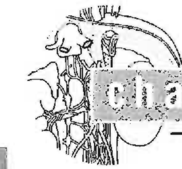

AUTONOMIC NERVOUS SYSTEM

chapter 11

did you know? ***The "fight-or-flight" response of the sympathetic nervous system is very helpful when you encounter a snarling dog or need to escape from a burning building. But when the emergency is over, your parasympathetic nervous system needs time to help your body relax and recover. What happens when stress builds up, and no recovery occurs? When your days are filled with negative stress and an overactivated sympathetic nervous system, stress-related health problems may develop. Chronic, unrelenting, overwhelming stress interferes with the body's ability to maintain homeostasis and health. Learning relaxation and stress reduction skills can reduce the harmful effects of stress upon the body.***

Focus on Wellness, page 278

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The part of the nervous system that regulates smooth muscle, cardiac muscle, and certain glands is the ***autonomic nervous system (ANS)***. Recall that together the ANS and somatic nervous system compose the peripheral nervous system; see Figure 9.1 on page 226. The ANS was originally named *autonomic* (*auto-* = self; *-nomic* = law) because it was thought to function in a self-governing manner. Although the ANS usually does operate without conscious control from the cerebral cortex, it is regulated by other brain regions, mainly the hypothalamus and brain stem. In this chapter, we compare the structural and functional features of the somatic and autonomic nervous systems. Then we discuss the anatomy of the motor portion of the ANS and compare the organization and actions of its two major branches, the sympathetic and parasympathetic divisions.

looking back to move ahead . . .

- **Structures of the Nervous System (page 226)**
- **Sensory and Motor Components of the ANS and ANS Effectors (page 227)**

COMPARISON OF SOMATIC AND AUTONOMIC NERVOUS SYSTEMS

OBJECTIVE • Compare the main structural and functional differences between the somatic and autonomic parts of the nervous system.

As you learned in Chapter 10, the somatic nervous system includes both sensory and motor neurons. The sensory neurons convey input from receptors for the special senses (vision, hearing, taste, smell, and equilibrium, described in Chapter 12) and from receptors for somatic senses (pain, temperature, touch, and proprioceptive sensations). All these sensations normally are consciously perceived. In turn, somatic motor neurons synapse with skeletal muscle—the effector tissue of the somatic nervous system—and produce conscious, voluntary movements. When a somatic motor neuron stimulates a skeletal muscle, the muscle contracts. If somatic motor neurons cease to stimulate a muscle, the result is a paralyzed, limp muscle that has no muscle tone. In addition, even though we are generally not conscious of breathing, the muscles that generate breathing movements are skeletal muscles controlled by somatic motor neurons. If the respiratory motor neurons become inactive, breathing stops.

The main input to the ANS comes from ***autonomic sensory neurons***. These neurons are associated with sensory receptors that monitor internal conditions, such as blood CO_2 level or the degree of stretching in the walls of internal organs or blood vessels. When the viscera are functioning properly, these sensory signals usually are not consciously perceived.

Autonomic motor neurons regulate ongoing activities in their effector tissues, which are cardiac muscle, smooth muscle, and glands, by both excitation and inhibition. Unlike skeletal muscle, these tissues often function to some extent even if their nerve supply is damaged. The heart continues to beat, for instance, when it is removed for transplantation into another person. Examples of autonomic responses are changes in the diameter of the pupil, dilation and constriction of blood vessels, and changes in the rate and force of the heartbeat. Because most autonomic responses cannot be consciously altered or suppressed to any great degree, they are the basis for polygraph ("lie detector") tests. However, practitioners of yoga or other techniques of meditation and those who employ biofeedback methods may learn how to modulate ANS activities. For example, they may be able to voluntarily decrease their heart rate or blood pressure.

Figure 11.1 compares somatic and autonomic motor neurons. The axon of a somatic motor neuron extends all the way from the CNS to the skeletal muscle fibers that it stimulates (Figure 11.1a). By contrast, autonomic motor pathways consist of sets of *two* motor neurons (Figure 11.1b). The first neuron, called the ***preganglionic neuron***, has its cell body in the CNS, either in the lateral gray horn of the spinal cord or in a nucleus of the brainstem. Its axon extends from the CNS via a cranial or a spinal nerve to an *autonomic ganglion*, where it synapses with the second neuron. (Recall that a ganglion is a collection of neuronal cell bodies usually outside the CNS.) The second neuron, the ***postganglionic neuron***, lies entirely in the peripheral nervous system. Its cell body is located in an autonomic ganglion, and its axon extends from the ganglion to the effector (smooth muscle, cardiac muscle, or a gland). The effect of the postganglionic neuron on the effector may be either excitation (causing contraction of smooth or cardiac muscle or increasing secretions of glands) or inhibition (causing relaxation of smooth or cardiac muscle or decreasing secretions of glands). In contrast, a single somatic motor neuron extends from the CNS and always excites its effector (causing contraction of skeletal muscle) (Figure 11.1a). Another difference between autonomic and somatic motor neurons is that all somatic motor neurons release acetylcholine (ACh) as their neurotransmitter. Some autonomic motor neurons release ACh; others release norepinephrine (NE).

