sharing information and generatHemispheric lateralization The isolation of a task to either the left or right hemisphere of the cerebrum.

ing different responses (SEE FIGURE 7.18). In this way, despite hemispheric lateralization of some tasks, the entire cerebrum is aware of incoming sensory information as well as outgoing motor responses.

THE RETICULAR ACTIVATING SYSTEM **IS THE BRAIN'S ALARM CLOCK**

The **reticular formation** serves as an important connection between various parts of the brain. This series of nuclei and tracts extends throughout the brain, receiving sensory information, parceling it to the

Nuclei

Areas of concentrated neuronal cell bodies in the brain.

higher centers, and directing motor responses to the appropriate body areas. The reticular activating system (RAS) is a portion of the reticular formation, important in maintaining alertness. Look around the next time you are trapped listening to a long-winded lecture. If your reticular activating system is doing its job, you will remain alert and attentive. But you might see some people whose RAS is not working so well. Their heads will be drooping; they might even be napping.

The RAS may also be important in our ability to learn. One symptom of Attention Deficit Hyperactivity **Disorder** (ADHD) is the inability to filter out extraneous noises and focus on what is important. The RAS is responsible for this filtering, allowing you to study while the radio is on. It is possible that ADHD is partly due to poor function of the RAS. You can read more about ADHD in the Ethics and Issues box (page 216).

Common mental disorders TABLE 7.4							
Class of disorder	Common types	Symptoms	Treatment				
Anxiety disorders	Phobias	Extreme fear or dread	Medications, cognitive and behavioral therapy				
	Panic disorders	Sudden intense feelings of terror for no apparent reason	Medications, cognitive and behavioral therapy				
	Obsessive compulsive disorder	Anxiety coping strategies that include repetitive actions or words, or ritualistic behaviours	Medications, cognitive and behavioral therapy				
Mood disorders	Depression and bipolar disorders	Extreme sadness, sleeping or eating pattern disturbances, changes in activity or energy levels, bipolar disorder includes violent mood swings	Psychotherapy and anti-depressants				
Schizophrenia	Schizophrenia	Chemical imbalances in the brain that lead to hallucinations, delusions, withdrawal, poor speech and reasoning patterns	Prescription anti-psychotic medications such as Haloperidol (Haldol) and Loxitane				
Dementias	Alzheimers	Loss of mental function, memory loss, decline in physical abilities	Prescription drugs such as donepezil, anti-inflammatories, and anti-oxidant treatments. Also, increased nursing care				
Eating disorders	Anorexia nervosa	Preoccupation with food and unnatural fear of becoming fat, self-starvation or over-exercising	Psychotherapy, lifestyle changes				
	Bulimia	Binging and purging cycles of huge caloric intake	Psychotherapy, life style change				

There are many other mental disorders that humans suffer from. **TABLE 7.4** gives some information on the most common of these ailments.

THE SPINAL CORD CONNECTS TO ALMOST EVERYWHERE

The spinal cord extends from the brain into the vertebral column and is the second organ of the CNS (FIG-**LRE 7.2**D). The spinal cord is composed of white tracts surrounding gray matter, opposite the arrangement in the brain. This means that the exterior of the spinal cord is composed of communication tracts running up and down the spinal cord, while the interior is composed of connections between spinal nerves. The spinal cord is the main route of communication between the brain and the body. Sensory information enters the spinal cord via the dorsal root and is transferred to an upward tract heading toward the brain.

Motor impulses generated in the brain are passed through the downward tracts of the spinal cord to the nerves of the body. These tracts are often called pyramids. The pyramids are continuations of the tracts in the medulla oblongata that cross to carry information generated in one hemisphere over to the opposite side of the body.

