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CHAPTER 8

The Nervous System

OBJECTIVES

After reading this chapter, you will be able to:

1. Describe the components and functions of the nervous system and how it helps maintain homeostasis.
2. Explain the relationship between the anatomical and functional divisions of the nervous system.
3. Describe how nerve impulses are conducted along nerves and across synapses.

AT A GLANCE

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THE NERVOUS SYSTEM

Although there are many ways we can communicate with our family, friends, and associates, we are going to focus on three common methods. First, we can communicate through personal conversation either one-on-one or in small groups. A second method is to call a person on the telephone or cell phone. That person receives the message almost instantaneously and can respond almost as quickly. The third possibility is to write a letter and place it in the mailbox. Then when the letter arrives a few days later, the person is able to respond.

We have similar methods of communication in the body. Some cells are able to communicate with their neighbors, share information, warn them there is a potential enemy in the neighborhood, or tell them it is time to perform some function—much like face-to-face communication.

The second process is similar to making a phone call. The individual receiving the call can make an immediate response. This form of rapid communication is similar to that of the nervous system. Nerves are able to quickly transmit information over relatively long distances in the body, thereby producing a very rapid response. After the receiver of the message has responded, the action is immediately over. In order for the response to continue, the brain must repeatedly send the same message to the same location.

The third communication process relies on the endocrine system, which places messages in the bloodstream. Those chemical messages travel throughout the bloodstream much like letters in the postal system. They travel throughout the bloodstream to affect a specific target organ. Our focus in this chapter is the rapid communication provided by the nervous system.

FUNCTIONS OF THE NERVOUS SYSTEM

The ability of the nervous system to provide rapid communication between cells allows it to perform three key functions: sensory function, integrative processing, and motor stimulation.

Sensory Function

The nervous system monitors sensory information from both the internal and external environments. This sensory input includes touch, pain, temperature, pressure, and location to keep the brain informed about conditions within as well as outside the body so that it can respond appropriately. Monitoring the surface of our body allows the brain to make informed decisions that safeguard us against potential external danger, changes in our surroundings, and communication with others. The ability to locate all areas of our body goes even beyond the ability to find areas of irritation or stimulation on our skin or knowing how far to reach. It even makes us identify with each part of our body. If we lose the sensation of location, we actually feel that the affected part no longer belongs to us.

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Integrative Processing

Integrative processes allow us to interpret sensory information and compare that information with past experience or with a desired homeostatic level designated as the set point. That information can then be used to formulate a decision that results in an appropriate course of action. For example, if I am touched on the back by someone I do not see at that moment, from the degree and speed of contact, my brain interprets these sensations as friend or foe, causing me to respond in a similar manner.

Motor Stimulation

Motor responses refer to the activation of mechanisms that allow the body to make internal changes. Many motor functions involve the conscious stimulation of skeletal muscle as well as unconscious autonomic stimulation of smooth muscle, cardiac muscle, and glands and the altering of internal conditions to maintain homeostasis.

NERVOUS SYSTEM DIVISIONS

There are two general ways in which we can view the nervous system. One is in anatomical terms, and the other is in terms of function. Our primary approach in this book is anatomical.

Anatomical Divisions

There are two anatomical divisions of the nervous system. The first is the **central nervous system**, where all sensory perception, decision making/integration, and motor control occur. The central nervous system consists of the following (Figure 8.1):

- Brain
- Spinal cord

central nervous system The anatomical division of the nervous system that includes the brain and spinal cord.

peripheral nervous system Nerves outside the central nervous system. The anatomical division of the nervous system consisting of cranial nerves and spinal nerves.

The **peripheral nervous system** consists of the outlying nerves that transmit impulses to skeletal muscle to cause muscle contraction or stimulate glands to secrete specific substances, or nerves that send sensory information about the body's internal and external environment, such as touch, pain, temperature, and pressure to the brain and spinal cord for analysis. The peripheral nervous system consists of the following:

- *Cranial nerves,* which exit through foramina (holes) in the skull
- *Spinal nerves,* which exit between vertebrae (Figure 8.2)

The details of the anatomical divisions of the nervous system are discussed later in this chapter.

Functional Divisions

There are two functional divisions of the nervous system. The somatic division is concerned with conscious decisions and control of skeletal muscle, whereas the autonomic division controls smooth muscle, cardiac muscle, and glands.

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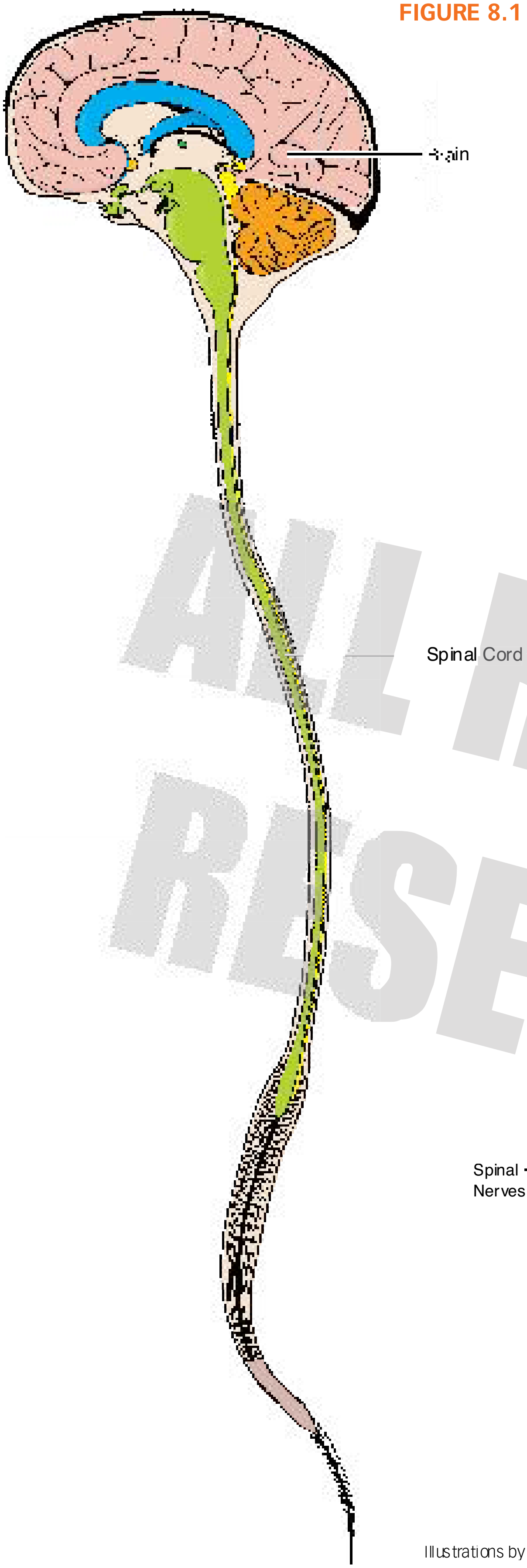

FIGURE 8.1 **Central Nervous System.**

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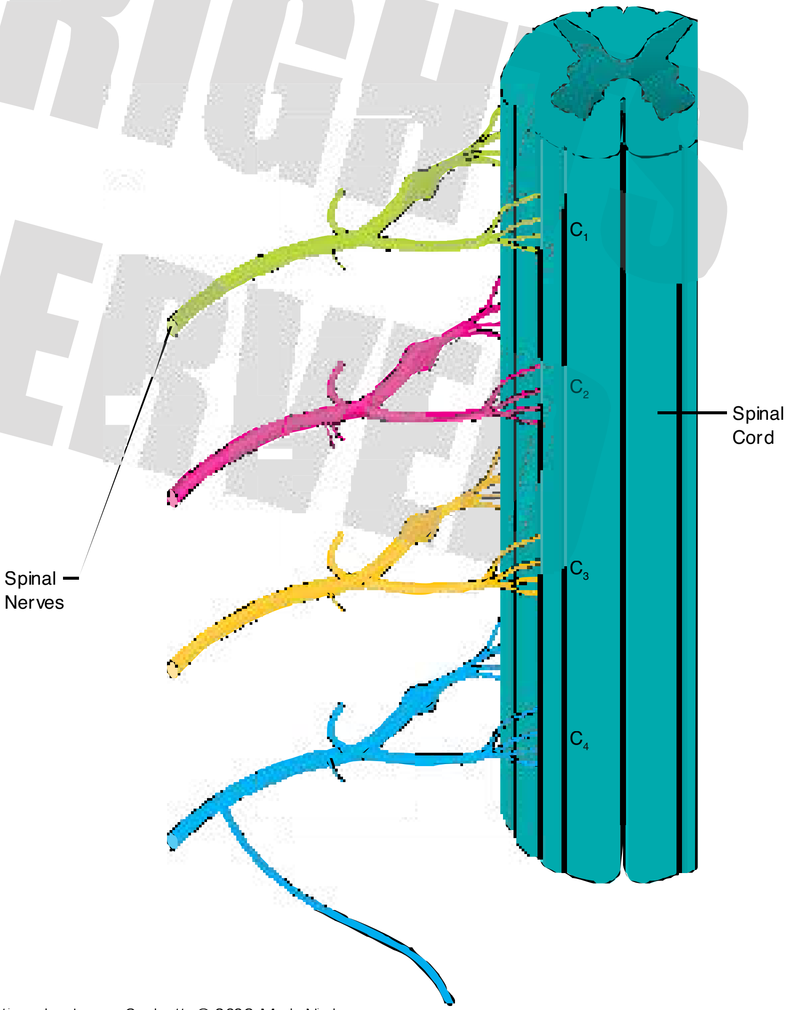

FIGURE 8.2 **Spinal Nerves (samples)—Peripheral Nervous System.**

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Somatic Nervous System

The **somatic nervous system** is concerned with movement of the body and sensing the environment. The two functions of the somatic nervous system are:

- Skeletal muscle stimulation
- Perception of general senses

Nerves that stimulate skeletal muscle run through our body together with nerves that sense the skin around those muscles. Conscious awareness is a major component in both the decision to move as well as the reception and interpretation of sensory information. Skeletal muscle is considered voluntary because it is consciously controlled by the cerebral cortex.

somatic nervous system The division of the nervous system that is concerned with movement of the body and sensing the environment.

Autonomic Nervous System

The second system is the **autonomic nervous system**, in which the control is automatic without the need for conscious decisions. The three major functions of the autonomic nervous system are as follows:

1. Smooth muscle stimulation to alter the diameter of blood vessels and also affect the rate of activity at which some organs function
2. Regulation of the intensity and rate of heart contraction
3. Gland control, which stimulates glands or the prevents glandular secretions to maintain homeostasis throughout the body

The two subdivisions of the autonomic nervous system are the:

- **Sympathetic nervous system**, commonly known as the "fight-or-flight" system
- **Parasympathetic nervous system**, also referred to as the "rest-and-digest" system.

The somatic nervous system allows us to concentrate on moving through the environment, whereas the autonomic nervous system makes internal adjustments as the need arises without diverting our attention.

autonomic nervous system The division of the nervous system that causes unconscious stimulation of smooth muscle and glands and regulation of intensity and speed of heart contractions.

sympathetic nervous system One division of the autonomic nervous system referred to as the *fight-or-flight system* because it prepares the body to defend itself or leave the situation.

parasympathetic nervous system The other division of the autonomic nervous system referred to as the *rest-and-digest system* because it causes the opposite responses of the sympathetic nervous system to calm the body after being in the fight-or-flight mode.

Comprehension Checkup

1. The central nervous system consists of the ______ and ______.
2. Automatic unconscious stimulation of smooth muscle, cardiac muscle, and glands is accomplished by the ______, a functional division of the nervous system.

1. brain spinal cord 2. autonomic nervous system

COMPONENTS OF THE NERVOUS SYSTEM

When asked about the nervous system, most people know about neurons (nerve cells), but few are aware that there is an abundance of non-nerve cells in the nervous system. These supporting cells are known as *neuroglia*. The action of the nervous system depends on the impulses created and transmitted by neurons, but the neuroglia protect and defend the neurons in addition to providing a means to increase their ability to conduct information.

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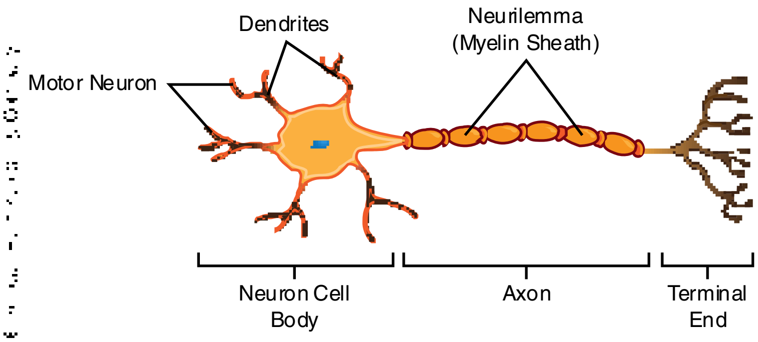

FIGURE 8.3 **Structures of a Neuron.**

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Neurons

Nerve cells are known as **neurons** (Figure 8.3). The following sections describe the anatomy and physiology of the neuron.

neurons The section of the nerve cell that contains the nucleus and organelles. It is also where synapses from other neurons connect.

Neuron Structure

A neuron consists of a cell body, axon, and terminal end. The cell body contains the nucleus and organelles, and on some neurons, there are extensions of the cell body, known as **dendrites**, which provide additional locations for attachment of other neurons. (Please note that the dendrites are not part of the cell body.) The cell body narrows to a thin threadlike structure known as the **axon**; the axon extends from the cell body to its intended receiver, sometimes at a long distance. In some individuals some of the axons run close to a meter in length. Many of the axons have a coating of neuroglia that forms what is known as the *neurilemma (myelin sheath)*. On one end of the axon is a **terminal end** that forms a junction with either the next neuron, muscle, or gland.

dendrites Finger-like projections on the neuron cell body that provide additional locations for attachment of other neurons.

axon The narrow threadlike extension of the cell body that runs to the intended receiver of the nerve impulse.

terminal end The distal end of a nerve that forms a junction with the next nerve, muscle, or a gland.

Types of Neurons

Neurons are classified as one of three types based on their morphology (shape) and function. These different morphologies enable them to make connections and conductions suitable for different types of functions (Figure 8.4).

- *Unipolar neurons* begin as a single process (pole) coming out of the cell body that splits to run in two directions (Figure 8.4a). It transmits sensory information such as touch, pain, temperature, and pressure and is often referred to a **sensory neuron**, or *afferent neuron* (meaning "inward"). They have an axon that runs the entire length of the neuron, with its cell body toward the center. On one end of the axon are sensory receptors that monitor the environment and create an impulse if stimulated. The impulse travels down the axon to the terminal end, where the nerve connects with the next neuron, carrying this information up to the brain for interpretation.
- *Bipolar neurons* have a projection on either side of the cell body (Figure 8.4b). They transmit information for vision and our sense of smell.
- *Multipolar neurons* have multiple processes on their cell body (Figure 8.4c). Surrounding the cell body are dendrites that provide sites for other neurons to attach. They stimulate all three types of muscle and are referred to as **motor neurons**, or *efferent neuron* (meaning "outward"). The impulse to contract is first received through the sensory receptors of the neuron via the dendrites or cell body, and then is transmitted along

sensory neuron A neuron that transmits sensory information such as touch, pain, temperature, and pressure.

motor neurons A neuron that transmits the stimulus to cause muscle to contract.

