Chapter 16: Neural Integration II: The Autonomic Nervous System and Higher-Order Functions

I. An Overview of the ANS, p. 518

• Routine homeostatic adjustments in physiological systems are made by the autonomic nervous system (ANS).

• The ANS coordinates cardiovascular, respiratory, digestive, urinary, and reproductive functions.

• The ANS adjusts internal water, electrolyte, nutrient, and dissolved gas concentrations in body fluids—and it does so without instructions or interference from the conscious mind.

*Figure 16-1*

*Figure 16-2*

• The integrative centers for autonomic activity are located in the hypothalamus.

• The neurons in these centers are comparable to the upper motor neurons in the SNS.

• Visceral motor neurons in the brain stem and spinal cord are known as preganglionic neurons.

• The axons of preganglionic neurons are called preganglionic fibers. Preganglionic fibers leave the CNS and synapse on ganglionic neurons—visceral motor neurons in peripheral ganglia (autonomic ganglia) which contain hundreds to thousands of ganglionic neurons.

• Ganglionic neurons innervate visceral effectors such as cardiac muscle, smooth muscle, glands, and adipose tissues.

• The axons of ganglionic neurons are called postganglionic fibers, because they begin at the autonomic ganglia and extend to the peripheral target organs.

• Somatic or visceral sensory information can trigger visceral reflexes, and the motor commands of those reflexes are distributed by the ANS.

• Sometimes those motor commands control the activities of target organs. For example, in cold weather, the ANS stimulates the arrector pili muscles and gives you “goosebumps.”
In other cases, the motor commands may alter some ongoing activity. These changes in visceral activity occur in response to the release of neurotransmitters by postganglionic fibers.

Divisions of the ANS, p. 519

- The ANS contains two primary subdivisions: the sympathetic division and the parasympathetic division.

- Most often, these two divisions have opposing effects; if the sympathetic division causes excitation, the parasympathetic causes inhibition. However, this is not always the case, because
  1. the two divisions may work independently, with some structures innervated by only one division or the other
  2. the two divisions may work together, each controlling one stage of a complex process.

- In general, the sympathetic division “kicks in” only during periods of exertion, stress, or emergency, and the parasympathetic division predominates under resting conditions.

- In the sympathetic division, or thoracolumbar division, preganglionic fibers from the thoracic and superior lumbar segments of the spinal cord synapse in ganglia near the spinal cord.

- In this division of the ANS the preganglionic fibers are short and the postganglionic fibers are long.

- The sympathetic division prepares the body for heightened levels of somatic activity.

- When fully activated, this division produces what is known as the “fight or flight” response, which readies the body for a crisis that may require sudden, intense physical activity.

- An increase in sympathetic activity generally stimulates tissue metabolism and increases alertness.

- The general pattern of responses to increased levels of sympathetic activity can be summarized as follows:
  1. heightened mental alertness
  2. increased metabolic rate
  3. reduced digestive and urinary functions
  4. activation of energy reserves
  5. increased respiratory rate and dilation of respiratory passageways
6. increased heart rate and blood pressure
7. activation of sweat glands

• In the parasympathetic division, or craniosacral division, preganglionic fibers originate in the brain stem and the sacral segments of the spinal cord, and synapse in ganglia very close to (or within) the target organs.

• In the parasympathetic division of the ANS, the pre-ganglionic fibers are long and the postganglionic fibers are short.

• The parasympathetic division stimulates visceral activity. For example, it is responsible for the state of “rest and repose” that follows a big dinner.

• General parasympathetic activation conserves energy and promotes sedentary activities, such as digestion.

• The overall pattern of responses to increased levels of parasympathetic activity is as follows:
  1. decreased metabolic rate
  2. decreased heart rate and blood pressure
  3. increased secretion by salivary and digestive glands
  4. increased motility and blood flow in the digestive tract
  5. stimulation of urination and defecation

• The ANS also includes a third division that most people have never heard of: the enteric nervous system (ENS), an extensive network of neurons and nerve networks located in the walls of the digestive tract.

• Although the activities of the enteric nervous system are influenced by the sympathetic and parasympathetic divisions, many complex visceral reflexes are initiated and coordinated locally, without instructions from the CNS.

• The ENS has roughly 100 million neurons—at least as many as the spinal cord—and all of the neurotransmitters found in the brain.

Key: The autonomic nervous system operates largely outside our awareness. It includes: a sympathetic division concerned with increasing alertness, metabolic rate, and muscular abilities, and a parasympathetic division concerned with reducing metabolic rate and promoting visceral activities such as digestion.

II. The Sympathetic Division, p. 521
**Figure 16-3**

- The sympathetic division consists of preganglionic neurons that are located between segments T₁ and L₂ of the spinal cord, and ganglionic neurons that are located in ganglia near the vertebral column.

- The cell bodies of the preganglionic neurons are situated in the lateral gray horns, and their axons enter the ventral roots of these segments.

**Figure 16-4**

- Ganglionic neurons occur in three locations:
  1. **Sympathetic chain ganglia**, also called paravertebral ganglia or lateral ganglia, lie on both sides of the vertebral column. Neurons in these ganglia control effectors in the body wall, inside the thoracic cavity, and in the head and limbs.