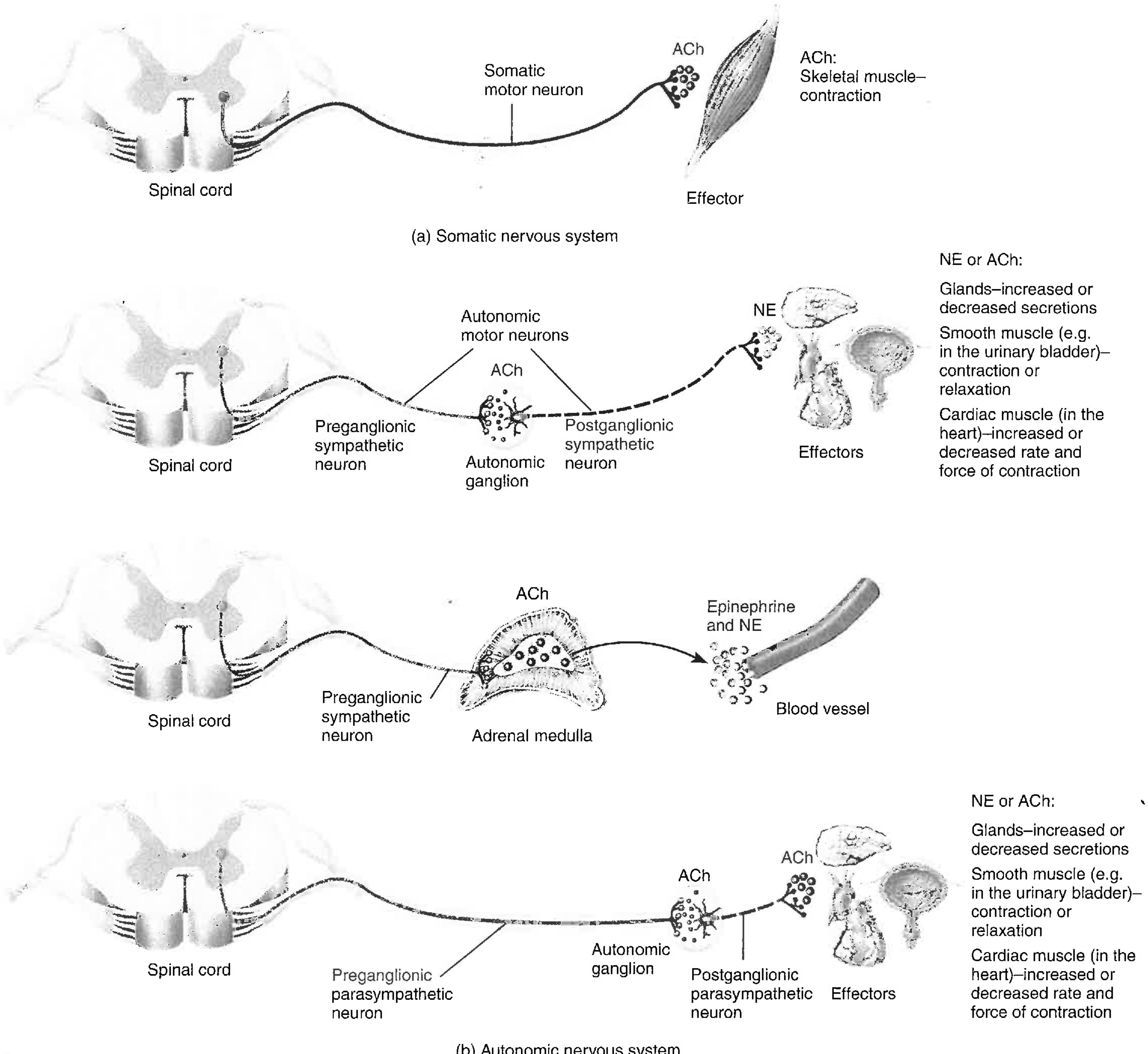
The output (motor) part of the ANS has two main branches: the ***sympathetic division*** and the ***parasympathetic division***. Most organs have ***dual innervation***; that is, they receive impulses from both sympathetic and parasympathetic neurons. In general, nerve impulses from one division stimulate the organ to increase its activity (excitation), whereas impulses from the other division decrease the organ's activity (inhibition). For example, an increased rate of nerve impulses from the sympathetic division increases heart rate, and an increased rate of nerve

Table 11.1 Comparison of Somatic and Autonomic Nervous Systems

Property	Somatic	Autonomic
Effectors	Skeletal muscles.	Cardiac muscle, smooth muscle, and glands.
Type of control	Mainly voluntary.	Mainly involuntary.
Neural pathway	One motor neuron extends from CNS and synapses directly with a skeletal muscle fiber.	One motor neuron extends from the CNS and synapses with another motor neuron in a ganglion; the second motor neuron synapses with an autonomic effector.
Neurotransmitter	Acetylcholine.	Acetylcholine or norepinephrine.
Action of neurotransmitter on effector	Always excitatory (causing contraction of skeletal muscle).	May be excitatory (causing contraction of smooth muscle, increased heart rate, increased force of heart contraction, or increased secretions from glands) or inhibitory (causing relaxation of smooth muscle, decreased heart rate, or decreased secretions from glands).

Figure 11.1 Comparison of somatic and autonomic motor neuron pathways to their effector tissues.

Stimulation by the autonomic motor neurons can either excite or inhibit smooth muscle, cardiac muscle, and glands. Stimulation by somatic motor neurons always causes contraction of skeletal muscle.



What does "dual innervation" mean?

impulses from the parasympathetic division decreases heart rate. Table 11.1 on page 272 summarizes the similarities and differences between the somatic and autonomic nervous systems.

CHECKPOINT

1. Why is the autonomic nervous system so named?
2. What are the main input and output components of the autonomic nervous system?

STRUCTURE OF THE AUTONOMIC NERVOUS SYSTEM

OBJECTIVE • Identify the structural features of the autonomic nervous system.

We will now examine the structure of preganglionic neurons, ganglia, and postganglionic neurons and how they relate to the activities of the autonomic nervous system.

Organization of the Sympathetic Division

The sympathetic division of the ANS is also called the *thoracolumbar division* (thōr′-a-kō-LUM-bar) because the outflow of sympathetic nerve impulses comes from the thoracic and lumbar segments of the spinal cord (Figure 11.2). The sympathetic preganglionic neurons have their cell bodies in the 12 thoracic and the first two lumbar segments of the spinal cord. The preganglionic axons emerge from the spinal cord through the anterior root of a spinal nerve along with axons of somatic motor neurons. After exiting the cord, the sympathetic preganglionic axons extend to a sympathetic ganglion.

In the sympathetic ganglia, sympathetic preganglionic neurons synapse with postganglionic neurons. Because the sympathetic trunk ganglia are near the spinal cord, most sympathetic preganglionic axons are short. ***Sympathetic trunk ganglia*** lie in two vertical rows, one on either side of the vertebral column (Figure 11.2). Most postganglionic axons emerging from sympathetic trunk ganglia supply organs above the diaphragm. Other sympathetic ganglia, the ***prevertebral ganglia***, lie anterior to the vertebral column and close to the large abdominal arteries. These include the *celiac ganglion* (SĒ-lē-ak), the *superior mesenteric ganglion*, and the *inferior mesenteric ganglion*. In general, postganglionic axons emerging from the prevertebral ganglia innervate organs below the diaphragm.