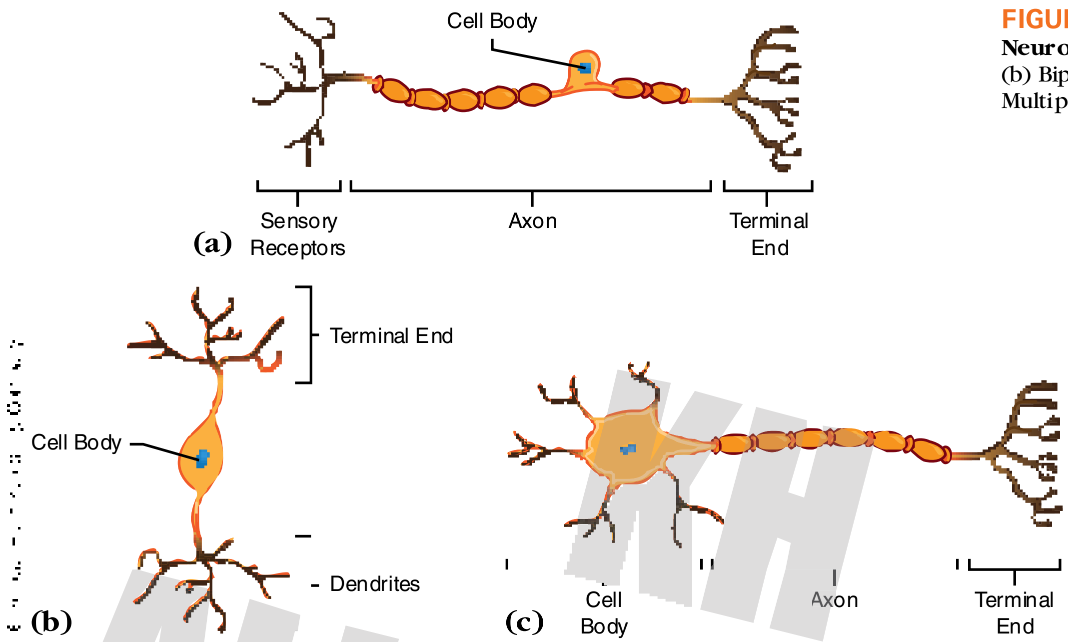

FIGURE 8.4 Types of Neurons. (a) Unipolar neuron. (b) Bipolar neuron. (c) Multipolar neuron.

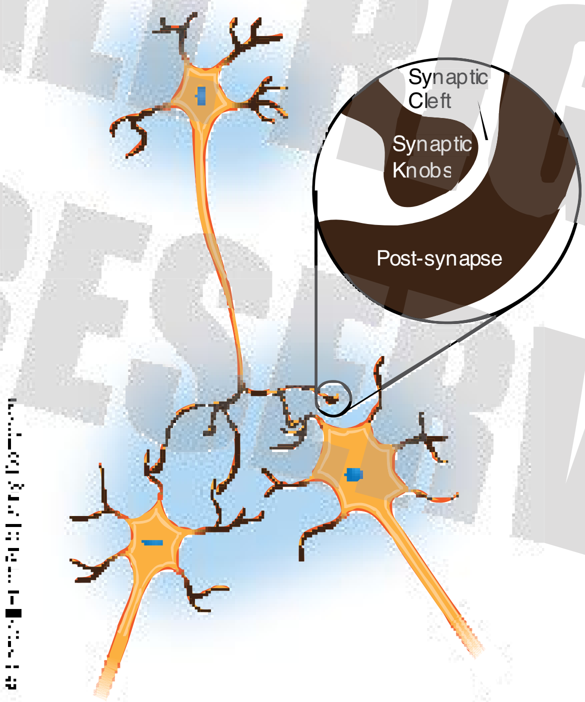

FIGURE 8.5 The Synapse. The synapse is the junction between the terminal end of one neuron and the next neuron or muscle fiber. It consists of the synaptic knob of the nerve delivering the impulse, the synaptic cleft, and the nerve or muscle fiber receiving the impulse.

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the axon to the terminal end attached to the motor end plate of a muscle fiber. Multipolar neurons usually attach to more than one muscle fiber, forming a motor unit.

Synapse

The connection of a neuron with an effector, another neuron, muscle fiber, or gland is known as a **synapse** (Figure 8.5). On the terminal end of the neuron are synaptic knobs. These synaptic knobs are close to but not in contact with the postsynapse. The space between the synaptic knob and postsynapse is known as the synaptic cleft.

synapse The connection of a neuron with another neuron, muscle fiber, or gland.

Comprehension Checkup

1. Axons are coated with myelin-containing cells forming the ________.
2. The type of neuron that has multiple processes on its cell body to which other neurons can attach is known as a _____ neuron.

1. neurilemma or myelin sheath 2. motor

NEUROGLIA

Supporting cells are found in the central nervous system that assist, insulate, and protect the delicate neurons in the brain and spinal cord. Neuroglial cells outnumber the neurons they support accounting for about half of the nervous tissue within the nervous system. There are five types of neuroglia, each having distinct functions (Figure 8.6).

- Astrocytes
- Oligodendrocytes
- Schwann cells
- Ependymal cells
- Microglia

Astrocytes

Astrocytes are found between blood vessels and brain cells (Figure 8.6a). They are so named because they are star-shaped (from *astro,* meaning "star"). They protect the crucial brain neurons. *Astrocytes,* along with specialized capillaries, form what is known as the *blood-brain barrier*. Substances in the bloodstream cannot reach the brain cells without first passing through the astrocytes. These protectors prevent potentially damaging substances from reaching highly critical brain cells. The down side of this arrangement is that if we need to provide the brain with useful chemicals, it is sometimes difficult for them to pass through the blood-brain barrier. Mental difficulties, such as depression or schizophrenia, are symptoms of a chemical imbalance in the brain. Drugs can correct or counteract this imbalance by regulating the transmission of neuron impulses, thereby alleviating the symptoms; however, it often takes weeks for the drug to penetrate the blood-brain barrier. Alcohol, on the other hand, readily passes through the blood-brain barrier and can therefore alter the mental state in a very short period.

white matter
Bundles of myelinated axons in the interior of the brain and superficial layer of the spinal cord carrying nerve impulses within the brain or between the brain and spinal cord.

Oligodendrocytes

Oligodendrocytes are wrapped around the axons of neurons in the brain and spinal cord (Figure 8.6b). They form the neurilemma, that is, the myelin sheath within the central nervous system. The interior of the brain and the superficial layer of the spinal cord are composed of bundles of myelinated axons forming **white matter** in the brain and spinal cord. They allow the rapid transmission of enormous numbers of impulses within the central nervous

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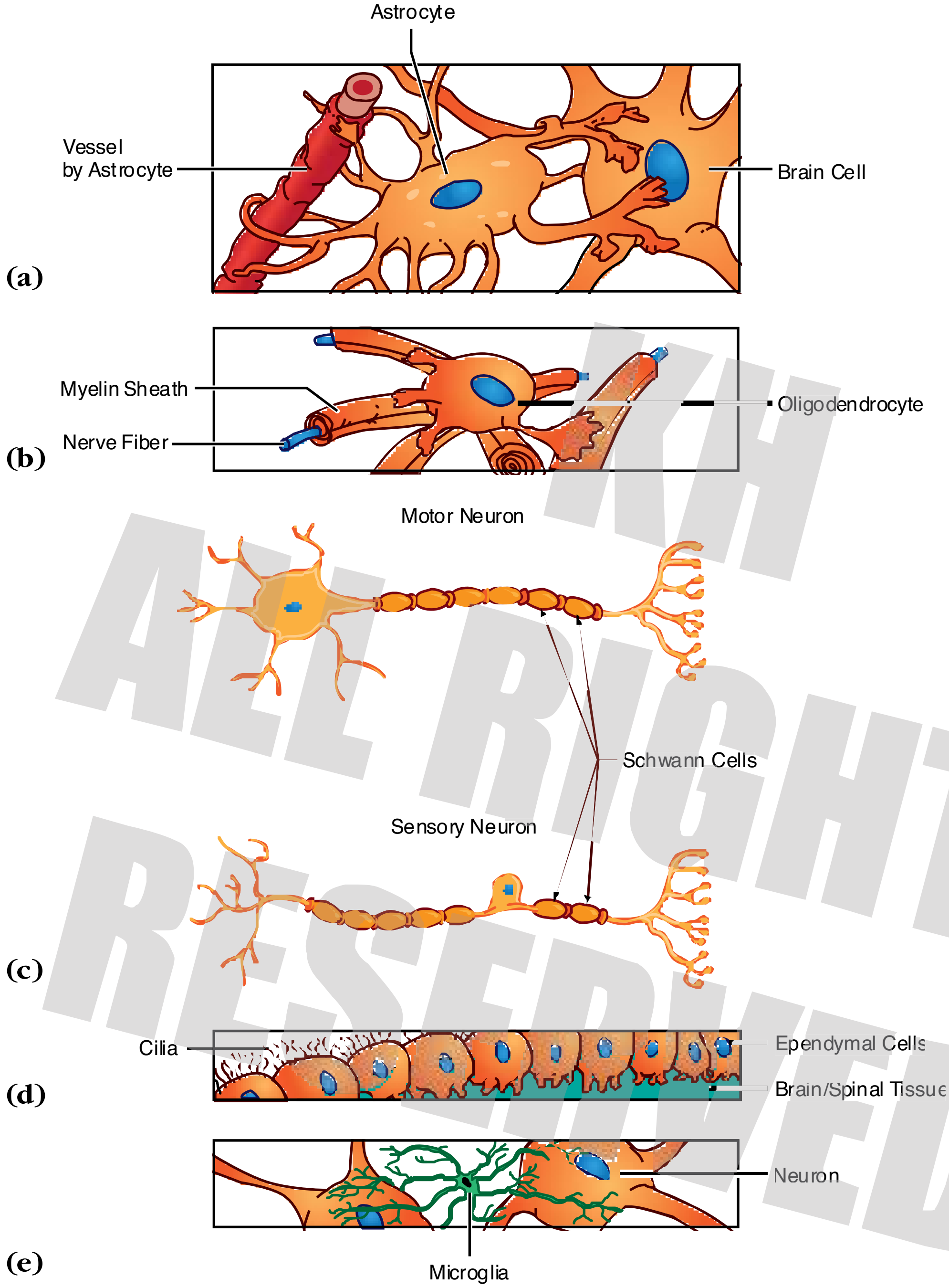

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FIGURE 8.6 **Neuroglia.** (a) Astrocyte. (b) Oligodendrocyte. (c) Schwann cells. (d) Ependymal cells. (e) Microglia.

system every second. Neuron cell bodies have no myelin covering and are known as **gray matter** in the central nervous system.

gray matter
Neuron cell bodies having no myelin covering in the central nervous system.

Schwann Cells

In the peripheral nervous system are myelin-containing cells, known as *Schwann cells,* that form the neurilemma on axons of cranial and spinal nerves (Figure 8.6c).They form the myelin sheath around axons that require rapid transmission of impulses.

Ependymal Cells

cerebrospinal fluid A clear protective fluid that flows between the brain and cranium and then between the spinal cord and vertebrae to minimize the potential of damage due to impact with surrounding bone.

Ependymal cells produce **cerebrospinal fluid** (Figure 8.6d). Ependymal cells line the ventricles of the brain and the central canal of the spinal cord. The ependymal cells join with blood vessels to form the choroid plexus which produces cerebrospinal fluid. This clear liquid flows between the cranium and brain and also down the spine between the vertebrae and spinal cord. This fluid serves as liquid protection around the central nervous system, helping to minimize the potential of damage resulting from impact with surrounding bone.

Microglia

Microglia are small phagocytes (Figure 8.6e). They wander around in the central nervous system killing and eating unwanted organisms and debris.

Comprehension Checkup

1. Star-shaped cells that form part of the blood-brain barrier are called ________.
2. ________ are small phagocytes that protect and defend the central nervous system.

1. astrocytes 2. Microglia

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NEURON PHYSIOLOGY: CREATION OF AN ACTION POTENTIAL

nerve impulse An action potential traveling through the neuron to its intended receiver.

Jerking my hand back after grabbing very hot pizza, pitching a baseball, jumping when feeling something crawling across my face in the middle of the night, and breaking out in a sweat are all caused by an action potential. An action potential, also known as a **nerve impulse**, travels down a nerve to cause some event to occur. It may be the stimulus to cause muscle contraction. It may cause a gland to start or stop its secretions. It may be information about some sensation of which our brain needs to be aware so that it can respond appropriately. The speed with which we create action potentials is incredible. Every movement of skeletal muscle is the result of an action potential sent by the brain or spinal cord. In fact, every thought we have is the result of a series of action potentials, waves of electricity traveling, colliding, and responding across the brain. Understanding how this process occurs provides an enormous amount of insight into the complexity of the human body.

Cell Membrane Potential

When discussing membrane potential it helps to explain the intent of the term *potential*. This is the "potential to do work" or to cause an event to occur. *Cellular membrane potential* results from positive and negative electrical

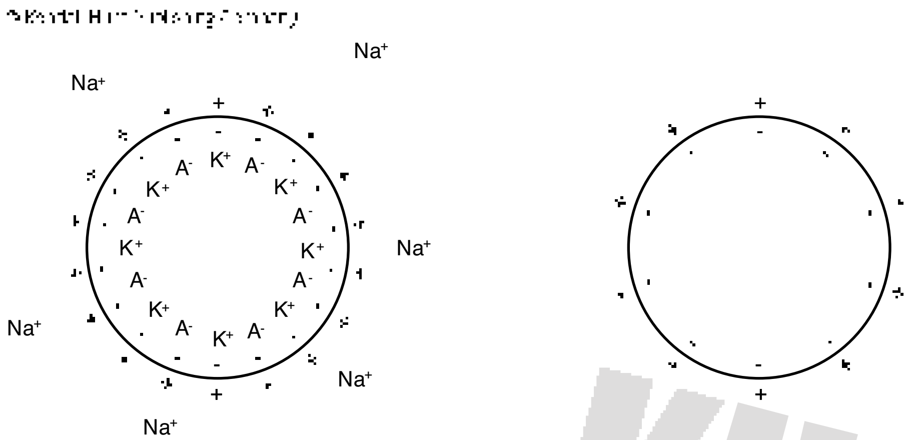

FIGURE 8.7 **Resting Potential.** The outside of the cell membrane is positively charged as a result of sodium ions, and the inside of the membrane has a negative charge as a result of negatively charged proteins (A^-). The inside is not as negative as it could be because of positively charged potassium ions.

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charges found on ions concentrated on opposite sides of the plasma membrane. Muscle and nerves have an accumulation of ions on both sides of their plasma membranes. It is the differences in concentrations of ions, that is, the electrical charges, on opposite sides of the membrane that provide the drive to cause an action potential.

Resting Potential

On the outside of the cell is a relatively high level of sodium ions. Because the membrane is surrounded by these positive sodium ions, the outside of the cell is positively charged. Attached to the inside of the plasma membrane are negatively charged proteins. The inside of the cell is negatively charged but does also contain positive potassium ions, so the inside of the cell membrane is not as negative as it could be thanks to potassium ions. A charged molecule is considered polar, so too a charged plasma membrane is considered polarized. When muscle or nerve cells are not active, their plasma membranes are polarized with positive charges on the outside and negative charges on the inside. This is known as its **resting potential** (Figure 8.7).

resting potential The electrical state of the plasma membrane of a nerve or muscle cell when at rest. The membrane is positively charged outside and negatively charged inside.