**Figure 16-4a**

  2. **Collateral ganglia**, also known as prevertebral ganglia, are anterior to the vertebral bodies. Collateral ganglia contain ganglionic neurons that innervate tissues and organs in the abdominopelvic cavity.

**Figure 16-4b**

  3. The center of each adrenal gland, an area known as the adrenal medulla, is a modified sympathetic ganglion. The ganglionic neurons of the adrenal medullae have very short axons; when stimulated, they release their neurotransmitters into the bloodstream. The release of neurotransmitters into a capillary, not at a synapse, allows them to function as hormones that affect target cells throughout the body.

**Figure 16-4c**

- In the sympathetic division, the preganglionic fibers are relatively short, because the ganglia are located relatively near the spinal cord.

- Postganglionic fibers are relatively long, except at the adrenal medullae.

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**Organization and Anatomy of the Sympathetic Division, p. 522**

- The ventral roots of spinal segments T₁ to L₂ contain sympathetic preganglionic fibers.

- After passing through the intervertebral foramen, each ventral root gives rise to a myelinated white ramus, which carries myelinated preganglionic fibers into a nearby sympathetic chain ganglion. These fibers may synapse within the
sympathetic chain ganglia, at one of the collateral ganglia, or in the adrenal medullae.

**Figure 16-4**

- Extensive divergence occurs, with one preganglionic fiber synapsing on two dozen or more ganglionic neurons.

- Preganglionic fibers running between the sympathetic chain ganglia interconnect them, making the chain resemble a string of pearls.

- Each ganglion in the sympathetic chain innervates a particular body segment or group of segments.

**Sympathetic Chain Ganglia, p. 522**

- If a preganglionic fiber carries motor commands that target structures in the body wall or thoracic cavity, or in the head, neck, or limbs, it will synapse in one or more sympathetic chain ganglia.

- The paths of the unmyelinated postganglionic fibers differ, depending on whether their targets lie in the body wall or within the thoracic cavity:
  1. Postganglionic fibers that control visceral effectors in the body wall, head, neck, or limbs enter the gray ramus and return to the spinal nerve for subsequent distribution. These postganglionic fibers innervate effectors such as the sweat glands of the skin and the smooth muscles in superficial blood vessels.

**Figure 16-4a**

2. Postganglionic fibers innervating structures in the thoracic cavity, such as the heart and lungs, form bundles known as sympathetic nerves.

**Figure 16-4b**

- Both innervation patterns occur on each side of the body.

**Figure 16-5**

- Each sympathetic chain contains 3 cervical, 10–12 thoracic, 4–5 lumbar, and 4–5 sacral ganglia, plus 1 coccygeal ganglion. (The numbers vary due to the occasional fusion of adjacent ganglia.)

- Preganglionic neurons are limited to spinal cord segments T<sub>1</sub>-L<sub>2</sub>, and these spinal nerves have both white rami (myelinated preganglionic fibers) and gray rami (unmyelinated postganglionic fibers).
The neurons in the cervical, inferior lumbar and sacral sympathetic chain ganglia are innervated by preganglionic fibers that run along the axis of the chain. In turn, these chain ganglia provide postganglionic fibers, through gray rami, to the cervical, lumbar, and sacral spinal nerves.

As a result, although only spinal nerves T1-L2 have white rami, every spinal nerve has a gray ramus that carries sympathetic postganglionic fibers for distribution in the body wall.

About 8 percent of the axons in each spinal nerve are sympathetic postganglionic fibers.

The spinal nerves, which provide somatic motor innervation to skeletal muscles of the body wall and limbs, also distribute sympathetic postganglionic fibers.

**Figures 16-4a and 16-5**

In the head and neck, postganglionic sympathetic fibers leaving the superior cervical sympathetic ganglia supply the regions and structures innervated by cranial nerves III, VII, IX, and X.

In summary:
1. The cervical, inferior lumbar and sacral chain ganglia receive preganglionic innervation by preganglionic fibers from spinal segments T1-L2, and every spinal nerve receives a gray ramus from a ganglion of the sympathetic chain.
2. Only the thoracic and superior lumbar ganglia (T1-L2) receive preganglionic fibers from white rami.
3. Every spinal nerve receives a gray ramus from a ganglion of the sympathetic chain.

**Figures 16-3 and 16-4b**

Preganglionic fibers that innervate the collateral ganglia form the splanchnic nerves, which lie in the dorsal wall of the abdominal cavity. Although they originate as paired ganglia (left and right), the two usually fuse together, and in adults the collateral ganglia are typically single rather than paired.

Postganglionic fibers leaving the collateral ganglia extend throughout the abdominopelvic cavity, innervating a variety of visceral tissues and organs.

The abdominopelvic viscera receive sympathetic innervation via sympathetic preganglionic fibers that pass through the sympathetic chain without synapsing. They synapse in separate collateral ganglia.
The general functional pattern is
1. a reduction of blood flow and energy use by organs that are not important to short-term survival (such as the digestive tract)
2. the release of stored energy reserves

The splanchnic nerves innervate three collateral ganglia.