Once the axon of a preganglionic neuron of the sympathetic division enters a sympathetic trunk ganglion, it may follow one of four paths:

1. It may synapse with postganglionic neurons in the sympathetic trunk ganglion it first reaches.
2. It may ascend or descend to a higher or lower sympathetic trunk ganglion before synapsing with postganglionic neurons.
3. It may continue, without synapsing, through the sympathetic trunk ganglion to end at a prevertebral ganglion and synapse with postganglionic neurons there.
4. It may extend to and terminate in the adrenal medulla.

A single sympathetic preganglionic axon has many branches and may synapse with 20 or more postganglionic neurons. Thus, nerve impulses that arise in a single preganglionic neuron may activate many different postganglionic neurons that in turn synapse with several autonomic effectors. This pattern helps explain why sympathetic responses can affect organs throughout the body almost simultaneously.

Most postganglionic axons leaving the cervical sympathetic trunk ganglia serve the head. They are distributed to sweat glands, smooth muscles of the eye, blood vessels of the face, nasal mucosa, and salivary glands. A few postganglionic axons from the cervical sympathetic trunk ganglia supply the heart. In the thoracic region, postganglionic axons from the sympathetic trunk serve the heart, lungs, and bronchi. Some axons from thoracic levels also supply sweat glands, blood vessels, and smooth muscles of hair follicles in the skin. In the abdomen, axons of postganglionic neurons leaving the prevertebral ganglia follow the course of various arteries to abdominal and pelvic autonomic effectors.

The sympathetic division of the ANS also includes part of the adrenal glands (Figure 11.2). The inner part of the adrenal gland, the ***adrenal medulla*** (me-DUL-a), develops from the same embryonic tissue as the sympathetic ganglia, and its cells are similar to sympathetic postganglionic neurons. Rather than extending to another organ, however, these cells release hormones into the blood. Upon stimulation by sympathetic preganglionic neurons, cells of the adrenal medulla release a mixture of hormones—about 80% ***epinephrine*** and 20% ***norepinephrine***. These hormones circulate throughout the body and intensify responses elicited by sympathetic postganglionic neurons.

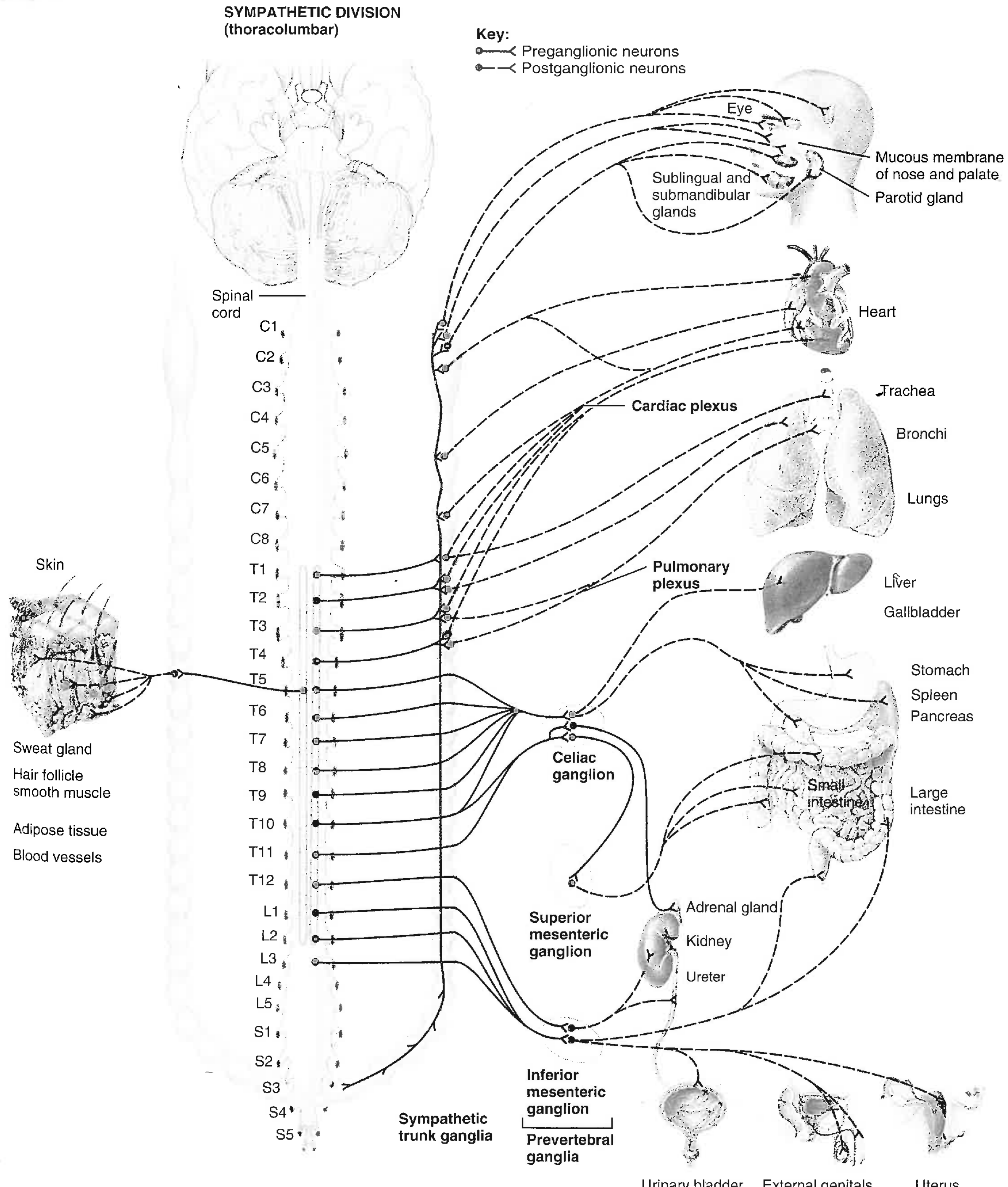
In **Horner's syndrome**, sympathetic stimulation of one side of the face is lost due to an inherited mutation, an injury, or a disease that affects sympathetic outflow through the superior cervical ganglion. Symptoms occur in the head on the affected side and include drooping of the upper eyelid, constricted pupil, and lack of sweating.