Depolarization: Sodium Gates

Referring to Figures 8.8 and 8.9 on pages 204 and 205, the events of the creation of an action potential are identified in the text by numbers within parentheses. We begin with a neuron or muscle fiber in its resting state when a stimulus occurs (1). This stimulus causes gates of sodium channels under the stimulus to open (2). Remember that across the plasma membrane are channels, tube-like structures that have gates on them. When the gate on a sodium channel opens, sodium ions diffuse from areas with the highest concentration (that is, outside the cell) to an area with a lower concentration (that is, inside the cell) (3). As sodium ions diffuse in, they add positive charges to the inside of the membrane and make it less negative. If the gates stay open long enough, sufficient sodium ions diffuse in and cancel the negative charges on the inside

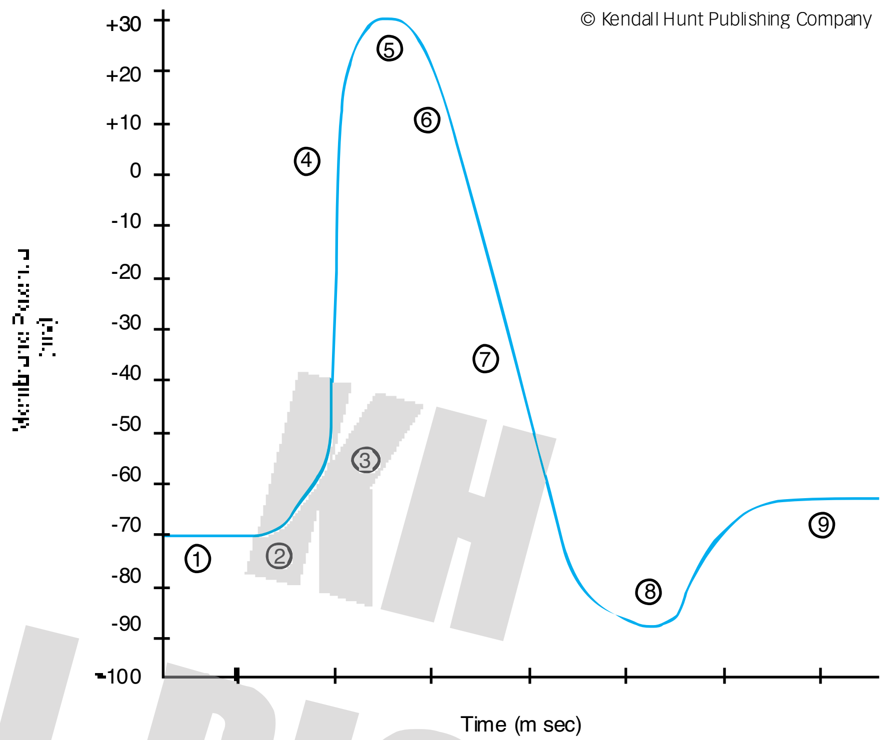

FIGURE 8.8 Action Potential. The events, numbered on the graph, causing changes in the membrane potential correspond to illustrations in Figure 8.9.

of the membrane. At that point, because there are no charges on the inside, we signify that location as *depolarized* (4).

This is generally what is happening with depolarization. As sodium ions enter, they eventually add enough positive charges to the inside of the membrane to cancel the negative charge. In actuality, enough sodium ions diffuse in to cause the inside of the membrane to briefly become positively charged.

Repolarization: Potassium Gates

As soon as the plasma membrane depolarizes, the sodium channels close and potassium channels open (5). Recall that there is a higher concentration of potassium ions inside the cell. When the potassium channels open, potassium ions diffuse out of the cell and take their positive charges with them. As positive charges leave, the inside of the membrane becomes negatively charged inside again; that is, it is *repolarized* (6).

The depolarization of one location on the nerve or muscle fiber causes neighboring sodium channels to open as well. As a result, the neighboring area of the plasma membrane depolarizes. This process continues over the cell in a wave as the entire membrane depolarizes (7). And why is this important? It is the depolarization of the membrane followed by repolarization that is a nerve impulse or the stimulus for a muscle fiber to shorten.

Now that the membrane is back to its original electrical state, being positive outside and negative inside, it is electrically back to its resting potential, but the ions are backward. To keep the concentrations as they should be, we use pumps to push the sodium ions out of the cell and potassium ions back in again (8). Adenosine triphosphate (ATP) is required for this

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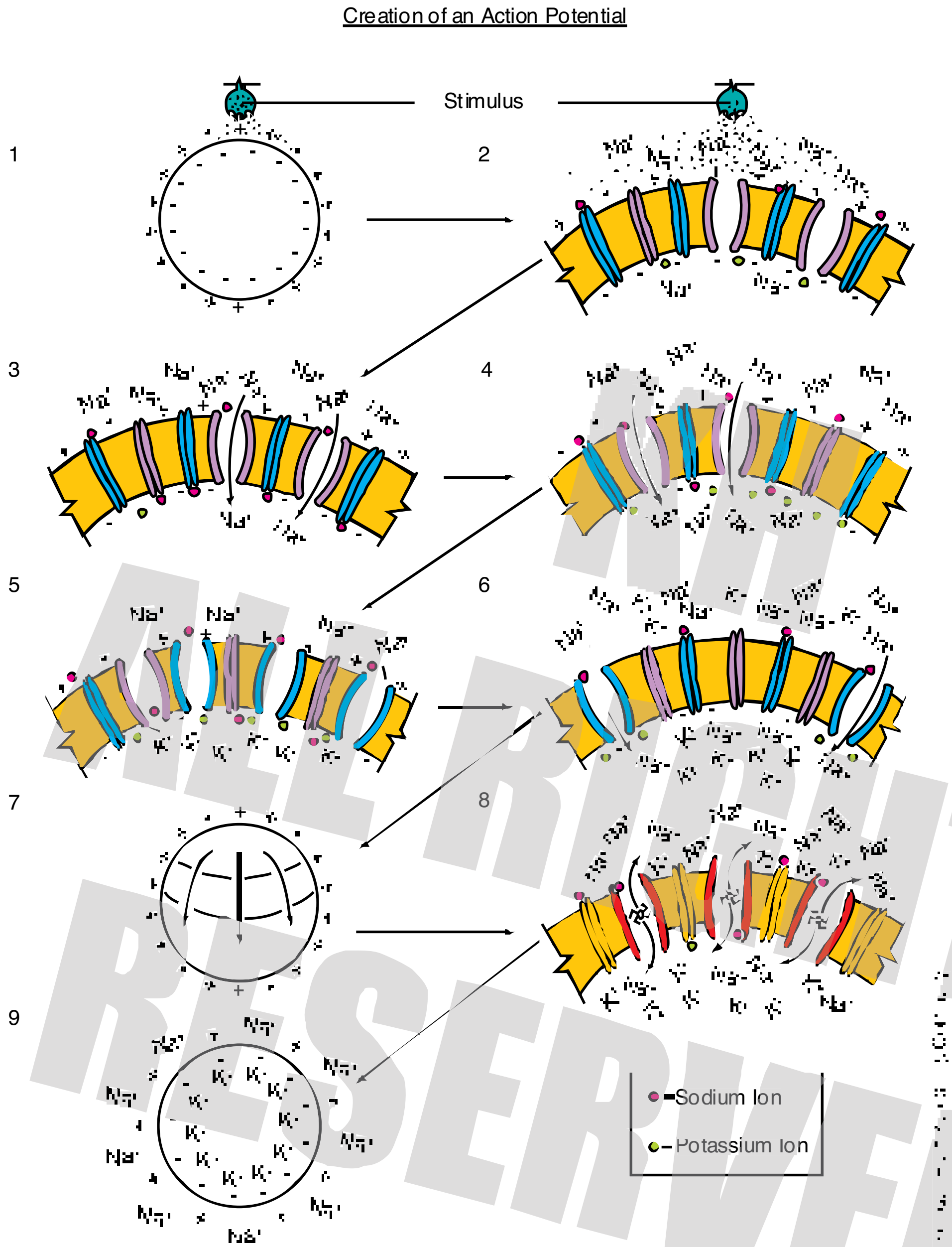

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FIGURE 8.9 **Creation of an Action Potential.**

process. Once the sodium and potassium ions are back in their original location, the cell is back to its resting state, where it stays until another stimulus occurs (9).

Comprehension Checkup

1. When a neuron is not stimulated, it has positive charges on the outside of the plasma membrane and negative charges on the inside. The cell is considered to be in its ______.
2. The term that describes the canceling of the negative charge inside a cell is ______.

1. resting rate 2. depolarization

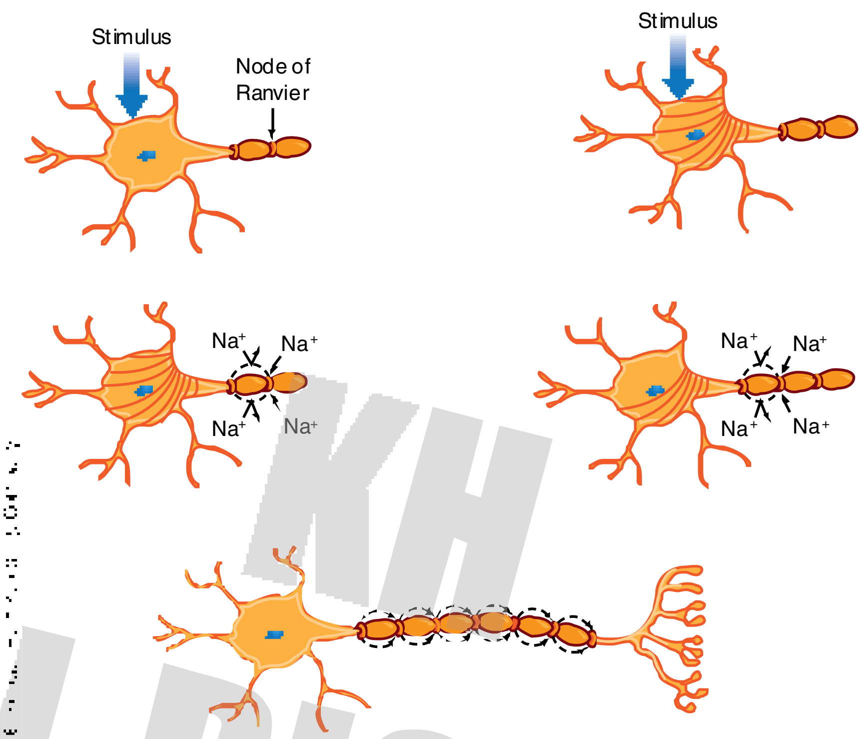

FIGURE 8.10 Transmission of an Action Potential down a Myelinated Axon. The nodes of Ranvier are the only locations on the axon where ions can exchange. As a result, the action potential skips down the axon from node to node, which greatly increases its speed.

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Transmission of the Action Potential

Depolarization of the plasma membrane followed by repolarization is known as an *action potential.* Once the action potential has begun in one area of the neuron, it will travel across the entire nerve. If the action potential begins on the cell body of a multipolar neuron, it will travel over the cell body until it reaches the axon. Many neurons have axons covered by a myelin sheath. Ions cannot penetrate the myelin sheath, and it would, at first, seem that the action potential would stop. However, there are places where ions can exchange. Between the neuroglia forming the neurilemma are spaces where the axon is exposed. These gaps are known as **nodes of Ranvier**. Depolarization on the proximal side of a neuroglial cell provides enough stimulus to open sodium channels in the next node of Ranvier. In essence, the action potential skips over the myelin-containing cells of the neurilemma, jumping from node to node (Figure 8.10). The advantage is that it is not necessary to depolarize every millimeter of the axon. By skipping from node to node, the action potential travels down the axon at greatly increased speed.

nodes of Ranvier The gap between myelin-containing cells wrapped around the axon. This is where the axon's plasma membrane is exposed and where sodium and potassium ions exchange through the cell membrane to cause an action potential.

Myelinated versus Unmyelinated Axon Conduction

Nerves that need to transmit the action potential rapidly are coated by the myelin sheath and are referred to as being *myelinated*. As discussed previously, these neuroglia insulate the axon, so the action potential must skip from one node of Ranvier to the next node, which greatly increases its speed of travel. Myelinated neurons are those stimulating skeletal muscle or sending information about touch, pain, or pressure to the brain. Nerves affecting smooth muscle or glands do not need rapid transmission capabilities because these organs are slow to react anyway; therefore, these neurons are *unmyelinated*.

Physiology of the Synapse

Referring to Figure 8.11, the events of the transfer of the action potential across the synaptic cleft are identified in the text by numbers within parentheses. Once the action potential has traveled down the axon to the terminal end, it causes the synaptic knobs to depolarize (1). Remember that the synaptic knob is next to but not touching the next nerve or muscle fiber (postsynapse). The synaptic cleft lies between. The action potential cannot jump across the synaptic cleft. Instead, once the synaptic knob depolarizes, it releases a chemical known as a **neurotransmitter** into the synaptic cleft (2). The neurotransmitter crosses the cleft (3) and attaches to receptors on the postsynapse that are designed to accept the neurotransmitter (4). When this chemical is attached to the other side, it causes specific ion channels, such as sodium channels, to open in the postsynapse (5) and sodium ions diffuse in, increasing the possibility of creating an action potential in those cells (6) (Figure 8.12). Some neurotransmitters may open other ion channels than sodium, resulting in alterations of the membrane potential to increase or decrease the possibility of an action potential being created.

The purpose for this process is to guarantee that the action potential can travel in only one direction. Because neurotransmitters are not released by the muscle fiber, for example, it cannot create an action potential in the reverse direction. Neurotransmitters attached to receptors are rapidly deactivated by an enzyme and taken up again by the presynapse for use at another time. If the neurotransmitter remained on the receptor, the sodium channels would remain open and the depolarization of the postsynapse would be continuous. If this situation occurred in a muscle fiber, it would contract and be unable to relax.

The amount of stimulus required by the post-synapse to create an action potential is known as the *threshold*. Any stimulation that does not reach the threshold is disregarded. Some neurotransmitters result in the production of an action potential in the post-synapse and are referred to as being *excitatory*. Others actually try to prevent the post-synapse from creating an action potential; these are called *inhibitory*.

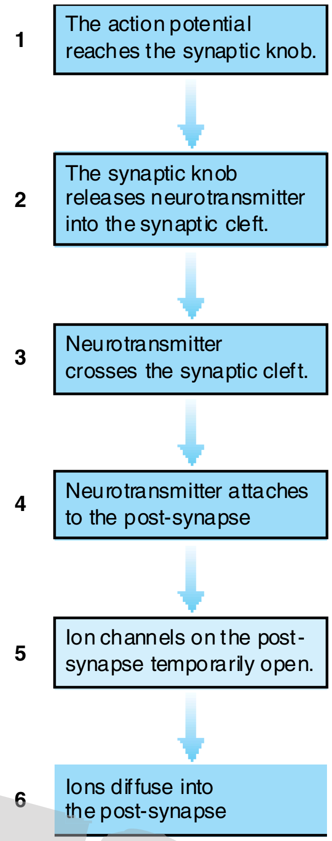

FIGURE 8.11 **Transmission of the Action Potential across the Synapse.**

neurotransmitter A chemical released by a synaptic knob of one neuron that may cause the creation of an action potential in the next nerve or muscle fiber.