**Figure 16-5**

- Preganglionic fibers from the seven inferior thoracic segments end at either the celiac ganglion or the superior mesenteric ganglion. These ganglia are embedded in an extensive network of autonomic nerves.

- Preganglionic fibers from the lumbar segments form splanchnic nerves that end at the inferior mesenteric ganglion.

- All three ganglia are named for their association with adjacent arteries:
  1. The celiac ganglion commonly consists of a pair of interconnected masses of gray matter situated at the base of that artery. The celiac ganglion may also form a single mass or many small, interwoven masses. Postganglionic fibers from this ganglion innervate the stomach, liver, gallbladder, pancreas, and spleen.
  2. The superior mesenteric ganglion is located near the base of the superior mesenteric artery, which provides blood to the stomach, small intestine, and pancreas. Postganglionic fibers leaving the superior mesenteric ganglion innervate the small intestine and the proximal two-thirds of the large intestine.
  3. The inferior mesenteric ganglion is located near the base of the inferior mesenteric artery, which supplies the large intestine and other organs in the inferior portion of the abdominopelvic cavity. Postganglionic fibers from this ganglion provide sympathetic innervation to the terminal portions of the large intestine, the kidney and urinary bladder, and the sex organs.

*The Adrenal Medullae*, p. 524

- Preganglionic fibers entering an adrenal gland proceed to its center, a region called the adrenal medulla.

*Figures 16-4c and 16-5*
• The adrenal medulla is a modified sympathetic ganglion where preganglionic fibers synapse on neuroendocrine cells, specialized neurons that secrete hormones (chemical messengers) into the bloodstream.

• The neuroendocrine cells of the adrenal medullae secrete the neurotransmitters epinephrine (E) and norepinephrine (NE).

• Epinephrine, or adrenaline, accounts for 75–80 percent of the secretory output; the rest is NE, or noradrenaline.

• The bloodstream carries the neurotransmitters throughout the body, causing changes in the metabolic activities of many different cells. These effects resemble those produced by the stimulation of sympathetic postganglionic fibers, but differ in two respects:
  1. cells not innervated by sympathetic postganglionic fibers are affected as well
  2. the effects last much longer than those produced by direct sympathetic innervation, because the hormones continue to diffuse out of the bloodstream for an extended period

*Sympathetic Activation, p. 524*

• The sympathetic division can change the activities of tissues and organs by releasing NE at peripheral synapses, and by distributing E and NE throughout the body in the bloodstream.

• The visceral motor fibers that target specific effectors, such as smooth muscle fibers in blood vessels of the skin, can be activated in reflexes that do not involve other visceral effectors.

• In a crisis the entire division responds. This event, called sympathetic activation, is controlled by sympathetic centers in the hypothalamus. The effects are not limited to peripheral tissues; sympathetic activation also alters CNS activity.

• When sympathetic activation occurs, an individual experiences the following changes:
  1. Increased alertness via stimulation of the reticular activating system, causing the individual to feel “on edge.”
  2. A feeling of energy and euphoria, often associated with a disregard for danger and a temporary insensitivity to painful stimuli.
  3. Increased activity in the cardiovascular and respiratory centers of the pons and medulla oblongata, leading to elevations in blood pressure, heart rate, breathing rate, and depth of respiration.
  4. A general elevation in muscle tone through stimulation of the medial and lateral pathways, so the person looks tense and may begin to shiver.
5. The mobilization of energy reserves, through the accelerated breakdown of glycogen in muscle and liver cells and the release of lipids by adipose tissues.

- These changes, plus the peripheral changes already noted, complete the preparations necessary for the individual to cope with a stressful situation.

*Neurotransmitters and Sympathetic Function, p. 525

*Neurotransmitter Release, p. 525

- The stimulation of sympathetic preganglionic neurons leads to the release of ACh at synapses with ganglionic neurons.
- Synapses that use ACh as a transmitter are called **cholinergic**.
- The effect on the ganglionic neurons is always excitatory.
- The stimulation of these ganglionic neurons leads to the release of neurotransmitters at specific target organs.
- The synaptic terminals are typically different from neuromuscular junctions of the somatic nervous system. Instead of forming synaptic knobs, telodendria form a branching network.
- Each branch resembles a string of pearls. Each “pearl,” a swollen segment called a **varicosity**, is packed with neurotransmitter vesicles.

*Figure 16-6*

- Chains of varicosities pass along or near the surfaces of the effector cells.
- There are no specialized postsynaptic membranes, but membrane receptors are scattered across the surfaces of the target cells.
- Most sympathetic ganglionic neurons release NE at their varicosities.
- Neurons that use NE as a neurotransmitter are called **adrenergic**.
- The sympathetic division also contains a small, but significant, number of ganglionic neurons that release ACh rather than NE.
- Varicosities releasing ACh are located in the body wall, the skin, the brain, and skeletal muscles.
• The NE released by varicosities affects its targets until it is reabsorbed or inactivated by enzymes.

• 50 to 80 percent of the NE is reabsorbed by varicosities and either reused or broken down by the enzyme monoamine oxidase (MAO).