REFLEXES BYPASS THE BRAIN

Sensory information that demands immediate attention may initiate a reflex. Reflexes are extremely quick responses to sensory stimuli, running through the spinal cord from the dorsal root immediately to the ventral root and bypassing the brain entirely. Evolution honed this brilliant system to keep our vertebrate ancestors safe from danger. Incoming sensory information is transferred to an association neuron in the innermost portion of the spinal cord and then directly to

root ganglion

=

of spinal nerve





Attention Deficit Hyperactivity Disorder: **Does Drug Treatment Make Sense?**



Attention Deficit Hyperactivity Disorder (ADHD, also called Attention Deficit Disorder, ADD) is one of the most common mental disorders among children. Characteristically, ADHD causes difficulties in concentration, taking directions, sitting still, and cooperating, all of which can lead to learning and social difficulties.

In terms of brain physiology, it is not clear what causes ADHD. Unlike Parkinson's or Alzheimer's disease, for example, nobody has made brain scan images showing that ADHD damages the brain. Some think ADHD may even be related to sleep deprivation. Some researchers have found abnormal levels of sleep apnea (the periodic cessation of breathing during sleep: a - = without, *pnea* = breath) among ADHD children. This breathing problem causes repeated awakenings at night, interfering with deep sleep. If this observation is correct, stimulants could merely be masking a condition of sleepiness that might better be treated more specifically.

Whatever the cause, the diagnosis of ADHD is growing more common. Widely varying statistics show that it affects 1 to 6 percent of American youths. ADHD is also being diagnosed among adults, with an estimated 1 percent of Americans aged 20 to 64 taking stimulants for the condition. Among adults, ADHD is less likely to cause hyperactivity than restlessness, difficulty paying attention, impulsive behavior, and frustration with failing to reach goals.

What can be done to treat ADHD? One approach is behavioral; parents try to shape behavior by rewarding desirable activity and imposing consequences for actions they want to discourage. The behavioral approach can be combined with, or replaced by, treatment with stimulant drugs, especially forms of amphetamine. Curiously, although amphetamines stimulate most people, they calm people with ADHD. That unexpected effect is actually a hallmark of the disease.

Still, the widespread use of prescription medication for ADHD is making some people nervous, especially those who suspect that an ADHD diagnosis is mainly a tactic to make business for psychiatrists and the pharmaceutical industry. These are reasons for concern:

- 1. Among 12- to 17-year-olds, abuse of prescription drugs is rising faster than abuse of illegal drugs, and amphetamines are addictive in some people.
- 2. Some college students with ADHD prescriptions say the amphetamines give them extra focus and energy during tests.
- 3. Stimulants have been linked to the death of 19 children and 6 adults (among an estimated 4 million people taking stimulants for ADHD) due to heart problems that may be related to the stimulants. The U.S. Food and Drug Administration is considering stronger warning labels on the packages. Although some unexplained deaths are inevitable among any group of 4 million people, the news should prompt doctors to evaluate heart health before prescribing stimulants for ADHD.
- 4. Shouldn't we just "let boys be boys?" According to this logic, boys typically have more of the "ADHD personality characteristics," like impulsivity, excess energy, and difficulty with planning. Should being male be considered a mental illness, especially in a society plagued by drug abuse?

Like other challenges of parenting, ADHD forces parents to persist, improvise, and decide. Behavioral therapy can be wearing, and it may require assistance from teachers and others who are important to the child. Stimulant drugs can send a message that psychological problems can be fixed with a pill. But if the consequences of failing to treat ADHD are negative enough, parents must choose a treatment strategy and philosophy, and carry it through.

Although scientists are improving their understanding of brain function, much remains to be understood, including the integration of different portions of the brain, and the function of various nuclei and neurotransmitters. As neuroscientists probe deeper into the brain's structure and function, we may learn to treat or even prevent some of the severe mental disorders that afflict our fellow humans.



Reflex arc FIGURE 7.21

tor organ.

Reflexes generate an immediate, lifesaving motor response. You pull your hand from an open flame even before you consciously recognize the heat. As you pull your hand away, the "that's hot!" information is

CONCEPT CHECK

List the meninges in order, beginning with the one closest to the axial skeleton.

a motor neuron. The motor neuron transmits an immediate response through the ventral root to the effecstill traveling to your brain. There, a series of motor responses begins, causing you to rub your hand, inspect it for burns, and exclaim in surprise or pain. Fortunately, before all these brain-initiated motor responses can occur, the reflex has already removed your hand from danger. (SEE FIGURE 7.21.)