Comprehension Checkup

1. The action potential can skip down the axon from node to node to greatly increase the speed of the impulse if the axon is ________.
2. The chemical released by the synaptic knob that opens sodium channels on the postsynapse is known as a ____________.

1. myelinated 2. neurotransmitter

All or None Principle

A neuron has only two options if an attempt has been made to cause an action potential in it. The *all or none principle* states that if the threshold is reached, and action potential is generated, it will progress all the way through the neuron or it simply will not start at all.

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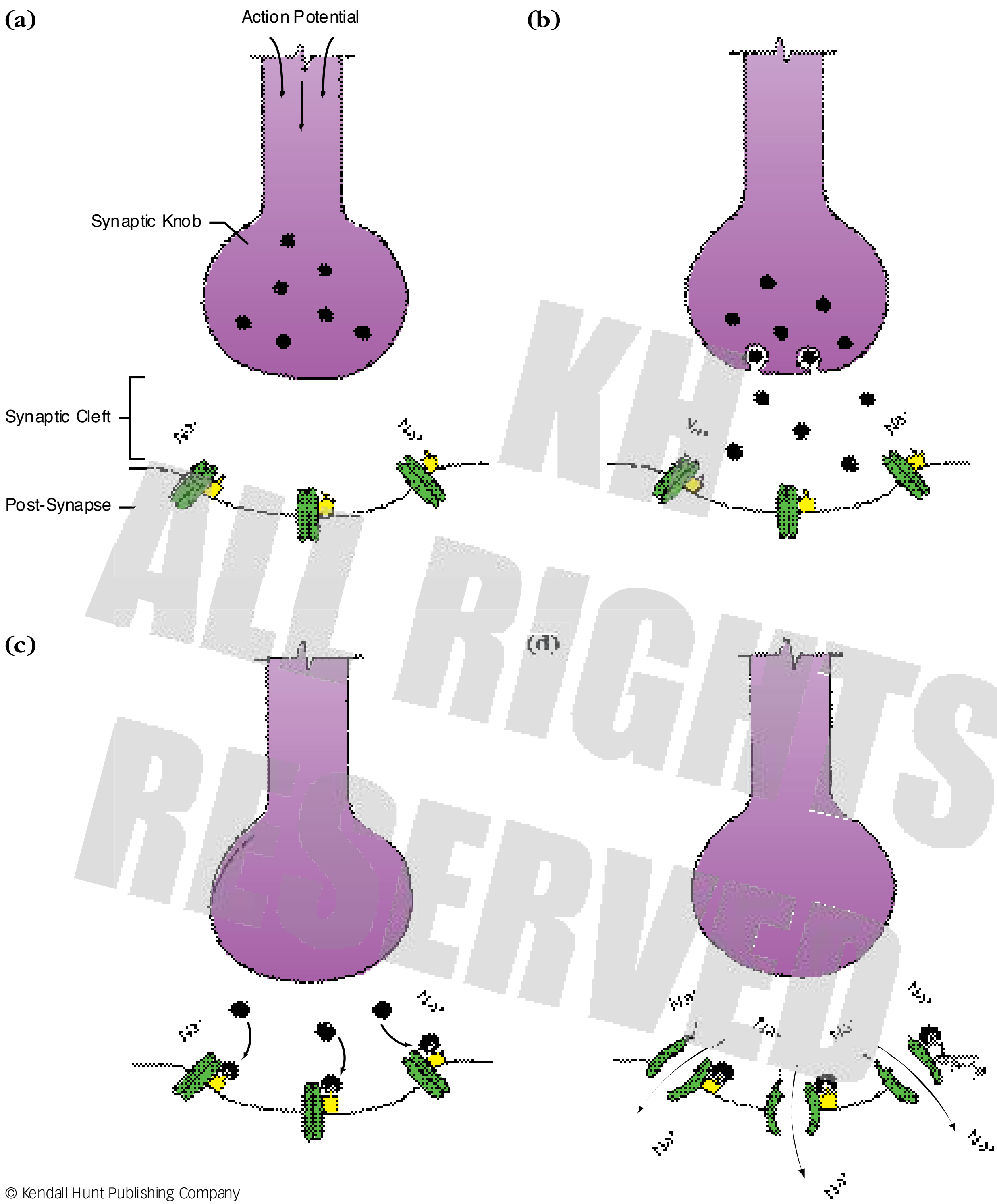

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FIGURE 8.12 **Action of Neurotransmitters in the Synapse.** (a) The action potential reaches the synaptic knob. (b) The depolarization of the synaptic knob releases neurotransmitter into the synaptic cleft. (c) The neurotransmitter attaches to receptor sites on the postsynapse, opening sodium channels. (d) Sodium ions diffuse into the postsynapse, heading it toward depolarization.

CENTRAL NERVOUS SYSTEM

We begin our discussion of the central nervous system by considering the most complex structure in the body: the brain. Each brain cell has roughly 20,000 synapses, with other neurons providing tremendous levels of information exchange.

Brain

The brain can be divided into four major areas: cerebrum, cerebellum, brain stem, and diencephalon (Figure 8.13):

Each of these areas has very different functions critical to maintaining normal body functions.

Cerebrum

The **cerebrum** is the largest of the four brain areas. It can be divided into a left and right **cerebral hemisphere** and into four lobes on each side.

> **cerebrum** The largest structure in the brain. It is responsible for conscious decision making, stimulation of skeletal muscle, interpretation of sensory information, communication, personality, and behavior.
>
> **cerebral hemisphere** The cerebrum can be divided into two halves, the left and right hemispheres.

Structures of the Cerebrum

When observing the cerebrum it is easy to see that there are ridges or folds on the outside; these are known as *gyri*. The valley between two gyri is known as a *sulcus* (Figure 8.14a on page 211). In some cases the divisions between sections of the brain are very deep, resulting in what is known as a *fissure* (Figure 8.14b and c). The left and right hemispheres of the cerebrum are separated by the longitudinal fissure. A wide band of axons, known as the *corpus callosum,* connects the two hemispheres. The corpus callosum contains more than 200 million axons carrying an estimated 4 billion impulses per second between the two hemispheres to ensure that the left side of the brain knows what the right side is doing and vice versa

Cerebral Hemispheres

The cerebral hemispheres both have similar functions when controlling the stimulation of muscle and the reception and interpretation of sensory information, but they specialize in higher levels of mental activity. The left hemisphere deals with activities requiring analysis. It is well suited for math, philosophy, and language skills such as writing and speaking. The right hemisphere specializes in creative activities, such as music and art (Figure 8.15 on page 212). As individuals progress through life, different environments, activities, injuries, etc., can impact the roles of the higher functions of the cerebral hemispheres so that they adapt as necessary.

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Lobes of the Cerebrum

Each hemisphere of the cerebrum is divided into four lobes. The lobes are identified by the sulci and gyri and named for their protecting cranial bones (Figure 8.16 on page 213).

- The **frontal lobe**, found in the anterior cerebrum, primarily performs analysis and decision making. It also deals with movement. It analyzes a situation and determines the appropriate action. It decides whether movement is required and then plans the number of motor units to activate and stimulates them at the appropriate time. The most anterior

> **frontal lobe** The most anterior lobe of the cerebrum that coordinates and stimulates contraction of skeletal muscle, as well as the location that controls personality, behavior, and analysis.

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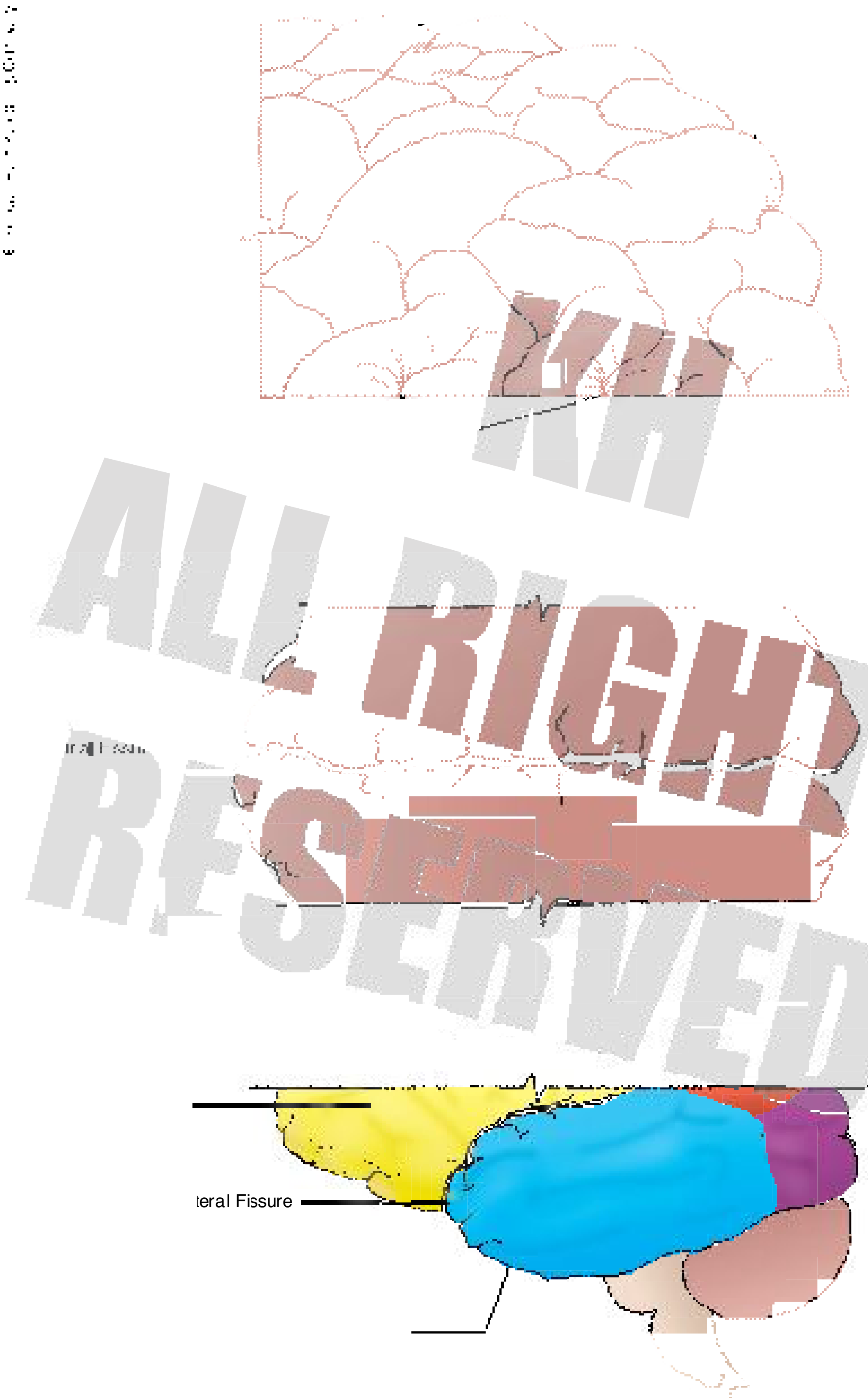
FIGURE 8.13 **Major Areas of the Brain.**

portion of the frontal lobe—the prefrontal cortex, deals with analysis that involves responses and behavior. Before mood-altering drugs were invented, some of the axons from the prefrontal lobe were disconnected from the rest of the brain as a means of controlling behavior, especially in dangerous individuals. This procedure, called a prefrontal lobotomy, resulted in a dramatic leveling out of the individual's personality. The person no longer went into rages but also lost the ability to become overly passionate about anything. For some individuals, it became a life-changing benefit. If, on the other hand, the disconnection was too extreme, the results could be devastating. In all cases the results of the prefrontal lobotomy were permanent.



(a)

(b)

(c)

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FIGURE 8.14 **Structures of the Brain.** (a) Gyri and sulci (b) Longitudinal fissure—superior view of the brain. (c) Lateral fissure—lateral view of the brain.

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FIGURE 8.15 **Cerebral Hemispheres.** The right hemisphere specializes in creative activities, whereas the left hemisphere is involved with analytical thought processes.

parietal lobe
The central superior lobe of the cerebrum that receives, locates, and interprets sensory information.

- The **parietal lobe** is directly posterior to the frontal lobe. It receives, locates, and interprets sensory information from the body. The interpretation of these sensations is based heavily on experience. If you placed your hand in a box containing several common objects, without looking you most likely could identify them by relating their sensations with similar experiences in your past.

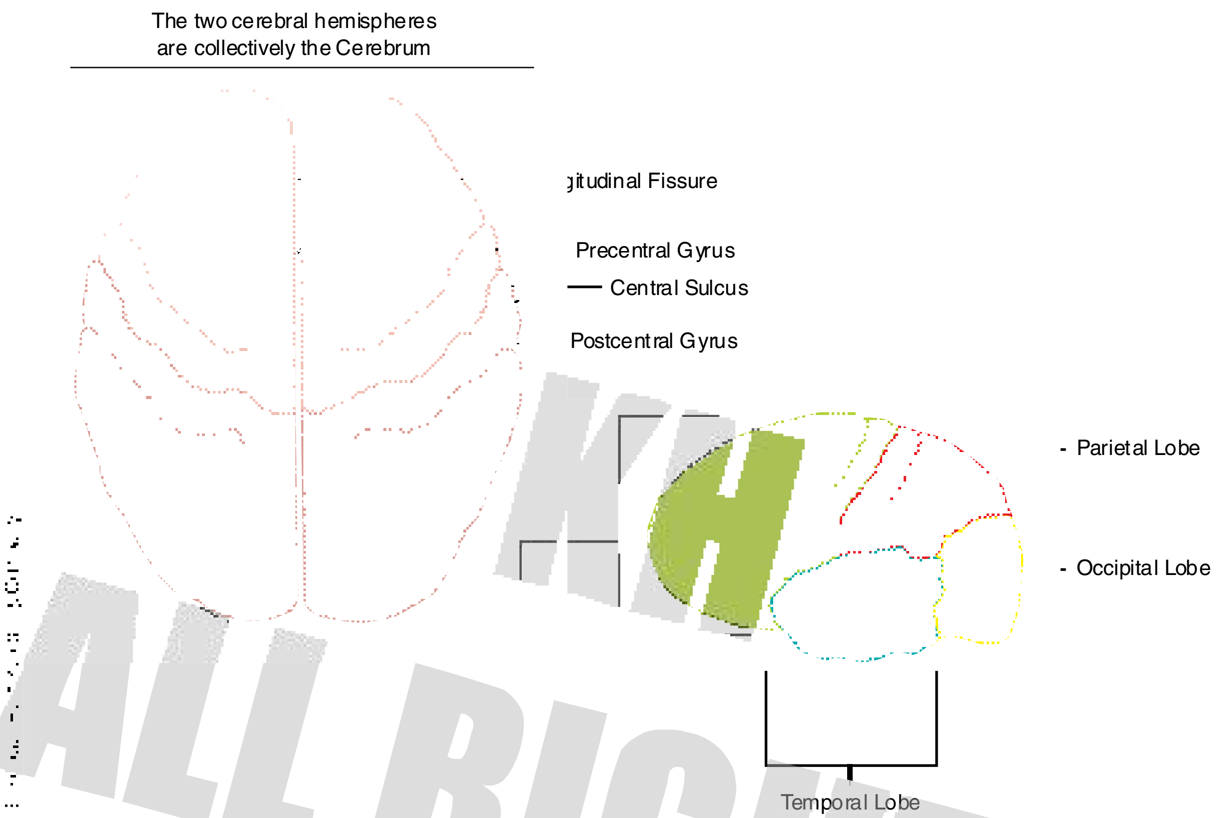

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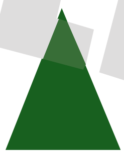
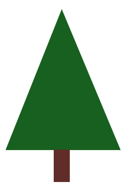
FIGURE 8.16 **The Lobes of the Cerebrum, Cerebellum, and Brain Stem—Lateral View.**

- The **occipital lobe**, which is the most posterior section of the cerebrum, receives visual images from the eyes and then interprets what they mean. This process is also experience based and is most easily explained through an example. If a sampling of people in the United States were asked to identify the following structure, most would reply that is a green triangle.

occipital lobe
The most posterior lobe of the cerebrum that receives and interprets vision.