Organization of the Parasympathetic Division

The parasympathetic division is also called the *craniosacral division* (krā′-nē-ō-SĀ-kral) because the outflow of parasympathetic nerve impulses comes from cranial nerve nuclei and sacral segments of the spinal cord. The cell bodies of parasympathetic preganglionic neurons are located in the nuclei of four cranial nerves (III, VII, IX, and X) in the brain stem and in the second through fourth sacral segments of the spinal cord (S2, S3, and S4) (Figure 11.3 on page 276). Parasympathetic preganglionic axons emerge from the CNS as part of a cranial nerve or as part of the anterior root of a spinal nerve. Axons of the vagus (X) nerve carry nearly 80% of the total parasympathetic outflow. In the thorax, axons of the vagus nerve extend to ganglia in the heart and the airways of the lungs. In the abdomen, axons of the vagus nerve extend to ganglia in the liver, stomach, pancreas, small intestine, and part of the large intestine. Parasympathetic preganglionic axons exit the sacral spinal cord in the anterior roots

Figure 11.2 Structure of the sympathetic division of the autonomic nervous system. Although some innervated structures are diagrammed only for one side of the body, the sympathetic division actually innervates tissues and organs on both sides.

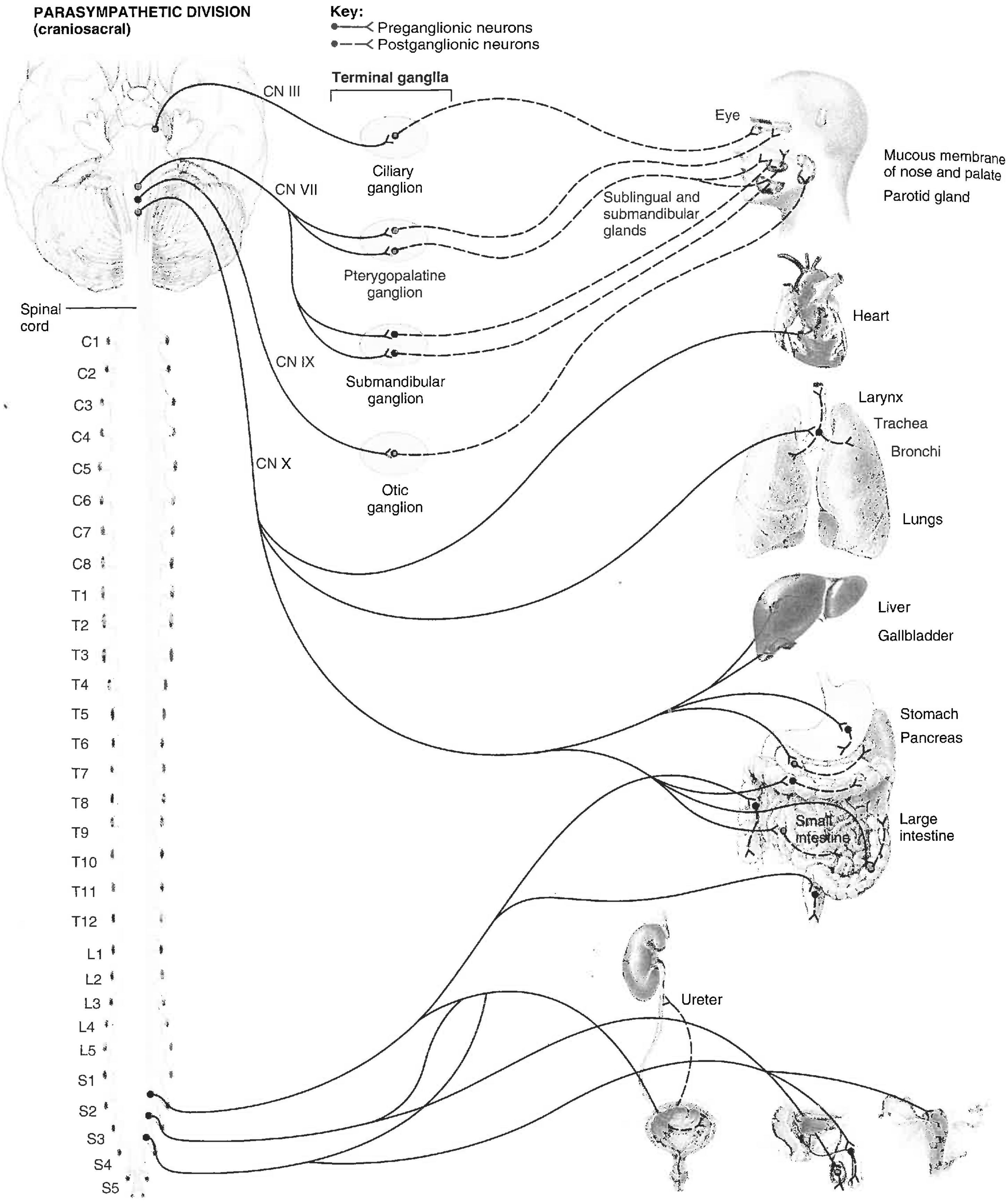
Cell bodies of sympathetic preganglionic neurons are located in the gray matter in the 12 thoracic and first two lumbar segments of the spinal cord.



Which neurons synapse in a sympathetic trunk ganglion?

Figure 11.3 Structure of the parasympathetic division of the autonomic nervous system. Although some innervated structures are diagrammed on one side of the body, the parasympathetic division actually innervates organs on both sides.

Cell bodies of parasympathetic preganglionic neurons are located in brain stem nuclei and in the gray matter in the second through fourth sacral segments of the spinal cord.