• The rest of the NE diffuses out of the area or is broken down by the enzyme catechol-O-methyltransferase (COMT) in surrounding tissues.

• In general, the effects of NE on the postsynaptic membrane persist for a few seconds, significantly longer than the 20-msec duration of ACh effects. (As usual, the responses of the target cells vary with the nature of the receptor on the postsynaptic membrane.)

• The effects of NE or E released by the adrenal medullae last even longer, because
  1. the bloodstream does not contain MAO or COMT
  2. most tissues contain relatively low concentrations of those enzymes

• After the adrenal medullae are stimulated, tissue concentrations of NE and E throughout the body may remain elevated for as long as 30 seconds, and the effects may persist for several minutes.

*Sympathetic Stimulation and the Release of NE and E, p. 525*

• The effects of sympathetic stimulation result primarily from the interactions of NE and E with adrenergic membrane receptors.

• There are two classes of sympathetic receptors: alpha receptors and beta receptors.

• Generally, norepinephrine stimulates alpha receptors to a greater degree than it does beta receptors, whereas epinephrine stimulates both classes of receptors.

• Localized sympathetic activity, involving the release of NE at varicosities, primarily affects alpha receptors located near the active varicosities.

• By contrast, generalized sympathetic activation and the release of E by the adrenal medulla affect alpha and beta receptors throughout the body.

• Alpha receptors and beta receptors are G proteins.

• The effects of stimulating such a receptor depend on the production of second messengers, intracellular intermediaries with varied functions.

• The stimulation of alpha (β) receptors activates enzymes on the inside of the cell membrane.
There are two types of alpha receptors: alpha-1 (\(\alpha_1\)) and alpha-2 (\(\alpha_2\)).

1. The function of \(\alpha_1\), the more common type of alpha receptor, is the release of intracellular calcium ions from reserves in the endoplasmic reticulum. This action generally has an excitatory effect on the target cell. For example, the stimulation of receptors on the surfaces of smooth muscle cells is responsible for the constriction of peripheral blood vessels and the closure of sphincters along the digestive tract.

2. Stimulation of \(\alpha_2\) receptors results in a lowering of cyclic-AMP (cAMP) levels in the cytoplasm. Cyclic-AMP is an important second messenger that can activate or inactivate key enzymes. This reduction generally has an inhibitory effect on the cell. The presence of \(\alpha_2\) receptors in the parasympathetic division helps coordinate sympathetic and parasympathetic activities. When the sympathetic division is active, the NE released binds to parasympathetic neuromuscular and neuroglandular junctions and inhibits their activity.

Beta (\(\beta\)) receptors are located on the membranes of cells in many organs, including skeletal muscles, the lungs, the heart, and the liver.

The stimulation of beta receptors triggers changes in the metabolic activity of the target cell. These changes occur indirectly, as each beta receptor is a G protein whose stimulation results in an increase in intracellular cAMP levels.

There are two major types of beta receptors: beta-1 (\(\beta_1\)) and beta-2 (\(\beta_2\)).

1. The stimulation of \(\beta_1\) receptors leads to an increase in metabolic activity. For example, the stimulation of receptors on skeletal muscles accelerates the metabolic activities of the muscles. The stimulation of \(\beta_1\) receptors in the heart causes increases in heart rate and force of contraction.

2. The stimulation of \(\beta_2\) receptors causes inhibition, triggering a relaxation of smooth muscles along the respiratory tract. As a result, the diameters of the respiratory passageways increase, making breathing easier. This response accounts for the effectiveness of inhalers used to treat asthma.

3. A third type of beta receptor, beta-3 (\(\beta_3\)), is found in adipose tissue. Stimulation of receptors leads to lipolysis, the breakdown of triglycerides stored within adipocytes. The fatty acids generated through lipolysis are released into the circulation for use by other tissues.

**Sympathetic Stimulation and the Release of Ach and NO, p. 526**

Although the vast majority of sympathetic postganglionic fibers are adrenergic (release NE), a few are cholinergic (release ACh). These postganglionic fibers innervate sweat glands of the skin and the blood vessels to skeletal muscles and the brain.
• The activation of these sympathetic fibers stimulates sweat gland secretion and dilates the blood vessels.

• In other regions of the body, ACh is released by the parasympathetic division rather than by the sympathetic division. However, neither the body wall nor skeletal muscles are innervated by the parasympathetic division, and in these areas both NE and ACh are needed to regulate visceral functions with precision.

• For example, whereas ACh causes dilation of most small peripheral arteries (vasodilation), NE causes their constriction (vasoconstriction).

• This means that the sympathetic division can increase blood flow to skeletal muscles, through activation of cholinergic terminals, at the same time that adrenergic terminals reduce the blood flow to other tissues in the body wall.

• The sympathetic division also includes nitroxidergic synapses, which release nitric oxide (NO) as a neurotransmitter.

• Such synapses occur where neurons innervate smooth muscles in the walls of blood vessels in many regions, notably in skeletal muscles and the brain.

• The activity of these synapses produces vasodilation and increased blood flow through these regions.