If a brown rectangle is now added to the triangle, the interpretation of many people from temperate climates changes.



When looking at the preceding illustration, a person may now identify it as a pine tree or a Christmas tree. Does it look like a pine tree? Not really, but the general shape is close enough for most to make the association or interpretation based on previous experience. To someone with no previous knowledge of pine trees or Christmas trees, it is merely a green triangle and a brown rectangle. It is this interpretation that is useful to us when seeing part of a total image.

temporal lobe The most lateral lobe of the cerebrum that receives and interprets sound.

- The **temporal lobe** is the most lateral of the divisions of the cerebrum. It receives and interprets sound based on experience. It is important to note that sound is not necessarily the same as language, which is processed elsewhere in the brain. The temporal lobe is more concerned with distinguishing between a ticking clock and a gunshot or differentiating between a purr and a growl.

The lobes of the cerebrum are interconnected to provide a constant assessment of the environment and initiate plans to respond to both desires and requirements to maintain safety and homeostasis.

Comprehension Checkup

1. The cerebrum can be divided into left and right sides, known as _______.
2. The lobe of the cerebrum that deals with the location and interpretation of sensory information is the ______ lobe.

1. hemispheres 2. parietal

cerebellum The structure of the brain that maintains balance and fine motor coordination to cause movements to be fluid.

Cerebellum

The **cerebellum** is posterior to the brain stem and inferior to the cerebrum (Figure 8.17). The cerebellum has two major functions. First, it provides significant input to help us maintain our balance. Someone with damage to the cerebellum may appear to be drunk when completely sober. Second, it deals with fine motor coordination. In other words, it makes our movements fluid and precise, rather than jerky.

brain stem The structure of the brain that connects the rest of the brain to the spinal cord. Within the brain stem are centers for vital functions such as control of breathing, heart rate, blood pressure, and processes necessary to maintain an open airway.

Brain Stem

Coming out of the center of the brain is the **brain stem** (Figure 8.17). As the center of vital functions, the brain stem is critical to our well-being. That is, it controls functions essential to life, such as breathing, blood pressure, heart rate, sneezing, coughing, and gagging. At first it would seem that sneezing and coughing are not as vital to life as breathing or controlling our blood pressure. They are, however, major factors in opening our airway to allow us to continue breathing. The brain stem can be divided into three sections:

- The *midbrain* connects the cerebrum to the rest of the central nervous system.
- The *pons* connects the cerebellum to the rest of the central nervous system. It also contains some of the respiratory centers that control the length of inspiration.
- The *medulla oblongata* connects the brain to the spinal cord. It also regulates cardiac activities and some respiratory activities, as well as other vital functions.

Centers for vital functions along with clusters of neurons dealing with other functions are found throughout the brain stem.

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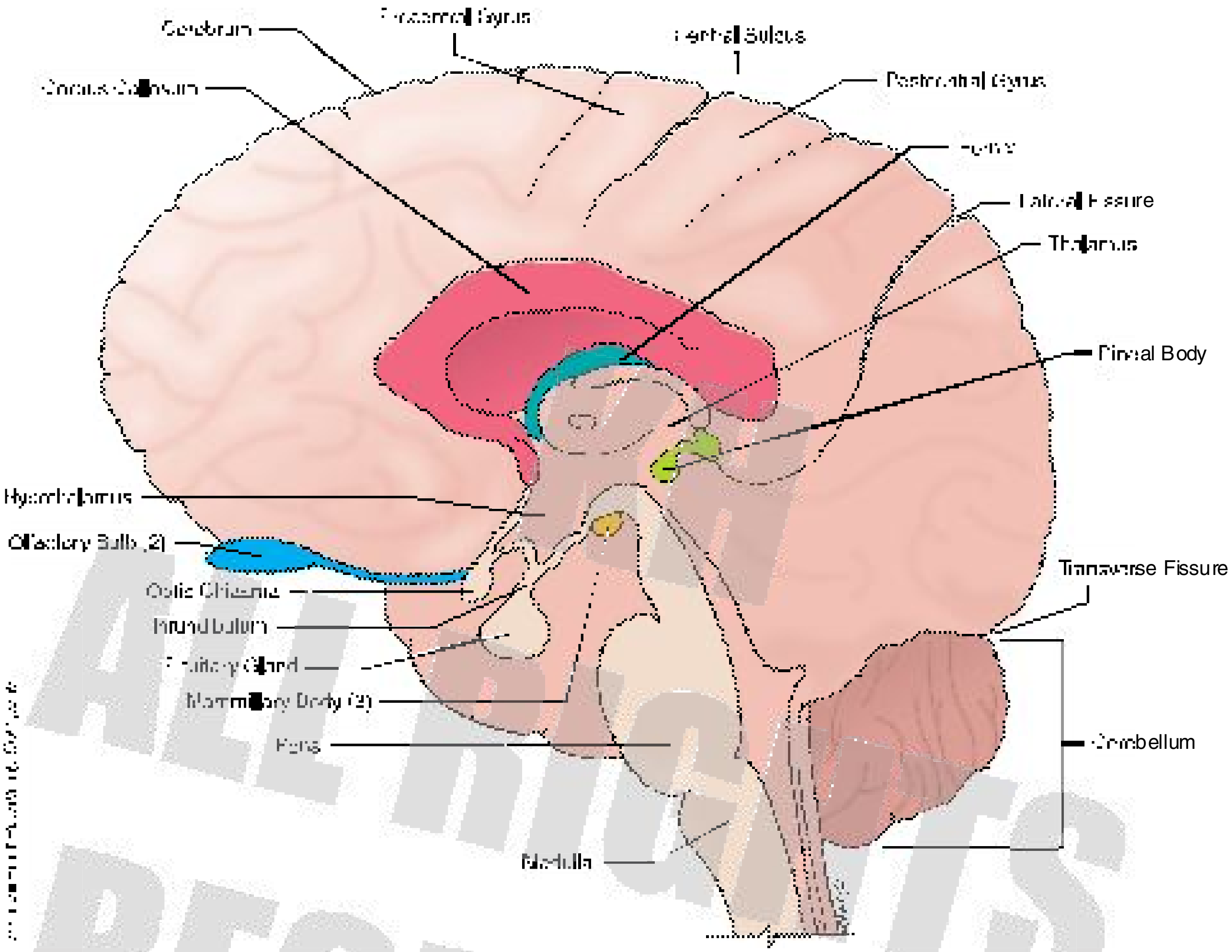

FIGURE 8.17 **Cerebellum, Brain Stem, and Diencephalon.**

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Diencephalon

In the center of the brain at the superior end of the brain stem is the *diencephalon* (Figure 8.17). Because it consists of several structures, the functions of the diencephalon are quite varied.

- The *thalamus* relays sensory information such as touch, pain, temperature, pressure, sight, and sound to multiple locations within the brain to provide quick analysis and interpretation.
- The *hypothalamus* maintains homeostasis of food and water intake, bodily temperature control, hormone levels. It is discussed in greater detail in a later chapter.
- The *pineal gland* is an endocrine gland that acts as our biological clock. It acts as a timer setting daily cycles known as *circadian rhythms.* Examples of rhythmic cycles are patterns that cause us to wake up or go to sleep at the same time every day. If meals are eaten at roughly the same time every day, as those times draw near we become hungry. This is also discussed in more detail in a later chapter.
- The *limbic system* involves numerous structures in the diencephalons and cerebral cortex. It is a functional classification more than an anatomical location. It deals with stress and emotion and also takes an active role in memory and learning.

Associated Structures in the Brain

There are several structures found in the brain that are not involved with its function but that are necessary for maintaining homeostasis of the brain and spinal cord.

Ventricles

Deep within the brain are spaces known as *ventricles* (Figure 8.18). There are four of them. Within these spaces are ependymal cells that produce cerebrospinal fluid. This fluid exits from the ventricles to surround and protect the brain and spinal cord.

Meninges

meninges Membranes covering the brain and spinal cord.

The brain and spinal cord are covered by three membranes known as **meninges** (Figure 8.19).

- The *dura mater* is a tough, thick membrane attached to the inside of the cranium and vertebral canal. This membrane essentially isolates the central nervous system from its protective structures and helps hold the brain in place.
- The *arachnoid mater* is the middle layer that consists of spiderweb-like fibers named after spiders—arachnids. This layer is filled with cerebrospinal fluid, which is produced in the ventricles. It provides a fluid cushion around the brain and spinal cord.
- The *pia mater* is a thin covering directly on the brain and spinal cord.

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Comprehension Checkup

1. The area of the brain that controls vital functions such as breathing, blood pressure, and heart rate is known as the ______.
2. The body's biological clock is the ______.
3. Membranes surrounding the brain are called the ______.

1. brain stem 2. pineal gland 3. meninges

Spinal Cord

The medulla oblongata of the brain stem connects the brain to the spinal cord when it exits the skull through the *foramen magnum,* Latin for "large hole," in the occipital bone. Inferior to the skull the spinal cord runs through the *vertebral canals* of the spine. The spinal cord transmits impulses for the stimulation of muscle from the brain and transmits sensory information to multiple areas in the brain. In addition, the spinal cord has the ability to initiate skeletal muscle contraction on its own without waiting for stimulation from the frontal lobe of the cerebrum by causing reflexes to occur. *Reflexes* are rapid responses to excessive sensory input from some area of the body. For example, if a person touches something hot with his or her bare hand, the arm is immediately jerked away as the input of heat and pain to the spinal cord causes stimulation of muscles to withdraw the upper extremity.

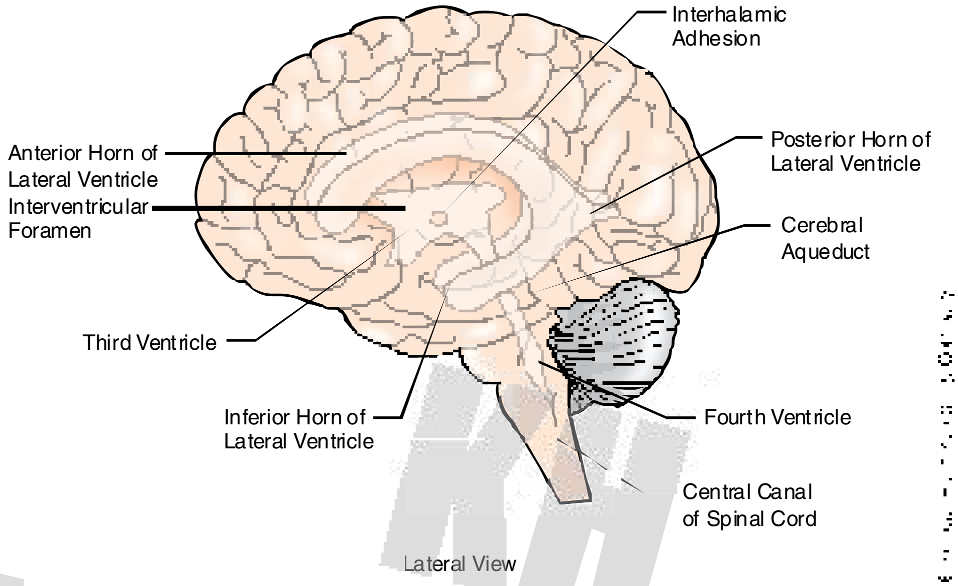

FIGURE 8.18 **Ventricles Seen from the Lateral View of the Brain.** Ventricles are spaces within the brain where cerebrospinal fluid is produced.

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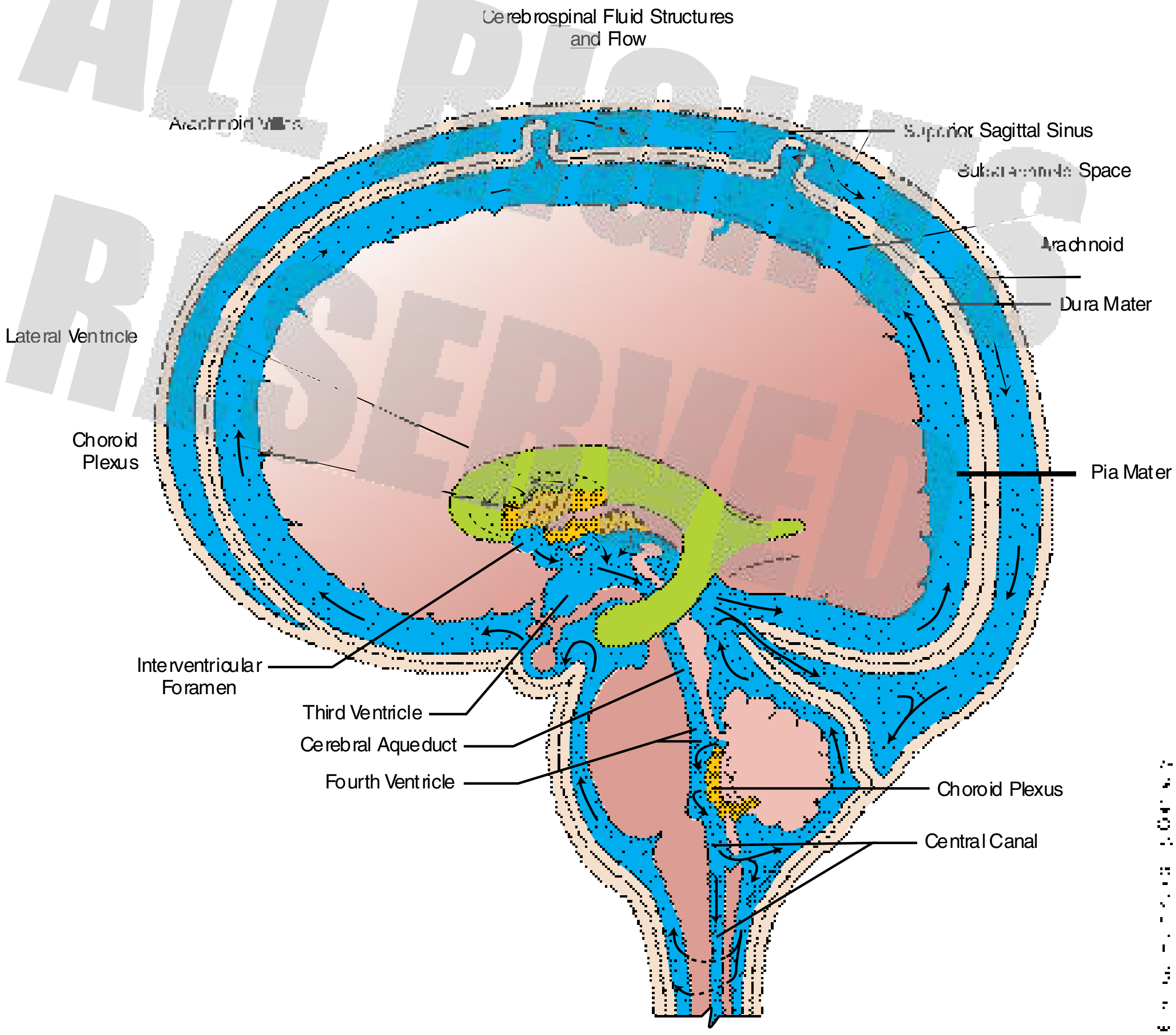

FIGURE 8.19 **Meninges.** These are the coverings of the brain and spinal cord.