Which division, sympathetic or parasympathetic, has longer preganglionic axons? ***(Hint: Compare Figures 11.2 and 11.3.)***

of the second through fourth sacral nerves. The axons then extend to ganglia in the walls of the colon, ureters, urinary bladder, and reproductive organs.

Preganglionic axons of the parasympathetic division synapse with postganglionic neurons in ***terminal ganglia***, which are located close to or actually within the wall of the innervated organ. Terminal ganglia in the head receive preganglionic axons from the oculomotor (III), facial (VII), or glossopharyngeal (IX) cranial nerves and supply structures in the head (Figure 11.3). Axons in the vagus (X) nerve extend to many terminal ganglia in the thorax and abdomen. Because the axons of parasympathetic preganglionic neurons extend from the brain stem or sacral spinal cord to a terminal ganglion in an innervated organ, they are longer than most of the axons of sympathetic preganglionic neurons (compare Figures 11.2 and 11.3).

In contrast to the preganglionic axons, most parasympathetic postganglionic axons are very short because the terminal ganglia lie in the walls of their autonomic effectors. In the ganglion, the preganglionic neuron usually synapses with only four or five postganglionic neurons, all of which supply the same effector. Thus, parasympathetic responses are localized to a single effector.

A **megacolon** (*mega-* = big) is an abnormally large colon. In congenital megacolon, parasympathetic nerves to the distal segment of the colon do not develop properly. Loss of motor function in the segment causes massive dilation of the normal proximal colon. The condition results in extreme constipation, abdominal distension, and occasionally, vomiting. Surgical removal of the affected segment of the colon corrects the disorder.

CHECKPOINT

3. Describe the locations of sympathetic trunk ganglia, prevertebral ganglia, and terminal ganglia. Which types of autonomic neurons synapse in each type of ganglion?
4. How can the sympathetic division produce simultaneous effects throughout the body, when parasympathetic effects typically are localized to specific organs?

FUNCTIONS OF THE AUTONOMIC NERVOUS SYSTEM

OBJECTIVE • **Describe the functions of the sympathetic and parasympathetic divisions of the autonomic nervous system.**

ANS Neurotransmitters

Neurotransmitters are chemical substances released by neurons at synapses. Autonomic neurons release neurotransmitters at synapses between neurons (preganglionic to postganglionic) and at synapses with autonomic effectors (smooth muscle, cardiac muscle, and glands). Some ANS neurons release acetylcholine; others release norepinephrine.

ANS neurons that release *acetylcholine* include (1) all sympathetic and parasympathetic preganglionic neurons, (2) all parasympathetic postganglionic neurons, and (3) a few sympathetic postganglionic neurons. Because acetylcholine is quickly inactivated by the enzyme *acetylcholinesterase (AChE)*, parasympathetic effects are short-lived and localized.

Most sympathetic postganglionic neurons release the neurotransmitter *norepinephrine (NE)*. Because norepinephrine is inactivated much more slowly than acetylcholine and because the adrenal medulla also releases epinephrine and norepinephrine into the bloodstream, the effects of activation of the sympathetic division are longer lasting and more widespread than those of the parasympathetic division. For instance, your heart continues to pound for several minutes after a near miss at a busy intersection due to the long-lasting effects of the sympathetic division.

Activities of the ANS

As noted earlier, most body organs receive instructions from both divisions of the ANS, which typically work in opposition to one another. The balance between sympathetic and parasympathetic activity or "tone" is regulated by the hypothalamus. Typically, the hypothalamus turns up sympathetic tone at the same time it turns down parasympathetic tone, and vice versa. A few structures receive only sympathetic innervation—sweat glands, arrector pili muscles attached to hair follicles in the skin, the kidneys, the spleen, most blood vessels, and the adrenal medullae (see Figure 11.2). In these structures there is no opposition from the parasympathetic division. Still, an increase in sympathetic tone has one effect, and a decrease in sympathetic tone produces the opposite effect.

Sympathetic Activities

During physical or emotional stress, high sympathetic tone favors body functions that can support vigorous physical activity and rapid production of ATP. At the same time, the sympathetic division reduces body functions that favor the storage of energy. Besides physical exertion, a variety of emotions—such as fear, embarrassment, or rage—stimulate the sympathetic division. Visualizing body changes that occur during "E situations" (exercise, emergency, excitement, embarrassment) will help you remember most of the sympathetic responses. Activation of the sympathetic division and release of hormones by the adrenal medullae result in a series of physiological responses collectively called the ***fight-or-flight response***, in which the following occur:

1. The pupils of the eyes dilate.
2. Heart rate, force of heart contraction, and blood pressure increase.

FOCUS ON WELLNESS

Mind-Body Exercise—An Antidote to Stress

When we think of exercise, we usually think of toning up our muscles and maybe our hearts. But when some people think of exercise, their focus is on toning up neural input from the parasympathetic division of the autonomic nervous system. As you learned in this chapter, activation of the parasympathetic division helps restore homeostasis in many systems and is associated with feelings of relaxation.

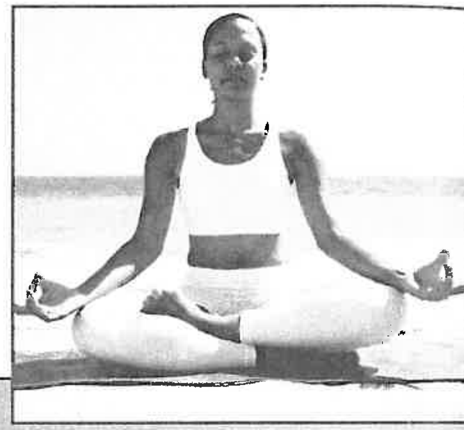
Mind-Body Harmony

Mind-body exercise refers to exercise systems such as tai chi, hatha yoga, and many forms of the martial arts that couple muscular activity with an internally directed focus. These exercise systems exercise the mind as well as the body. Their internally directed focus usually includes an awareness of breathing, energy, and other physical sensations.