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LEARNING

Describe

Compare

Compare

E

The Peripheral Nervous System Operates Beyond the Central Nervous System

OBJECTIVES			
he difference betw	een spinal and cranial nerves.		
he sympathetic an		-	
Cranial and Spinal Nerves			these
			brain

he peripheral nervous system (PNS) is composed of all neural tissue other than the brain and spinal cord. The PNS includes the nerves that protrude from structures. The 12 nerves that extend from the are called the **cranial nerves** (TABLE 7.5). These nerves are identified by name and a Roman numeral number (FIGURE 7.22). Some are sensory



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Cranial nerves TABLE 7.5











Olfactory nerve

Olfactory tract

nerve

Facial

nerve

Vagus

nerve



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only, others are motor only, and the remainder serve both functions. Most cranial nerves carry impulses that deal with the head, neck, and facial regions. However, the **vagus** nerve (X) branches to the throat, voice box, and abdominal organs.

Thirty-one pairs of **spinal nerves** extend from the spinal cord. These are all mixed nerves, carrying both sensory and motor information. Each spinal nerve connects with body structures near the region where it originates (FIGURE 7.23).

Sensory neurons carry information to the CNS. They join other motor and sensory neural processes to form a spinal nerve. These sensory neurons separate from the motor neurons after they enter the spinal cord. Sensory neurons enter the spinal cord at the back, through the dorsal root of the spinal nerve. Their cell bodies are located just outside the CNS, in the dorsal root ganglia. Motor neurons exit the spinal cord at the front. Their cell bodies are within the CNS, and their axons extend out through the ventral root of the spinal cord. These processes can be long. The axon of the motor neuron that moves the great toe reaches from the sacral area of the spinal cord down the entire length of the leg, a distance of up to 1 meter! (see FIG-URE 7.20).

THE PNS ALSO CONTAINS SYMPATHETIC AND **PARASYMPATHETIC NERVES**

Autonomic nerves—the ones you do not consciously control-are also part of the PNS. Along with the physiological differences in sympathetic and parasympathetic divisions discussed previously, these nerves display anatomical differences (FIGURE 7.24). The



Sweat gland Hair follicle smooth muscle

Adipose tissue Blood vessels



The Peripheral Nervous System Operates Beyond the Central Nervous System 221



sympathetic nervous system includes nerves in the thoracic and lumbar region of the spinal cord only. Sympathetic fibers extend from the spinal cord to a series of ganglia (group of cell bodies) called the sympathetic chain, on either side of the spinal cord. At these ganglia, neurons from the CNS synapse with a second neuron that extends to the effector organ. Thus sympathetic neurons leaving the spinal cord are shorter than those leaving the sympathetic chain. We call the neurons leav-



CHAPTER SUMMARY

The Nervous System Makes Sense of Everything

The nervous system is responsible for maintaining homeostasis by reacting almost instantaneously to stimuli. It works in concert with the endocrine system to maintain homeostasis. The work of the system is performed by neurons, supported by neuroglial cells.

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ing the spinal cord and synapsing in the ganglia preganglionic. Those that leave the ganglion and synapse with the effector organ are called postganglionic.

Parasympathetic fibers are found only in the cranial, cervical, and sacral region of the cord. These neurons leave the spinal or cranial nerve and join a ganglion near or in the effector organ. The parasympathetic preganglionic fibers are long, and the postganglionic neurons are extremely short.

CONCEPT CHECK

Define spinal nerve. How do sympathetic

What is the sympathetic chain? neurons differ from parasympathetic neurons anatomically?