Structure of the Spinal Cord

A cross section of the spinal cord reveals two general areas (Figure 8.20). The inside of the spinal cord appears gray and resembles the shape of a butterfly. This is the gray matter of the spinal cord, where the cell bodies of neurons are found. Surrounding the gray matter is white matter. White matter consists of axons that run up and down the spinal cord carrying information to or from the brain to the gray matter.

Gray Matter of the Spinal Cord

The gray matter of the spinal cord can be divided into three sections known as *horns:*

1. The *anterior (ventral) horn* contains the cell bodies of motor neurons. These neurons form the motor units that stimulate groups of skeletal muscle fibers.
2. The *posterior (dorsal) horn* receives sensory information from the body, primarily from the skin and joints.
3. The *lateral horn* contains cell bodies of autonomic neurons that stimulate or alter the movement of smooth muscles and glands.

Interneurons

In the gray matter of the spinal cord are neurons that connect sensory neurons to motor neurons known as *interneurons*. If sensory information coming into the spinal cord is strong enough to create an action potential in the interneuron, it may also result in the stimulation of skeletal muscle to cause a reflex or response initiated in the spinal cord.

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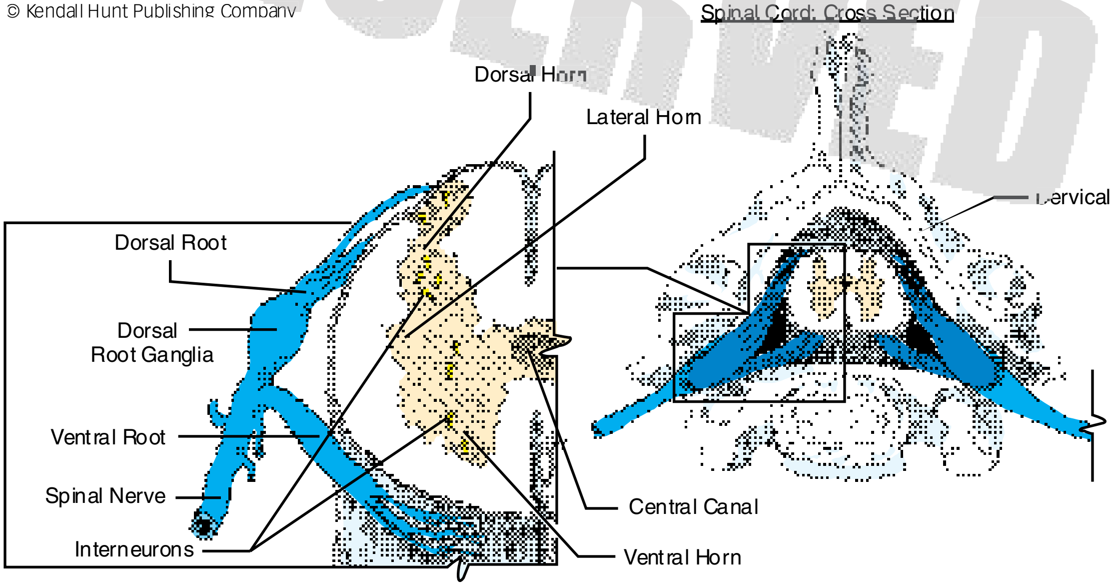

FIGURE 8.20 **Spinal Cord—Cross Section, Superior View.**

Comprehension Checkup

1. The cell bodies of motor neurons stimulating skeletal muscle are found in the ______ horn of the spinal cord gray matter.
2. Sensory neurons are connected to motor neurons in the gray matter of the spinal cord by _______.

1. anterior 2. interneurons

Reflex Arc and Reflexes

The *reflex arc* consists of a sensory neuron that is connected to an interneuron; the interneuron stimulates a motor neuron to activate a muscle contraction (Figure 8.21). The purpose of the reflex arc is to cause muscle contraction at the level of the spinal cord before there is time for complete analysis and stimulation from the brain. Even though the brain is able to provide a rapid response, originating the muscle contraction in the spinal cord instead could increase the response time such that a slight injury becomes a major catastrophe or even becomes the difference between life and death. For example, a person

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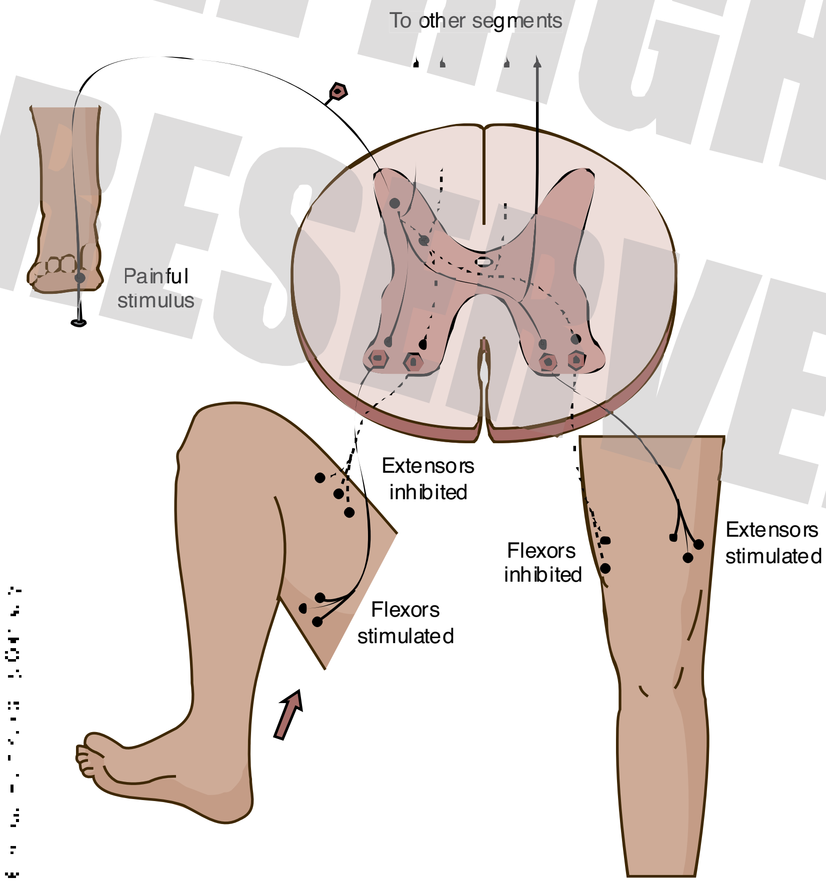

FIGURE 8.21 **The Reflex Arc.** Muscle contraction originates in the spinal cord rather than in the brain.

touching a hot stove would pull his or her hand away before even having time to realize how hot it was. As a result, the burn is minimized.

The response discussed in the previous paragraph is considered an *unconditioned reflex* in which the unplanned response is due to sensory input to the spinal cord. It is also possible to perform a *conditioned reflex* if a pattern is established to which the individual anticipates the need for a response. The classic example of a conditioned response occurs in an experiment performed by Dr. Ivan Pavlov. In his procedure, Dr. Pavlov rang a bell whenever he fed a group of dogs. He discovered that, after time, just ringing the bell caused the dogs to salivate even though food was not yet present.

Reflexes may result from the sudden stretching of a tendon. This is commonly tested by a physician when he or she uses a rubber hammer to tap on various tendons on the body and observe the results. Best known is the tapping of the patellar tendon in the knee. Striking just below the patella, the percussion hammer stretches the tendon, causing the impulse from stretch receptors to be transmitted through sensory neurons to the spinal cord. There interneurons create an action potential in motor neurons to the quadriceps femoris, resulting in a *knee jerk reflex*. Another type of reflex occurs when pain sensors are activated. The reflex resulting would be a sudden *withdrawal reflex* from the source of injury. Again the action is initiated in the spinal cord rather than the brain.

Interneurons also connect to motor neurons on the opposite side to counterbalance sudden movements. If an individual suddenly jerks back from danger, losing balance could potentially put that person at risk of falling. By counterbalancing the movement, the individual remains in a stable position.

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White Matter of the Spinal Cord

The axons carrying information between the brain and spinal cord in the white matter are often found in bundles called *tracts,* which run to or from a common place. There are two general categories of tracts: those transmitting stimulation from the brain and those carrying information to the brain.

- *Descending tracts* carry action potentials originating in the brain and descending the axons in the spinal cord to motor neurons in the anterior horn to stimulate skeletal muscle. Two examples of descending tracts are:
  - — *Corticospinal* or *pyramidal tract,* which is named based on its origin and termination. These neurons begin in the motor cortex of the frontal lobe. Their axons cross to the opposite side of the spinal cord, where they terminate in the anterior horn to stimulate skeletal muscle on the opposite side of the body. In the motor cortex of the frontal lobe of the cerebrum are pyramid-shaped cell bodies of muscle-stimulating neurons forming the pyramidal tract.
  - — *Extrapyramidal tract,* which contains axons from neurons that originate in areas of the brain other than the motor cortex. They provide regulation of muscle contraction.
- *Ascending tracts,* which receive action potentials from sensory receptors in the skin or throughout the body. This information is received by neu-

rons in the posterior horn. The axons carry information to the brain for interpretation. An example of an ascending tract is the *spinothalamic tracts.* Again named for their origin and termination, they originate in the posterior horn of the spinal cord and terminate in the thalamus, where sensory information can be distributed to the appropriate locations in the brain for evaluation and action, if necessary.

Nerve Roots

Axons outside the spinal cord that carry information to or from the cord are found in bundles. The bundles of axons inside the vertebral canal are the *nerve roots.* The axons exiting the anterior spinal cord are the *ventral roots,* and those running into the posterior cord are the *dorsal roots*. The cell bodies of these neurons are outside the spinal cord but inside the vertebral canal. When there are groups of neuron cell bodies outside the central nervous system, they are known as *ganglia.* These groups of ganglia are found on the dorsal root and are known as the dorsal root ganglia.

Comprehension Checkup

1. The ability of the spinal cord to initiate contraction as a result of excessive sensory input before the brain has time for complete analysis is known as a ______.
2. Axons outside of the spinal cord but inside the vertebral canal form ______.

1. reflex 2. nerve roots

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PERIPHERAL NERVOUS SYSTEM

The peripheral nervous system is located outside the central nervous system. It consists of two major divisions:

1. Cranial nerves exit through foramina (holes) in the skull to stimulate muscle and glands in the head and neck and to transmit sensory input from those areas.
2. Spinal nerves exit between each vertebra to stimulate muscle below the head. They also conduct sensory input from the body to the central nervous system.

Each of these divisions is considered in detail next.

Cranial Nerves

There are twelve pairs of cranial nerves, most of which originate in the brain stem. They pass through the foramina in the skull to stimulate muscle or to transmit sensory impulses from areas involving the face, special senses, or mouth. Each nerve is designated with a Roman numeral and a name. The following list identifies each cranial nerve by number, name, and a brief description of its major function (Figure 8.22).

- CN I—The *olfactory nerve* transmits impulses for smell.
- CN II—The *optic nerve* carries impulses from the eye back toward the occipital lobe for interpretation (Figure 8.23).
- CN III—The *oculomotor nerve* stimulates several muscles that move the eyeball.
- CN IV—The *trochlear nerve* stimulates a muscle that rotates the eyeball.
- CN V—The *trigeminal nerve* is both a motor and sensory nerve of the face (Figure 8.24).
- CN VI—The *abducens nerve* stimulates a muscle that allow us to look to the side, abducting the eye.
- CN VII—The *facial nerve* stimulates the muscles of facial expression and transmits impulses for taste from the anterior tongue (Figure 8.25 on page 224).
- CN VIII—The *vestibulocochlear nerve* carries impulses from sensors for balance and hearing to the brain.
- CN IX—The *glossopharyngeal nerve* carries impulses for taste from the posterior tongue and stimulates the muscles in the pharynx or throat that are responsible for swallowing.
- CN X—The *vagus nerve* is involved with calming the body after being startled. It slows the heart rate, lowers blood pressure, and stimulates the digestive system, just to name a few of its activities.
- CN XI—The *accessory nerve* stimulates muscles involved with swallowing as well as the muscles that allow us to shrug our shoulders.
- CN XII—The *hypoglossal nerve* stimulates tongue movement (Figure 8.26 on page 225).

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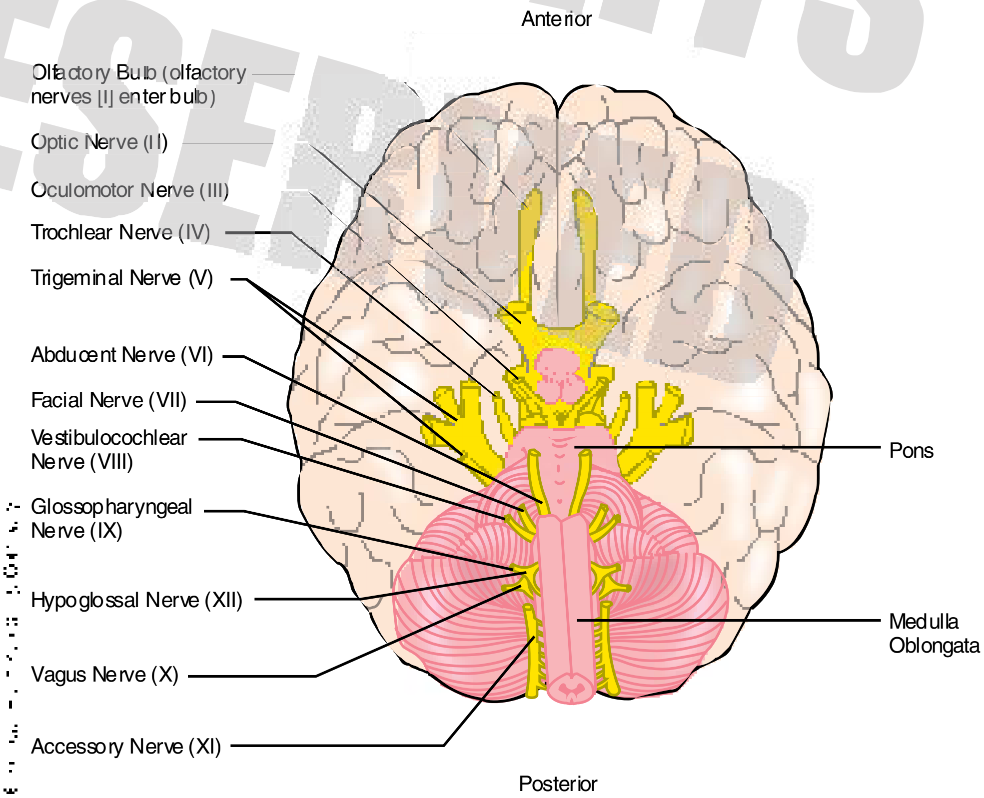

FIGURE 8.22 **Brain—Inferior View.** Origins of cranial nerves.