Practitioners often refer to this internal awareness as "mindful," meaning that the exerciser is open to physical and emotional sensations with an understanding, nonjudgmental attitude. A mindful attitude is typical of many kinds of meditation and relaxation practices. For example, when practicing a yoga pose, you would think something like "Deep, steady breathing; relax into the pose; shoulders pulling back, neck lengthening," rather than "That girl next to me sure is flexible; I'm really a failure at this stuff." Of course, in real life such external thoughts do sneak in, but we can redirect our attention back to a more neutral, nonjudgmental style.

Mind-Body Benefits

People practicing mind-body activities reap benefits from both the physical and mental activity. Hatha yoga, tai chi, and the martial arts increase muscular strength and flexibility, posture, balance, and coordination, and if performed vigorously, they can even improve cardiovascular health and endurance to some extent. In addition, the stress relief provided by the activity extends into both physical and psychological realms. Feelings of mental relaxation and emotional well-being translate into better resting blood pressure, a healthier immune system, and more relaxed muscles. Less stress can also mean an improvement in health habits. Those who practice mind-body exercise often improve their eating habits and reduce harmful behaviors such as cigarette smoking.



► THINK IT OVER . . .

► *How could you make walking more of a mind-body activity?*

3. The airways dilate, allowing faster movement of air into and out of the lungs.
4. The blood vessels that supply nonessential organs such as the kidneys and gastrointestinal tract constrict, which reduces blood flow through these tissues. The result is a slowing of urine formation and digestive activities, which are not essential during exercise.
5. Blood vessels that supply organs involved in exercise or fighting off danger—skeletal muscles, cardiac muscle, liver, and adipose tissue—dilate, which allows greater blood flow through these tissues.
6. Liver cells break down glycogen to glucose, and adipose cells break down triglycerides to fatty acids and glycerol, providing molecules that can be used by body cells for ATP production.
7. Release of glucose by the liver increases blood glucose level.
8. Processes that are not essential for meeting the stressful situation are inhibited. For example, muscular movements of the gastrointestinal tract and digestive secretions decrease or even stop.

Parasympathetic Activities

In contrast to the "fight-or-flight" activities of the sympathetic division, the parasympathetic division enhances "rest-and-digest" activities. Parasympathetic responses support body functions that conserve and restore body energy during times of rest and recovery. In the quiet intervals between periods of exercise, parasympathetic impulses to the digestive glands and the smooth muscle of the gastrointestinal tract predominate over sympathetic impulses. This allows energy-supplying food to be digested and absorbed. At the same time, parasympathetic responses reduce body functions that support physical activity.

The acronym *SLUDD* can be helpful in remembering five parasympathetic responses. It stands for salivation (S), lacrimation (L), urination (U), digestion (D), and defecation (D). Mainly the parasympathetic division stimulates all of these activities. Besides the increasing SLUDD responses, other important parasympathetic responses are "three decreases": decreased heart rate, decreased diameter of airways, and decreased diameter (constriction) of the pupils.

Table 11.2 lists the responses of glands, cardiac muscle, and smooth muscle to stimulation by the sympathetic and parasympathetic divisions of the ANS.

Table 11.2 Functions of the Autonomic Nervous System

Effector	Effect of Sympathetic Stimulation	Effect of Parasympathetic Stimulation
Glands		
Sweat	Increased sweating.	No known effect.
Lacrimal (tear)	Slight secretion of tears.	Secretion of tears.
Adrenal medulla	Secretion of epinephrine and norepinephrine.	No known effect.
Pancreas	Inhibition of secretion of digestive enzymes and insulin (hormone that lowers blood glucose level); secretion of glucagon (hormone that raises blood glucose level).	Secretion of digestive enzymes and insulin.
Posterior pituitary	Secretion of antidiuretic hormone (ADH).	No known effect.
Liver*	Breakdown of glycogen into glucose, synthesis of new glucose, and release of glucose into the blood; decreases bile secretion.	Promotes synthesis of glycogen; increases bile secretion.
Adipose tissue*	Breakdown of triglycerides and release of fatty acids into blood.	No known effect.
Cardiac Muscle		
Heart	Increased heart rate and increased force of atrial and ventricular contraction.	Decreased heart rate and decreased force of atrial contraction.
Smooth Muscle		
Radial muscle of iris of eye	Dilation of the pupil.	No known effect.
Circular muscle of iris of eye	No known effect.	Constriction of the pupil.
Ciliary muscle of eye	Relaxation to adjust shape of lens for distant vision.	Contraction to adjust shape of lens for close vision.
Gallbladder and ducts	Storage of bile in the gallbladder.	Release of bile into the small intestine.
Stomach and intestines	Decreased motility (movement); contraction of sphincters.	Increased motility; relaxation of sphincters.
Lungs (smooth muscle of bronchi)	Widening of the airways (bronchodilation).	Narrowing of the airways (bronchoconstriction).
Urinary bladder	Relaxation of muscular wall; contraction of internal sphincter.	Contraction of muscular wall; relaxation of internal sphincter.
Spleen	Contraction and discharge of stored blood into general circulation.	No known effect.
Smooth muscle of hair follicles	Contraction that results in erection of hairs, producing "goose bumps."	No known effect.
Uterus	Inhibits contraction in nonpregnant women; stimulates contraction in pregnant women.	Minimal effect.
Sex organs	In men, causes ejaculation of semen.	Vasodilation; erection of clitoris (women) and penis (men).
Salivary glands (arterioles)	Decreases secretion of saliva.	Stimulates secretion of saliva.
Gastric glands and intestinal glands (arterioles)	Inhibits secretion.	Promotes secretion.
Kidney (arterioles)	Decreases production of urine.	No known effect.
Skeletal muscle (arterioles)	Vasodilation in most, which increases blood flow.	No known effect.
Heart (coronary arterioles)	Vasodilation in most, which increases blood flow.	Causes slight constriction, which decreases blood flow.

*Listed with glands because they release substances into the blood.

Dysautonomia (dis-aw-tō-NŌ-mē-a; *dys-* = difficult; *autonomia* = self-governing) is an inherited disorder in which the autonomic nervous system functions abnormally. Symptoms include reduced tear gland secretions, poor vasomotor control, motor incoordination, skin blotching, absence of pain sensation, difficulty swallowing, decreased reflex responses, excessive vomiting, and emotional instability.