Chapter Summary 223

CHAPTER SUMMARY

The Nervous System Is Categorized by Function and Structure

The nervous system is divided into the central and peripheral nervous systems. The CNS includes the brain and spinal cord and is the main integration center of the body. The PNS includes the autonomic, sensory, and somatic nerves of the body. The autonomic division is further subdivided into the sympathetic and parasympathetic divisions. A nerve is composed of a bundle of neurons, protected by layers of connective tissue. Sensory information enters the CNS, which analyzes it and sends a motor response through the PNS to muscular or glandular tissue.



5 The Brain and Spinal Cord Are Central to the Nervous System

The spinal cord carries impulses to and from the brain. The CNS organs are nourished and protected from physical damage by CSF and meninges. The lobes and internal structures of the brain each have distinct, but overlapping, functions. The brain stem contains vital centers that regulate heart rate, breathing, and blood pressure. The cerebellum focuses on mus-

Nerve Tissue Is Made of **5** Neurons and Glial Cells

The nervous system contains neurons and neuroglial cells. Neurons carry impulses, whereas glial cells carry out supporting functions. Sensory neurons detect conditions in the environment or body, motor neurons carry instructions to the body, and interneurons connect the two systems. Dendrites bring signals to the cell body, and the long axons deliver signals to other neurons or tissue.





cles and movement. The diencephalon is a relay center between other parts of the brain, whereas the cerebrum is a central processing center, home of logic and skills. The reticular activating system is the brain's alarm clock. Reflexes are twoor three-neuron circuits that bypass the brain to allow fast retreat from injury.

4 Neurons Work Through Action Potentials

An action potential is a brief change in electrical conditions at a neuron's membrane that occurs when a neuron "fires." An action potential occurs when the charge differential across the neuron's membrane suddenly reverses polarity, as a result of changing ion concentrations inside and outside the neuron. Impulse speed is determined by axon diameter, degree of myelination, and other factors. Neurotransmitters carry signals from one neuron to the next across a tiny gap called the synapse. IPSPs and EPSPs also influence the generation of action potentials.



O Beyond the Central Nervous System

The peripheral nervous system includes the nerves that protrude from the brain and spinal cord. The PNS originates with 12 cranial nerves and 31 pairs of spinal nerves. Peripheral nerves may be sensory, motor, or mixed. The autonomic nerves are not under conscious control. Sympathetic autonomic nerves control visceral organs in the thoracic and lumbar region of the spinal cord. Parasympathetic autonomic nerve fibers emerge from the cranial, cervical, and sacral region of the spinal cord.

KEY TERMS

- **afferent** p. 000
- **autonomic division** p. 000
- **cerebrospinal fluid (CSF)** p. 000
- **cortex** p. 000
- **efferent** p. 000
- **gyri** p. 000
- hemispheric lateralization p. 000
- **medulla oblongata** p. 000
- membrane potential p. 000

- differences?
- ion conditions would cause an EPSP?

The Peripheral Nervous System Operates



- **myelin** p. 000 neuroglia p. 000
- **neuron** p. 000
- **neurotransmitter** p. 000

- **nuclei** p. 000
- **pons** p. 000
- **postsynaptic neuron** p. 000
- **presynaptic neuron** p. 000
- **proprioception** p. 000

- **somatic division** p. 000
- **special senses** p. 000
- **sulci** p. 000
- **terminal bulb** p. 000
- **tracts** p. 000



CRITICAL THINKING QUESTIONS

1. Compare the structure of a nerve to the structure of a muscle. What explains the anatomical similarities? What are the main

3. Why are reflexes faster than conscious thought? Why is the response slower when the brain is involved? Why do we even have reflexes?

2. Review the steps in an action potential, as well as the definition of IPSP and EPSP. Using what you know, describe a neuron that is exhibiting an IPSP. How would the ion concentrations across the membrane be different from an EPSP? Can you predict what

SELF TEST

- **1.** The functional unit of the nervous system is
- a. the brain.
- b. the brain and spinal cord.