**Summary: The Sympathetic Division, p. 526**

• To summarize our discussion of the sympathetic division:
  1. The sympathetic division of the ANS includes two sets of sympathetic chain ganglia, one on each side of the vertebral column; three collateral ganglia anterior to the vertebral column; and two adrenal medullae.
  2. The preganglionic fibers are short, because the ganglia are close to the spinal cord. The postganglionic fibers are longer and extend a considerable distance before reaching their target organs. (In the case of the adrenal medullae, very short axons end at capillaries that carry their secretions to the bloodstream.)
  3. The sympathetic division shows extensive divergence, and a single preganglionic fiber may innervate two dozen or more ganglionic neurons in different ganglia. As a result, a single sympathetic motor neuron in the CNS can control a variety of visceral effectors and can produce a complex and coordinated response.
  4. All preganglionic neurons release ACh at their synapses with ganglionic neurons. Most postganglionic fibers release NE, but a few release ACh or NO.
  5. The effector response depends on the second messengers activated when NE or E binds to alpha receptors or beta receptors.
III. The Parasympathetic Division, p. 527

- The parasympathetic division of the ANS consists of:

**Figure 16-7**

1. *Preganglionic Neurons in the Brain Stem and in Sacral Segments of the Spinal Cord.* The mesencephalon, pons, and medulla oblongata contain autonomic nuclei associated with cranial nerves III, VII, IX, and X. In sacral segments of the spinal cord, the autonomic nuclei lie in the lateral gray horns of spinal segments S₂–S₄.

2. *Ganglionic Neurons in Peripheral Ganglia within or Adjacent to the Target Organs.* Preganglionic fibers of the parasympathetic division do not diverge as extensively as do those of the sympathetic division. A typical preganglionic fiber synapses on six to eight ganglionic neurons. These neurons may be situated in a terminal ganglion, located near the target organ, or in an intramural ganglion, which is embedded in the tissues of the target organ. Terminal ganglia are usually paired; examples include the parasympathetic ganglia associated with the cranial nerves. Intramural ganglia typically consist of interconnected masses and clusters of ganglion cells.

- In contrast to the pattern in the sympathetic division, all these ganglionic neurons are located in the same ganglion, and their postganglionic fibers influence the same target organ.

- The effects of parasympathetic stimulation are more specific and localized than are those of the sympathetic division.

*Organization and Anatomy of the Parasympathetic Division, p. 528*

**Figure 16-8**

- Parasympathetic preganglionic fibers leave the brain as components of cranial nerves III (oculomotor), VII (facial), IX (glossopharyngeal), and X (vagus). These fibers carry the cranial parasympathetic output.

- Parasympathetic fibers in the oculomotor, facial, and glossopharyngeal nerves control visceral structures in the head. These fibers synapse in the ciliary, pterygopalatine, submandibular, and otic ganglia.

- Short postganglionic fibers continue to their peripheral targets.

- The vagus nerve provides preganglionic parasympathetic innervation to structures in the neck and in the thoracic and abdominopelvic cavity as distant as the distal portion of the large intestine.
The vagus nerve alone provides roughly 75 percent of all parasympathetic outflow.

The numerous branches of the vagus nerve intermingle with preganglionic and postganglionic fibers of the sympathetic division, forming plexuses comparable to those formed by spinal nerves innervating the limbs.

The preganglionic fibers in the sacral segments of the spinal cord carry the sacral parasympathetic output. These fibers do not join the ventral roots of the spinal nerves. Instead, the preganglionic fibers form distinct pelvic nerves, which innervate intramural ganglia in the walls of the kidneys, urinary bladder, terminal portions of the large intestine, and sex organs.

Parasympathetic Activation, p. 529

The major effects produced by the parasympathetic division include the following:
1. Constriction of the pupils (to restrict the amount of light that enters the eyes) and focusing the lenses of the eyes on nearby objects.
2. Secretion by digestive glands, including salivary glands, gastric glands, duodenal glands, intestinal glands, the pancreas (exocrine and endocrine), and the liver.
3. The secretion of hormones that promote the absorption and utilization of nutrients by peripheral cells.
5. An increase in smooth muscle activity along the digestive tract.
6. The stimulation and coordination of defecation.
7. Contraction of the urinary bladder during urination.
8. Constriction of the respiratory passageways.
9. A reduction in heart rate and in the force of contraction.
10. Sexual arousal and the stimulation of sexual glands in both sexes.

These functions center on relaxation, food processing, and energy absorption.

The parasympathetic division has been called the anabolic system, because its stimulation leads to a general increase in the nutrient content of the blood. Cells throughout the body respond to this increase by absorbing nutrients and using them to support growth, cell division, and the creation of energy reserves in the form of lipids or glycogen.

Neurotransmitters and Parasympathetic Function, p. 529

All parasympathetic neurons release ACh as a neurotransmitter.
• The effects on the postsynaptic cell can vary widely due to variations in the type of receptor or the nature of the second messenger involved.

*Neurotransmitter Release, p. 529*

• The neuromuscular and neuroglandular junctions of the parasympathetic division are small and have narrow synaptic clefts.

• The effects of stimulation are short-lived, because most of the ACh released is inactivated by acetylcholinesterase (AChE) at the synapse.