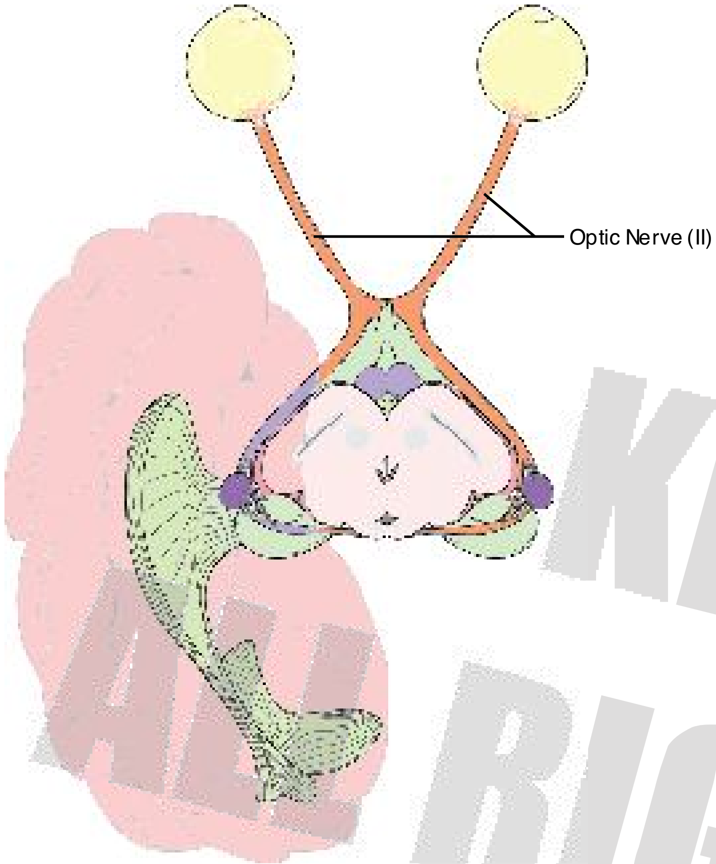

FIGURE 8.23 **Optic Nerve—Superior View.**

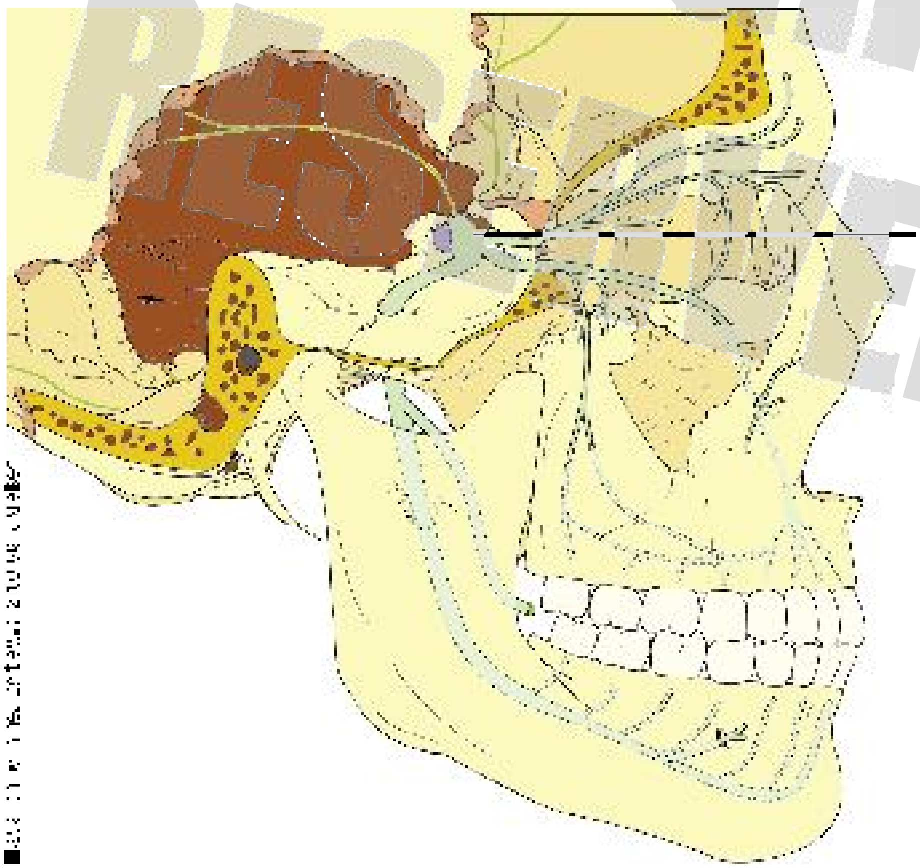

FIGURE 8.24 **Trigeminal Nerve.**

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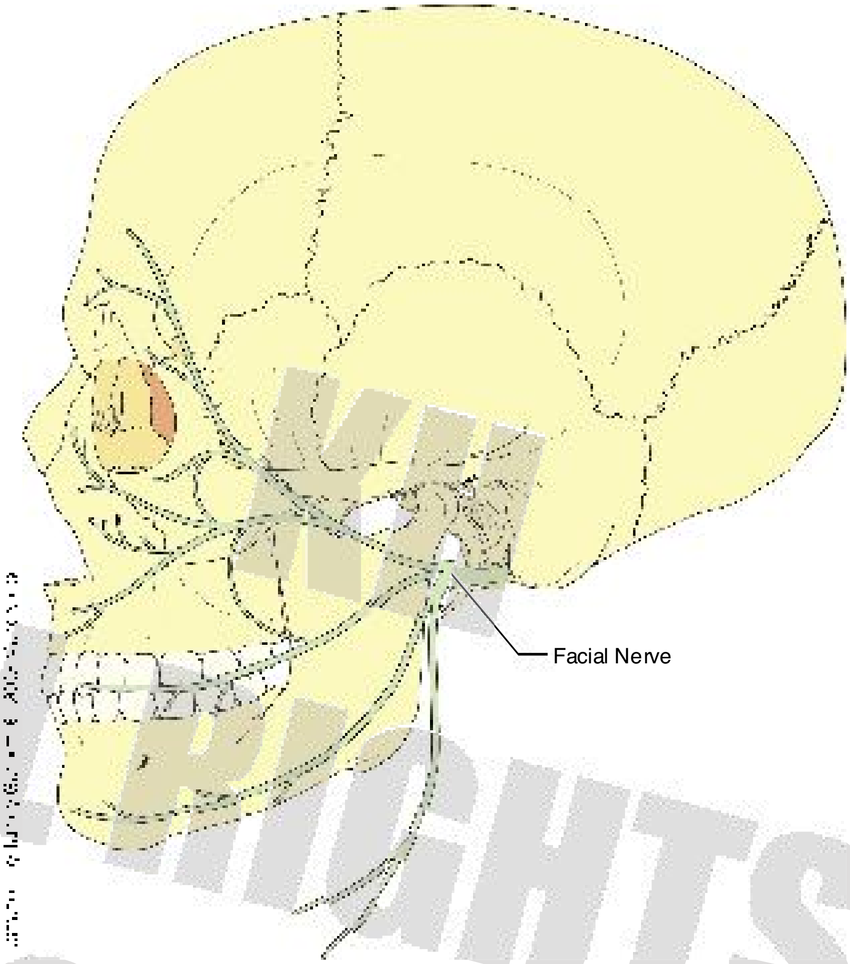

FIGURE 8.25 **Facial Nerve.**

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Comprehension Checkup

1. Cranial nerve _____ stimulates the muscles that change facial expression.
2. The sense of smell is detected by cranial nerve _____.

1. CN VII—facial nerve 2. CN I—olfactory nerve

Spinal Nerves

Spinal nerves are formed when the ventral and dorsal roots inside the vertebral canal combine to form a common nerve as they exit from the spinal column. A spinal nerve exits from between each vertebra on both left and right sides. Spinal nerves are associated with each region of the spinal column (Figure 8.27 on page 226).

- Cervical nerves (1–8) exit from both sides of the neck. Remember that there are only seven cervical vertebrae; however, there is a pair of spinal nerves exiting between the skull and first cervical vertebra resulting in an extra pair of cervical nerves.

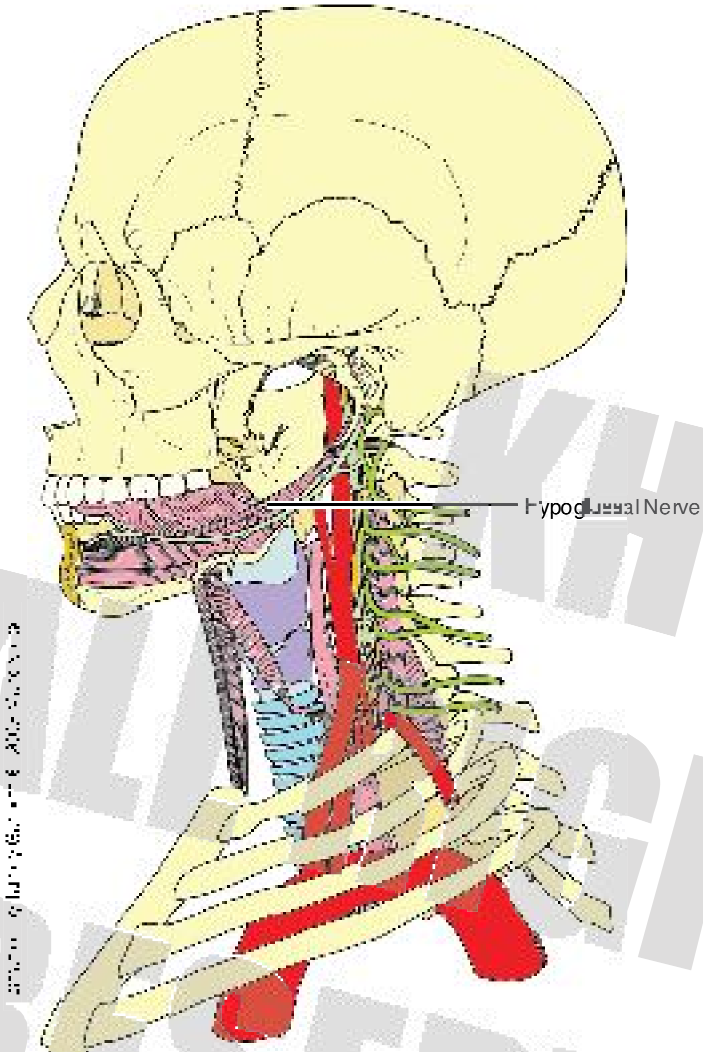

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FIGURE 8.26 **Hypoglossal Nerve.**

- Thoracic nerves (1–12) are found exiting between the 12 thoracic vertebrae.
- Lumbar nerves (1–5) are associated with the five lumbar vertebrae.
- Sacral nerves (1–5) are associated with the sacrum. There are five sacral nerves even though there is only one sacrum. Recall that the sacrum is actually composed of five bones fused together.
- Coccygeal nerves (1) are associated with the coccyx. Although there are three or four bones fused together in the coccyx, there is only one pair of coccygeal nerves.

Each spinal nerve is identified by the vertebrae next to it. The exception is the cervical nerves because there is one more nerve than vertebrae.

Plexus

There are groups of spinal nerves that run together to a network of nerves known as a *plexus*. There are three major plexuses (Figure 8.28 on page 227).

- **Cervical plexus**—Cervical nerves C1–C4 exit the neck and form a group of nerves that stimulates muscles in the neck and the diaphragm. It transmits sensory input from these areas.

cervical plexus
A group of spinal nerves (C_1–C_5) that innervate structures in the neck.

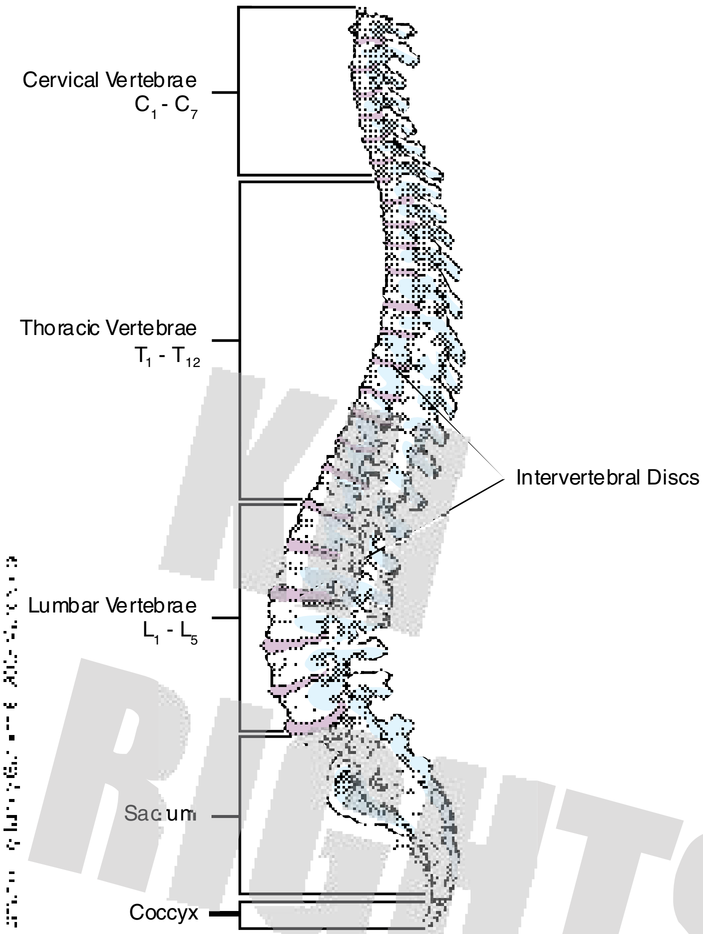

FIGURE 8.27 **Vertebral Column—Lateral View.**

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brachial plexus A group of spinal nerves (C_5- T_1) that innervate structures in the upper extremity.

lumbosacral plexus A group of spinal nerves (L_2–S_3) that innervate structures in the lower extremity.

- **Brachial plexus**—Cervical nerves C5–C8 and thoracic nerve T1 form a group of nerves located in the shoulder and into the upper extremity. They stimulate muscles in the upper extremities and relay sensory impulses from the upper extremity
- **Lumbosacral plexus**—Lumbar nerves L2–L5 along with sacral nerves S1–S4 stimulate muscles in the lower extremities and transmit sensory input from the lower extremity.

Comprehension Checkup

1. There are _____ cervical nerves.
2. The muscles of the upper extremity are stimulated by nerves from the ______ plexus.