CHECKPOINT

5. What are some examples of the opposite effects of the sympathetic and parasympathetic divisions of the autonomic nervous system?
6. What happens during the fight-or-flight response?
7. Why is the parasympathetic division of the ANS considered the rest-and-digest division?

• • •

Now that we have discussed the structure and function of the nervous system, we will next consider in Chapter 12 how sensory information is relayed to the nervous system and how the nervous system responds to it.

COMMON DISORDERS

Autonomic Dysreflexia

Autonomic dysreflexia is an exaggerated response of the sympathetic division of the ANS that occurs in about 85% of individuals with spinal cord injury at or above the level of T6. The condition occurs due to interruption of the control of ANS neurons by higher centers. When certain sensory impulses, such as those resulting from stretching of a full urinary bladder, are unable to ascend the spinal cord, mass stimulation of the sympathetic nerves below the level of injury occurs. Among the effects of increased sympathetic activity is severe vasoconstriction, which elevates blood pressure. In response, the cardiovascular center in the medulla oblongata (1) increases parasympathetic output via the vagus nerve, which decreases heart rate, and (2) decreases sympathetic output, which causes dilation of blood vessels above the level of the injury.

Autonomic dysreflexia is characterized by a pounding headache; severe high blood pressure (hypertension); flushed, warm skin with profuse sweating above the injury level; pale, cold, and dry skin below the injury level; and anxiety. It is an emergency condition that requires immediate intervention. If untreated, autonomic dysreflexia can cause seizures, stroke, or heart attack.

Raynaud Phenomenon

In ***Raynaud phenomenon*** (rā-NŌ), the fingers and toes become ischemic (lack blood) after exposure to cold or with emotional stress. The condition is due to excessive sympathetic stimulation of smooth muscle in the arterioles of the fingers and toes. When the arterioles constrict in response to sympathetic stimulation, blood flow is greatly diminished. Symptoms are colorful—red, white, and blue. Fingers and toes may look white due to blockage of blood flow or look blue (cyanotic) due to deoxygenated blood in capillaries. With rewarming after cold exposure, the arterioles may dilate, causing the fingers and toes to look red. The disorder is most common in young women and occurs more often in cold climates.

STUDY OUTLINE

Comparison of Somatic and Autonomic Nervous Systems (p. 272)

1. The part of the nervous system that regulates smooth muscle, cardiac muscle, and certain glands is the autonomic nervous system (ANS). The ANS usually operates without conscious control from the cerebral cortex, but other brain regions, mainly the hypothalamus and brain stem, regulate it.
2. The axons of somatic motor neurons extend from the CNS and synapse directly with an effector (skeletal muscle). Autonomic motor pathways consist of two motor neurons. The axon of the first motor neuron extends from the CNS and synapses in a ganglion with the second motor neuron; the second neuron synapses with an effector (smooth muscle, cardiac muscle, or a gland).
3. The output (motor) portion of the ANS has two divisions: sympathetic and parasympathetic. Most body organs receive dual innervation; usually one ANS division causes excitations and the other causes inhibition.

4. Somatic motor neurons release acetylcholine (ACh), and autonomic motor neurons release either acetylcholine or norepinephrine (NE).
5. Somatic nervous system effectors are skeletal muscles; ANS effectors include cardiac muscle, smooth muscle, and glands.
6. Table 11.1 on page 272 compares the somatic and autonomic nervous systems.

Structure of the Autonomic Nervous System (p. 273)

1. The sympathetic division of the ANS is also called the thoracolumbar division because the outflow of sympathetic nerve impulses comes from the thoracic and lumbar segments of the spinal cord. Cell bodies of sympathetic preganglionic neurons are in the 12 thoracic and the first two lumbar segments of the spinal cord.
2. Sympathetic ganglia are classified as sympathetic trunk ganglia (lateral to the vertebral column) or prevertebral ganglia (anterior to the vertebral column).
3. A single sympathetic preganglionic axon may synapse with 20 or more postganglionic neurons. Sympathetic responses can affect organs throughout the body almost simultaneously.
4. The parasympathetic division is also called the craniosacral division because the outflow of parasympathetic nerve impulses comes from cranial nerve nuclei and sacral segments of the spinal cord. The cell bodies of parasympathetic preganglionic neurons are located in the nuclei of cranial nerves III, VII, IX, and X in the brain stem and in three sacral segments of the spinal cord (S2, S3, and S4).
5. Parasympathetic ganglia are called terminal ganglia and are located near or within autonomic effectors. Parasympathetic terminal ganglia are close to or in the walls of their autonomic effectors, so most parasympathetic postganglionic axons are very short. In the ganglion, the preganglionic neuron usually synapses with only four or five postganglionic neurons, all of which supply the same effector. Thus, parasympathetic responses are localized to a single effector.

Functions of the Autonomic Nervous System (p. 277)

1. Some ANS neurons release acetylcholine, and others release norepinephrine; the result is excitation in some cases and inhibition in others.
2. ANS neurons that release acetylcholine include (1) all sympathetic and parasympathetic preganglionic neurons, (2) all parasympathetic postganglionic neurons, and (3) a few sympathetic postganglionic neurons.
3. Most sympathetic postganglionic neurons release the neurotransmitter norepinephrine (NE). The effects of NE are longer-lasting and more widespread than those of acetylcholine.
4. Activation of the sympathetic division causes widespread responses and is referred to as the fight-or-flight response. Activation of the parasympathetic division produces more restricted responses that typically are concerned with rest-and-digest activities.
5. Table 11.2 on page 279 summarizes the main functions of the sympathetic and parasympathetic divisions of the ANS.