• Any ACh diffusing into the surrounding tissues will be inactivated by the enzyme tissue cholinesterase, also called pseudocholinesterase.

• As a result, the effects of parasympathetic stimulation are quite localized, and they last a few seconds at most.

*Membrane Receptors and Responses, p. 529*

• Although all the synapses (neuron to neuron) and neuromuscular or neuroglandular junctions (neuron to effector) of the parasympathetic division use the same transmitter, ACh, two types of ACh receptors occur on the postsynaptic membranes:
  1. **Nicotinic receptors** are located on the surfaces of ganglion cells of both the parasympathetic and sympathetic divisions, as well as at neuromuscular junctions of the somatic nervous system. Exposure to ACh always causes excitation of the ganglionic neuron or muscle fiber by the opening of chemically gated channels in the postsynaptic membrane.
  2. **Muscarnic receptors** are located at cholinergic neuromuscular or neuroglandular junctions in the parasympathetic division, as well as at the few cholinergic junctions in the sympathetic division. Muscarinic receptors are G proteins and their stimulation produces longer-lasting effects than does the stimulation of nicotinic receptors. The response, which reflects the activation or inactivation of specific enzymes, can be excitatory or inhibitory.

• Nicotinic receptors bind nicotine, a powerful toxin that can be obtained from a variety of sources, including tobacco leaves.

• Muscarinic receptors are stimulated by muscarine, a toxin produced by some poisonous mushrooms.

• These compounds have discrete actions, targeting either the autonomic ganglia and skeletal neuromuscular junctions (nicotine) or the parasympathetic neuromuscular or neuroglandular junctions (muscarine). They produce
dangerously exaggerated, uncontrolled responses due to abnormal stimulation of cholinergic or adrenergic receptors.

- Nicotine poisoning occurs if as little as 50mg is ingested or absorbed through the skin.
  1. The signs and symptoms reflect widespread autonomic activation: vomiting, diarrhea, high blood pressure, rapid heart rate, sweating, and profuse salivation.
  2. Because the neuromuscular junctions of the somatic nervous system are stimulated, convulsions occur.
  3. In severe cases, the stimulation of nicotine receptors inside the CNS can lead to coma and death within minutes.

- The signs and symptoms of muscarine poisoning are mostly restricted to the parasympathetic division: salivation, nausea, vomiting, diarrhea, constriction of respiratory passages, low blood pressure, and an abnormally slow heart rate (bradycardia).

**Table 16-1**

*Summary: The Parasympathetic Division, p. 530*

- In summary:
  1. The parasympathetic division includes visceral motor nuclei associated with cranial nerves III, VII, IX, and X and with sacral segments S<sub>2</sub>-S<sub>4</sub>.
  2. Ganglionic neurons are located within or next to their target organs.
  3. The parasympathetic division innervates areas serviced by the cranial nerves and organs in the thoracic and abdominopelvic cavities.
  4. All parasympathetic neurons are cholinergic. Ganglionic neurons have nicotinic receptors, which are excited by ACh. Muscarinic receptors at neuromuscular or neuroglandular junctions produce either excitation or inhibition, depending on the nature of the enzymes activated with ACh binds to the receptor.
  5. The effects of the parasympathetic stimulation are generally brief and restricted to specific organs and sites.

**Key:** The preganglionic neurons of the autonomic nervous system release acetylcholine (ACh) as a neurotransmitter. The ganglionic neurons of the sympathetic division primarily release norepinephrine as a neurotransmitter (and both NE and E as hormones at the adrenal medulla). The ganglionic neurons of the parasympathetic division release ACh as a neurotransmitter.

IV. Interactions between the Sympathetic and Parasympathetic Divisions, p. 531

*Figure 16-9*
Table 16-2

- The sympathetic division has widespread impact, reaching organs and tissues throughout the body.

- The parasympathetic division innervates only visceral structures that are serviced by the cranial nerves or that lie within the abdominopelvic cavity.

- Although some organs are innervated by just one division, most vital organs receive dual innervation, receiving instructions from both the sympathetic and parasympathetic divisions.

- Where dual innervation exists, the two divisions commonly have opposing effects.

- Dual innervation with opposing effects is most evident in the digestive tract, heart, and lungs. At other sites, the responses may be separate or complementary.

Table 16-3

Anatomy of Dual Innervation, p. 531

- Parasympathetic postganglionic fibers from the ciliary, pterygopalatine, submandibular, and otic ganglia of the head accompany the cranial nerves to their peripheral destinations.

- The sympathetic innervation reaches the same structures by traveling directly from the superior cervical ganglia of the sympathetic chain.

- In the thoracic and abdominopelvic cavities, the sympathetic postganglionic fibers mingle with parasympathetic preganglionic fibers, forming a series of nerve networks collectively called autonomic plexuses: the cardiac plexus, the pulmonary plexus, the esophageal plexus, the celiac plexus, the inferior mesenteric plexus, and the hypogastric plexus.

Figure 16-10

- Nerves leaving these networks travel with the blood vessels and lymphatic vessels that supply visceral organs.