1. 8 2. brachial

Spinal Nerves

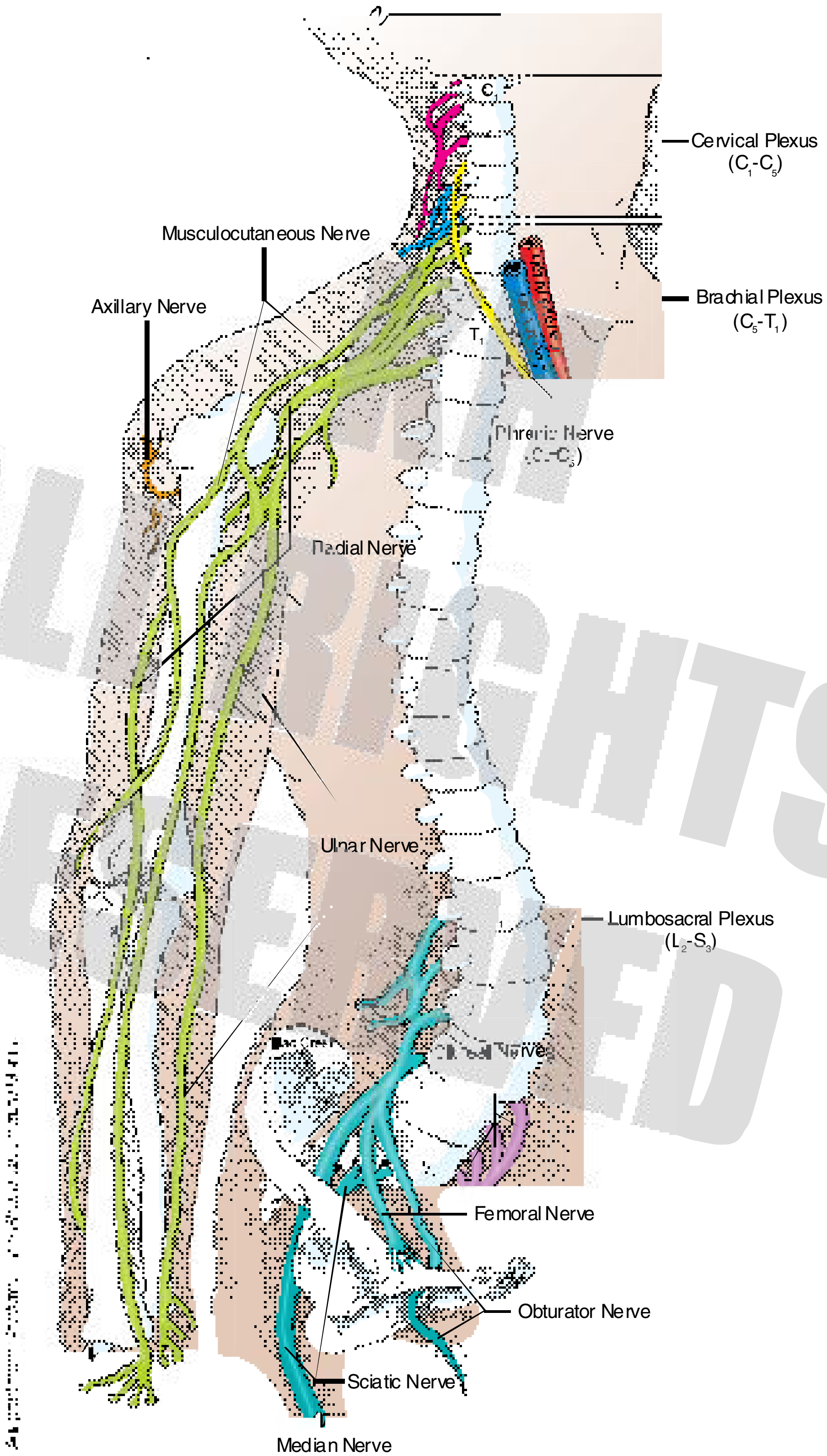

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FIGURE 8.28 **Spinal Nerves Plexus: Cervical Plexus, Brachial Plexus, and Lumbosacral Plexus.**

Nervous System Responses to Daily Life

The following scenario illustrates some of the involvement of the nervous system in the simple act of taking a sip of hot coffee. The terms discussed in this chapter are highlighted.

My intention is simply to sit down and enjoy my morning cup of coffee. It seems simple enough. Before I pick up my cup, the occipital lobe of my cerebrum is going to collect data from my eyes about the shape, color, and location of the cup. Those parameters are relayed to my frontal lobe to assimilate information from my eyes through CN II about the size of the cup and correlate it with previous data about the weight of a cup of coffee to determine how many motor units it will take to lift the cup. A decision also has to be made concerning the length of time I intend to hold my coffee cup. The frontal lobe of my brain works out a movement plan and the motor cortex begins stimulating motor units. I reach for the cup.

As my fingers grasp the handle, sensors in my skin detect the texture and touch of the cup. The information generated by sensors in my hand passes through sensory neurons to the posterior horn of my spinal cord and is relayed up to the thalamus through my spinothalamic tract. The thalamus distributes the information to various areas of my brain for analysis and decision. The parietal lobe of my cerebrum determines where the sensations originated. As I begin to lift the cup, pressure sensors in my hand monitor the weight of the cup as receptors in the muscles in my upper extremity send information to my brain about the amount of tension being created. The frontal lobe of my cerebrum quickly makes adjustments to my motor unit stimulation to correct for any miscalculation concerning the weight of the cup. My cerebellum is actively making the lifting of my coffee cup smooth and coordinated.

Other areas of my brain are concerned with maintaining my posture so that I don't spill my coffee. As I lift the cup to my mouth, I smell the coffee through CN I and detect the warmth through CN V as it nears my lips. Muscles in my face, stimulated by CN VII, position my lips to drink. I am close to enjoying the taste of coffee when I am accidentally bumped by a family member passing by. The coffee splashes over the edge of the cup onto my leg. The heat from the spilled coffee is sensed by temperature receptors in my thigh. The sensing of heat and pain is rapidly transmitted by sensory neurons to the posterior horn of my spinal cord, where interneurons in the reflex arc pass the action potential to motor neurons in the anterior horn that stimulate muscles in my lower extremity, causing a withdrawal reflex that moves my thigh out of the way just in time to prevent another splash from causing more pain. The impulse from the posterior horn of my spinal cord has also traveled through the ascending spinothalamic tract to the thalamus, where it is distributed to the appropriate areas of my brain. One area is the parietal lobe of the cerebrum, where I interpret this sensation as very unpleasant. As that information is transmitted to the prefrontal area of my frontal lobe, I weigh the consequences of my reactions and decisions and determine I will not allow this incident to negatively affect my day.

Homeostasis—Holding in Balance

The nervous system is active in maintaining the homeostasis of many areas of the body. Of particular importance is the hypothalamus, which controls body temperature, regulates food and water intake, and causes the release of hormones affecting water balance, growth, metabolism, development, and reproduction. Not only is the brain responsible for conscious interpretation, decisions, and interactions, it also, through regulation of the respiration rate, maintains the level of carbon dioxide in our bloodstream as a means of assisting in the control of blood pH within homeostatic range.

There Is No Substitute for Exercise

Exercise relieves stress. Stress causes us to create a sympathetic response, resulting in our "fight-or-flight" system increasing blood pressure, heart rate, and respiration rate. During times of emergency, we decrease our vigilance against foreign invaders because we are more concerned at the moment with immediate survival. By relieving stress, we increase our resistance against disease.

Regular exercise also increases coordination and reflex action. Repeated practice creates conditioned reflexes that allow us to respond without having to think through the same process time after time. For example, a basketball player, after repeatedly practicing shooting a basketball, does not have to think about the position of his feet, the angle of the shot, or the degree of force needed behind the throw of the ball in order to be successful most of the time. The movement becomes programmed as a reflex because of repeated exercise.

The brain also controls the level of muscle tone required to stabilize joints and maintain posture. Exercise improves muscle tone and thereby reduces the risk of injury that could result because of the rapid change of position and movement that occurs throughout the activity.

SUMMARY

I. Divisions of the Nervous System
- A. Anatomical divisions
  1. Central nervous system, which consists of the brain and spinal cord
  2. Peripheral nervous system, which is composed of cranial and spinal nerves
- B. Functional divisions
  1. Somatic nervous system, which is involved with the conscious sensing of the environment, integration and decision making, and the activation of skeletal muscle
  2. Autonomic nervous system, which includes unconscious stimulation of smooth muscles, cardiac muscle, and glands in response to emergencies or stress

II. Components of the Nervous System
- A. Neurons are nerve cells consisting of a cell body, axon, and terminal end.
  1. Physiology of the neuron
     - a. Resting state—The neuron is polarized with positive charges outside the plasma membrane and negative charges inside.
     - b. Depolarization—Stimulation causes sodium channels to open, allowing positive sodium ions to diffuse in and cancel the negative charges inside the membrane. The influx of positive charges causes the inside of the plasma membrane to actually become positively charge.
     - c. Repolarization—As sodium channels close, potassium channels open to allow positive potassium ions to leave the cell. This causes the inside of the membrane to become negatively charged again.
  2. Synapse—the junction between a neuron and the next nerve or muscle fiber
     - a. Physiology of the synapse
       - (1) Depolarization of the synaptic knob causes neurotransmitter to cross the synaptic cleft.
       - (2) Neurotransmitter attaches to receptors on the effector to open sodium channels on them, possibly creating an action potential.

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B. Neuroglia—non-nerve cells in the central nervous system that support and protect neurons

III. Central Nervous System

A. The brain is the center of muscle stimulation, integration of thought, and interpretation, location, and response to sensory information.

1. Cerebrum—This is the center for stimulation of skeletal muscle, interpretation and location of sensory information, integration of information, decision making, and higher functions of thought and action.
2. Cerebellum—It is concerned with maintaining balance and coordination of movement.
3. Brain stem—The brain stem interconnects areas of the brain and the spinal cord. It is the center for functions vital for life, such as the control of breathing, heart rate, and blood pressure and maintenance of an airway.
4. Diencephalon—Its functions include relaying sensory information to various areas of the brain, maintaining homeostasis, acting as a biological clock, coping with stress, and memory/learning
5. Associated structures—These structures are not directly involved in brain or spinal cord function
   a. Ventricles are spaces within the brain where cerebrospinal fluid is produced.
   b. Meninges are protective coverings over the brain and the spinal cord.

B. The spinal cord is the location for the exchange of sensory information and muscle stimulation between the central nervous system and peripheral nervous system. It also has to ability to generate skeletal muscle stimulation without coordination from the brain.

1. Gray matter contains the cell bodies of motor neurons that stimulate skeletal muscle, sensory neuron terminal ends that bring in information from the body, and interneurons that are able to cause direct muscle stimulation if sensory input is strong enough.
2. White matter is composed of axons that carry impulses between the brain and spinal cord.
3. Reflexes are the contraction of skeletal muscle resulting from strong sensory input. They are caused by interneurons within the spinal cord before the brain has time to decide how to respond.
4. The peripheral nervous system consists of the following:
   a. Cranial nerves exit through foramina in the skull. There are 12 pairs that detect sensations from head, stimulate facial muscles and those involved with chewing and swallowing, and carry impulses created by the special senses.
   b. Spinal nerves exit from the vertebral column. They stimulate muscle and detect the environment on the surface of the skin and changes in the status of internal organs.

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KEY TERMS

autonomic nervous system (197)
axon (198)
brachial plexus (226)
brain stem (214)
central nervous system (195)
cerebellum (214)
cerebral hemisphere (209)
cerebrospinal fluid (202)
cerebrum (209)
cervical plexus (225)
dendrite (198)
frontal lobe (209)
gray matter (201)
lumbosacral plexus (226)
meninges (216)
motor neuron (198)
nerve impulse (202)
neuron (198)
neurotransmitter (207)
node of Ranvier (206)
occipital lobe (213)
parasympathetic nervous system (197)
parietal lobe (212)
peripheral nervous system (195)
resting potential (203)
sensory neuron (198)
somatic nervous system (197)
sympathetic nervous system (197)
synapse (199)
temporal lobe (214)
terminal end (199)
white matter (200)

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TEST YOURSELF

Match the following areas of the nervous system with their definition

1. peripheral nervous system	A. sodium ions diffuse into the cell
2. axon	B. spaces inside the brain
3. synapse	C. receives and interprets vision
4. depolarization	D. contains cranial nerves and spinal nerves
5. ependymal cells	E. potassium ions diffuse out of the cell
6. hypothalamus	F. threadlike extension of the neuron
7. occipital lobe of the cerebrum	G. produce cerebrospinal fluid
8. repolarization	H. receives and interprets sound
9. ventricles	I. maintains homeostasis
10. temporal lobe of the cerebrum	J. the junction between two nerves or a muscle fiber and a nerve

Choose the best answer to the following multiple choice questions:

1. There are spaces between the cells of the neurilemma that expose the axon. These spaces are known as
   a. the synaptic cleft.
   b. neurotransmitters.
   c. nodes of Ranvier.
   d. the foramen of Magendie.

2. What type of neuron is a sensory neuron?
   a. multipolar
   b. bipolar
   c. tripolar
   d. unipolar

3. The space between the synaptic knob and the postsynapse is known as
   a. the synaptic cleft.
   b. neurotransmitters.
   c. nodes of Ranvier.
   d. the foramen of Magendie.

4. A ridge on the cerebrum is known as a
   a. fissure.
   b. frenulum.
   c. sulcus.
   d. gyrus.

5. Creative activities such as music and art are a specialty of the ______ hemisphere of the cerebrum.
   a. superior
   b. left
   c. inferior
   d. right
6. The lobe of the cerebrum that performs analysis and decision making along with stimulation of skeletal muscle is the ____ lobe.
   a. occipital
   b. frontal
   c. temporal
   d. parietal
7. The area of the brain stem that connects the cerebellum to the rest of the central nervous system is the
   a. midbrain.
   b. medulla oblongata.
   c. pons.
   d. thalamus.
8. The functional area of the brain that deals with stress and emotion as well as learning is the
   a. limbic system.
   b. thalamus.
   c. pineal gland.
   d. hypothalamus.
9. The thin meningeal covering directly on the brain and spinal cord is known as the
   a. dura mater.
   b. pia mater.
   c. arachnoid mater.
   d. cetateous mater.
10. A sensory neuron connected to an interneuron that can stimulate a motor neuron to cause skeletal muscle to contract forms the
   a. somatic nervous system.
   b. corpus callosum.
   c. central nervous system.
   d. reflex arc.

Match the following cranial nerves and plexuses with their action:

1. CN VIII (vestibulocochlear nerve)	A. sense of sight
2. CN X (vagus nerve)	B. eye movement
3. Lumbosacral plexus	C. balance and hearing
4. CN V (trigeminal nerve)	D. tongue movement
5. Cervical plexus	E. movement and sensations from the neck
6. CN II (optic nerve)	F. slows heart rate; lowers blood pressure
7. CN XII (hypoglossal nerve)	G. sensory nerve of the face
8. CN III (oculomotor nerve)	H. movement and sensations in the lower extremity

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THOUGHT QUESTIONS

1. What would happen to muscle stimulation if a synaptic knob could not produce any neurotransmitters?
2. What would happen to a muscle fiber if it could not repolarize?
3. If an individual had a large amount of potassium in the extracellular fluid, would the creation of an action potential be affected?
4. Do all neurons have a myelin sheath? Why or why not?
5. If a person had a spinal cord injury, would there be any reflexes below the point of injury?

MEDICAL QUESTIONS

1. What would happen if someone had a stroke that affected the hypothalamus?
2. What kind of problems would a person have if the frontal lobes of the cerebrum were damaged by an accident?
3. What serious effect would a stroke in the brain stem cause to body functions?
4. If the neurilemma is destroyed, as sometimes occurs in autoimmune disease, how would that affect muscle contraction?
5. Why would a pinched nerve in the lower back cause pain in the lower extremity?

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