SELF-QUIZ

1. In comparing the somatic nervous system with the autonomic nervous system, which of the following statements is true?
   a. The autonomic nervous system controls involuntary movements in skeletal muscle.
   b. The somatic nervous system controls voluntary activity in glands and smooth muscle.
   c. The autonomic nervous system controls involuntary activity in cardiac muscle, smooth muscle, and glands.
   d. The autonomic nervous system produces voluntary activity in smooth muscle and glands.
   e. The somatic nervous system controls involuntary movements, in smooth muscle, cardiac muscle, and glands.
2. Neurons in the autonomic nervous system include
   a. two motor neurons and one ganglion
   b. one motor neuron and two ganglia
   c. two motor neurons and two ganglia
   d. one motor and one sensory neuron, and no ganglia
   e. one motor and one sensory neuron, and one ganglion
3. Which statement is NOT true?
   a. Most sympathetic postganglionic neurons release norepinephrine.
   b. Parasympathetic preganglionic neurons release acetylcholine.
   c. Sympathetic effects are more localized and short-lived than parasympathetic effects.
   d. The effects from norepinephrine tend to be long-lasting.
   e. Branches of a single postganglionic neuron in the sympathetic division extend to many organs.
4. Which of the following pairs is mismatched?
   a. acetylcholine, parasympathetic nervous system
   b. fight-or-flight, sympathetic nervous system
   c. conserves body energy, parasympathetic nervous system
   d. rest-and-digest, parasympathetic nervous system
   e. norepinephrine, parasympathetic nervous system

5. Which of the following statements is NOT true concerning the autonomic nervous system?
   a. Most autonomic responses cannot be consciously cotrolled.
   b. In general, if the sympathetic division increases the activity in a specific organ, then the parasympathetic division decreases the activity of that organ.
   c. Sensory receptors monitor internal body conditions.
   d. Sensory neurons include pre- and postganglionic neurons.
   e. Most visceral effectors receive dual innervation.
6. Which part of the central nervous system contains centers that regulate the autonomic nervous system?
   a. hypothalamus b. cerebellum c. spinal cord
   d. basal ganglia e. thalamus
7. Place the following structures in the correct order as they relate to an autonomic nervous system response from receipt of the stimulus to response:
   1. visceral effector 2. centers in the CNS 3. autonomic ganglion 4. receptor and autonomic sensory neuron 5. preganglionic neuron 6. postganglionic neuron
   a. 4, 5, 2, 3, 6, 1 b. 5, 6, 2, 3, 1, 4 c. 1, 6, 3, 5, 2, 4
   d. 4, 2, 5, 3, 6, 1 e. 2, 4, 5, 6, 3, 1
8. Which of the following activities would NOT be monitored by autonomic sensory neurons?
   a. carbon dioxide levels in the blood
   b. hearing and equilibrium
   c. blood pressure
   d. stretching of the walls of visceral organs
   e. nausea from damaged viscera
9. The autonomic ganglia associated with the parasympathetic division are the
   a. trunk ganglia b. prevertebral ganglia c. posterior root ganglia d. terminal ganglia e. basal ganglia
10. Which of these statements about the parasympathetic division of the autonomic nervous system is NOT true? The parasympathetic division
    a. arises from the cranial nerves in the brain stem and sacral spinal cord segments
    b. is concerned with conserving and restoring energy
    c. uses acetylcholine as its neurotransmitter
    d. has ganglia near or within visceral effectors
    e. initiates responses in preganglionic neurons that synapse with 20 or more postganglionic neurons
11. Which nerve carries most of the parasympathetic output from the brain?
    a. spinal b. vagus c. oculomotor d. facial
    e. glossopharyngeal
12. Which of the following would NOT be affected by the autonomic nervous system?
    a. heart b. intestines c. urinary bladder
    d. skeletal muscle e. reproductive organs
13. Which of the following neurons release norepinephrine?
    a. somatic motor neurons
    b. sympathetic postganglionic neurons
    c. sympathetic preganglionic neurons
    d. parasympathetic postganglionic neurons
    e. parasympathetic preganglionic neurons
14. Match the following:
    ___ a. cluster of cell bodies outside the CNS
    ___ b. cell body is in ganglion; unmyelinated axon extends to effector
    ___ c. cell body lies inside the CNS; myelinated axon extends to ganglion
    ___ d. their postganglionic axons innervate organs below the diaphragm
    ___ e. their postganglionic axons supply organs above the diaphragm
    ___ f. contain the cell bodies and dendrites of parasympathetic postganglionic neurons

    A. sympathetic trunk ganglia
    B. prevertebral ganglia
    C. ganglion
    D. terminal ganglia
    E. preganglionic neuron
    F. postganglionic neuron
15. For each of the following, place a P if it refers to increased activity of the parasympathetic division or an S if it refers to increased activity of the sympathetic division.
    ___ a. dilates pupils
    ___ b. decreases heart rate
    ___ c. causes bronchoconstriction
    ___ d. stimulates breakdown of triglycerides
    ___ e. inhibits secretion of digestive enzymes and insulin
    ___ f. stimulates the gastrointestinal tract
    ___ g. occurs during exercise
    ___ h. causes release of glucose from the liver
    ___ i. dilates blood vessels to cardiac muscle

CRITICAL THINKING APPLICATIONS

1. It's Thanksgiving and you've just eaten a huge turkey dinner with all the trimmings. Now you're going to watch the big game on TV, if you can make it to the couch! Which division of the nervous system will be handling your body's post-dinner activities? Give examples of some organs and the effects on their functions.

2. Anthony wanted a toy on the top of the bookcase, so he climbed up the shelves. His mother ran in when she heard the crash and lifted the heavy bookcase with one arm while pulling her son out with the other. Later that day, she could not lift the bookcase back into position by herself. How do you explain the temporary "supermom" effect?

3. Taylor was watching a scary late-night horror movie when she heard a door slam and a cat's yowl. The hair rose on her arms and she was covered with goose bumps. Trace the pathway taken by the impulses from her CNS to her arms.

4. In the novel *The Hitchhiker's Guide to the Galaxy*, the character Zaphod Beebleborox has two heads and therefore two brains. Is this what is meant by dual innervation? Explain.

ANSWERS TO FIGURE QUESTIONS

11.1 Dual innervation means that an organ receives impulses from both the sympathetic and parasympathetic divisions of the ANS.

11.2 In the sympathetic trunk ganglia, sympathetic preganglionic axons form synapses with cell bodies and dendrites of sympathetic postganglionic neurons.

11.3 Most parasympathetic preganglionic axons are longer than most sympathetic preganglionic axons because parasympathetic ganglia are located in the walls of visceral organs, while most sympathetic ganglia are close to the spinal cord in the sympathetic trunk.