- Autonomic fibers entering the thoracic cavity intersect at the cardiac plexus and the pulmonary plexus. These plexuses contain sympathetic and parasympathetic fibers bound for the heart and lungs, respectively, as well as the parasympathetic ganglia whose output affects those organs.
• The esophageal plexus contains descending branches of the vagus nerve and splanchnic nerves leaving the sympathetic chain on either side.

• Parasympathetic preganglionic fibers of the vagus nerve enter the abdominopelvic cavity with the esophagus. There the fibers enter the celiac plexus, also known as the solar plexus.

• The celiac plexus and associated smaller plexuses, such as the inferior mesenteric plexus, innervate viscera within the abdominal cavity.

• The hypogastric plexus contains the parasympathetic outflow of the pelvic nerves, sympathetic postganglionic fibers from the inferior mesenteric ganglion, and splanchnic nerves from the sacral sympathetic chain.

• The hypogastric plexus innervates the digestive, urinary, and reproductive organs of the pelvic cavity.

*Autonomic Tone, p. 533*

• Even in the absence of stimuli, autonomic motor neurons show a resting level of spontaneous activity.

• The background level of activation determines an individual’s autonomic tone.

• Autonomic tone is an important aspect of ANS function, just as muscle tone is a key aspect of SNS function.

• If a nerve is absolutely inactive under normal conditions, then all it can do is increase its activity on demand. But if the nerve maintains a background level of activity, it can increase or decrease its activity, providing a greater range of control options.

• Autonomic tone is significant where dual innervation occurs and the two ANS divisions have opposing effects.

• Autonomic tone is even more important in situations in which dual innervation does not occur.

• The heart receives dual innervation (cardiac muscle tissue, triggered by specialized pacemaker cells).

• The two autonomic divisions have opposing effects on heart function.

• Acetylcholine released by postganglionic fibers of the parasympathetic division causes a reduction in heart rate, whereas NE released by varicosities of the sympathetic division accelerates heart rate.
• Because autonomic tone is present, small amounts of both of these neurotransmitters are released continuously.

• Parasympathetic innervation dominates under resting conditions.

• Heart rate can be controlled very precisely to meet the demands of active tissues through small adjustments in the balance between parasympathetic stimulation and sympathetic stimulation.

• In a crisis, stimulation of the sympathetic innervation and inhibition of the parasympathetic innervation accelerate the heart rate to the maximum extent possible.

• The sympathetic control of blood vessel diameter demonstrates how autonomic tone allows fine adjustment of peripheral activities when the target organ is not innervated by both ANS divisions.

• Blood flow to specific organs must be controlled to meet the tissue demands for oxygen and nutrients.

• When a blood vessel dilates, blood flow through it increases; when it constricts, blood flow is reduced.

• Sympathetic postganglionic fibers that release NE innervate the smooth muscle cells in the walls of peripheral vessels.

• The background sympathetic tone keeps these muscles partially contracted, so the blood vessels are ordinarily at roughly half their maximum diameter.

• When increased blood flow is needed, the rate of NE release decreases and sympathetic cholinergic fibers are stimulated.

• The smooth muscle cells relax, the vessels dilate, and blood flow increases.

• By adjusting sympathetic tone and the activity of cholinergic fibers, the sympathetic division can exert precise control of vessel diameter over its entire range.

V. Integration and Control of Autonomic Functions, p. 534

• Centers involved in somatic motor control are found in all portions of the CNS.
• The lowest level of regulatory control consists of the lower motor neurons involved in cranial and spinal reflex arcs.

• The highest level consists of the pyramidal motor neurons of the primary motor cortex, operating with the feedback from the cerebellum and basal nuclei.

• The ANS is also organized into a series of interacting levels.

• At the bottom are visceral motor neurons in the lower brain stem and spinal cord that are involved in cranial and spinal visceral reflexes.

• Visceral reflexes provide automatic motor responses that can be modified, facilitated, or inhibited by higher centers, especially those of the hypothalamus.
  1. For example, when a light is shined in one of your eyes, a visceral reflex constricts the pupils of both eyes (the consensual light reflex).

• The visceral motor commands are distributed by parasympathetic fibers.

• In darkness, your pupils dilate; this pupillary reflex is directed by sympathetic postganglionic fibers.

• However, the motor nuclei directing pupillary constriction or dilation are also controlled by hypothalamic centers concerned with emotional states.
  1. When you are queasy or nauseated, your pupils constrict; when you are sexually aroused, your pupils dilate.

*Visceral Reflexes*, p. 535

• Each *visceral reflex arc* consists of a receptor, a sensory neuron, a processing center (one or more interneurons), and two visceral motor neurons.

*Figure 16-11*

• All visceral reflexes are polysynaptic; they are either long reflexes or short reflexes.

• *Long reflexes* are the autonomic equivalents of the polysynaptic reflexes.

• Visceral sensory neurons deliver information to the CNS along the dorsal roots of spinal nerves, within the sensory branches of cranial nerves, and within the autonomic nerves that innervate visceral effectors.

• The processing steps involve interneurons within the CNS, and the ANS carries the motor commands to the appropriate visceral effectors.
• **Short reflexes** bypass the CNS entirely; they involve sensory neurons and interneurons whose cell bodies are located within autonomic ganglia.