 $\overline{=}$

 \oplus

- c. the neuron.
- d. the neuroglia.
- 2. Information reaches the CNS from the
- a. afferent division of the PNS.
- b. efferent division of the PNS.
- c. motor neurons.
- d. sympathetic division.
- **3.** True or False: The division of the autonomic nervous system that is responsible for digestion, energy storage, and relaxation is the parasympathetic division of the PNS.
- 4. Identify the type of neuroglion shown.
- a. Astrocyte
- b. Motor neuron
- c. Microglion
- d. Oligodendrocyte
- **5.** The neuron pictured here is responsible for
- a. sending and receiving sensory information.
- b. sending and receiving motor information.
- c. integrating information from sensory and motor neurons.
- d. Neuron function cannot be determined from neuron anatomy.



6. The type of membrane protein that allows ions to enter the cell only during a shift in membrane voltage is a

- a. mechanically regulated channel.
- b. ligand-gated channel.
- c. voltage-gated channel.
- d. leaky gated channel.





- **7.** The original membrane potential of a resting neuron is
 - a. -70 mV.

d. dependent on neuron location.

8. The first ion to enter the neuron at the beginning of an action potential is

c. 0 mV.

- c. sodium. a. calcium.
- d. ATP. b. potassium.
- 9. The period of time immediately after an action potential, during which the neuron cannot send a second action potential is the
- a. relative refractory period.
- b. absolute refractory period.
- c. dead zone.

b. +90 mV.

d. sodium/potassium ATPase period.

10. The function of the cell shown in the diagram below is to

- a. myelinate PNS neurons.
- b. myelinate CNS neurons.
- c. increase action potential propagation speed.
- d. decrease action potential propagation speed.
- e. Both a and c are correct.



11. What cell provides this same function in the brain? a. Schwann cell

- b. Astrocyte
- c. Oligodendrocyte
- d. Microglial cell
- tion potential.
- **13.** Identify the specific layer of the meninges indicated by the letter A on this figure.
 - a. Dura mater
 - b. Pia mater
 - c. Arachnoid
- 14. The ventricles in your brain are the site of
- a. sensory input.
- b. CSF formation.
- c. memory formation.
- d. CSF absorption.
- **15.** Identify the portion of the brain indicated in this figure.
- a. Brainstem
- b. Cerebrum
- c. Cerebellum
- d. Diencephalon

16. The functions of this structure include

- a. sensory interpretation.
- b. proprioception.
- c. learning.
- d. heart rate control.





- **12.** True or False: An EPSP causes a slight hyperpolarization of the neuron cell membrane, making it more difficult to initiate an ac-





- **17.** The portion of the brain that is responsible for emotions is the
 - a. hypothalamus.
 - b. thalamus.
 - c. reticular formation.
 - d. limbic system.
- **18.** The surface of the spinal cord is white, indicating that it functions as
 - a. a highway for information traveling up and down the cord.
- b. an integration center, where impulses are connected to one another and then passed to the brain.
- c. an insulation layer surrounding the functioning neurons underneath.
- d. In nervous tissue, color does not indicate function.
- **19.** The correct sequence of structures in a reflex is
 - a. sensory receptor \rightarrow sensory neuron \rightarrow spinal cord \rightarrow brain \rightarrow spinal cord \rightarrow motor neuron \rightarrow effector organ.
- b. sensory receptor \rightarrow spinal cord \rightarrow brain \rightarrow motor neuron \rightarrow effector organ.
- c. sensory receptor \rightarrow motor neuron \rightarrow spinal cord \rightarrow sensory neuron \rightarrow effector organ.
- d. sensory receptor \rightarrow sensory neuron \rightarrow spinal cord \rightarrow motor neuron \rightarrow effector organ.
- e. sensory receptor \rightarrow effector organ \rightarrow brain \rightarrow motor neuron \rightarrow spinal cord.
- **20.** Which of the two divisions of the autonomic division of the PNS has the longer postsynaptic neurons?
 - a. Sympathetic division
 - b. Parasympathetic division
- 21. What is the function of
- the autonomic division of the PNS shown in this figure?
- a. Increased digestive activity
- b. Increased respiratory and heart rate
- c. Increased urinary output
- d. Decreased mental

alertness



Self Test 227