• The interneurons synapse on ganglionic neurons, and the motor commands are then distributed by postganglionic fibers.

• Short reflexes control very simple motor responses with localized effects.

• In general, short reflexes may control patterns of activity in one small part of a target organ, whereas long reflexes coordinate the activities of an entire organ.

• In most organs, long reflexes are most important in regulating visceral activities, but this is not the case with the digestive tract and its associated glands. In these areas, short reflexes provide most of the control and coordination required for normal functioning.

• The neurons involved form the enteric nervous system.

• The ganglia in the walls of the digestive tract contain the cell bodies of visceral sensory neurons, interneurons, and visceral motor neurons, and their axons form extensive nerve nets.

• Although parasympathetic innervation of the visceral motor neurons can stimulate and coordinate various digestive activities, the enteric nervous system is quite capable of controlling digestive functions independent of the central nervous system.

*Table 16-4*

• The parasympathetic division participates in a variety of reflexes that affect individual organs and systems. This specialization reflects the relatively specific and restricted pattern of innervation.

• In contrast, fewer sympathetic reflexes exist.

• The sympathetic division is typically activated as a whole, in part because it has such a high degree of divergence and in part because the release of hormones by the adrenal medullae produces widespread peripheral effects.

*Higher Levels of Autonomic Control, p. 535*

• The levels of activity in the sympathetic and parasympathetic divisions of the ANS are controlled by centers in the brain stem that regulate specific visceral functions.
• As in the SNS, in the ANS simple reflexes based in the spinal cord provide relatively rapid and automatic responses to stimuli.

• More complex sympathetic and parasympathetic reflexes are coordinated by processing centers in the medulla oblongata.

• In addition to the cardiovascular and respiratory centers, the medulla oblongata contains centers and nuclei involved with salivation, swallowing, digestive secretions, peristalsis, and urinary function. These centers are in turn subject to regulation by the hypothalamus.

• Because the hypothalamus interacts with all other portions of the brain, activity in the limbic system, thalamus, or cerebral cortex can have dramatic effects on autonomic function.
  1. For example, when you become angry, your heart rate accelerates, your blood pressure rises, and your respiratory rate increases
  2. When you remember your last big dinner, your stomach “growls” and your mouth waters.

*The Integration of SNS and ANS Activities*, p. 536

**Figure 16-12**

**Table 16-5**

• Although we have considered somatic and visceral motor pathways separately, the two have many parallels, in terms of both organization and function.

• Integration occurs at the level of the brain stem, and both systems are under the control of higher centers.

**VI. Higher-Order Functions, p. 537**

• Higher-order functions share three characteristics:
  1. The cerebral cortex is required for their performance, and they involve complex interactions among areas of the cortex and between the cerebral cortex and other areas of the brain.
  2. They involve both conscious and unconscious information processing.
  3. They are not part of the programmed “wiring” of the brain; therefore, the functions are subject to modification and adjustment over time.

*Memory*, p. 537

• Memories are stored bits of information gathered through experience.
• **Fact memories** are specific bits of information
  1. such as the color of a stop sign or the smell of a perfume

• **Skill memories** are learned motor behaviors.
  1. You can probably remember how to light a match or open a screw-top jar, for example.

• With repetition, skill memories become incorporated at the unconscious level.
  1. Examples include the complex motor patterns involved in skiing, playing the violin, and similar activities.

• Skill memories related to programmed behaviors, such as eating, are stored in appropriate portions of the brain stem.

• Complex skill memories involve the integration of motor patterns in the basal nuclei, cerebral cortex, and cerebellum.

• Two classes of memories are recognized.
  1. **Short-term memories**, or primary memories, do not last long, but while they persist the information can be recalled immediately. Primary memories contain small bits of information, such as a person’s name or a telephone number. Repeating a phone number or other bit of information reinforces the original short-term memory and helps ensure its conversion to a long-term memory.
  2. **Long-term memories** last much longer, in some cases for an entire lifetime.

• The conversion from short-term to long-term memory is called memory consolidation.

• There are two types of long-term memory:
  1. Secondary memories are long-term memories that fade with time and may require considerable effort to recall.
  2. Tertiary memories are long-term memories that are with you for a lifetime, such as your name or the contours of your own body.

**Figure 16-13**

*Brain Regions Involved in Memory Consolidation and Access, p. 538*

• The amygdaloid body and the hippocampus, two components of the limbic system, are essential to memory consolidation.

**Figure 14-11**
• Damage to the hippocampus leads to an inability to convert short-term memories to new long-term memories, although existing long-term memories remain intact and accessible.

• Tracts leading from the amygdaloid body to the hypothalamus may link memories to specific emotions.

• The nucleus basalis, a cerebral nucleus near the diencephalon, plays an uncertain role in memory storage and retrieval.

• Tracts connect this nucleus with the hippocampus, amygdaloid body, and all areas of the cerebral cortex.

• Damage to this nucleus is associated with changes in emotional states, memory, and intellectual function.

• Most long-term memories are stored in the cerebral cortex.

• Conscious motor and sensory memories are referred to the appropriate association areas.
  1. For example, visual memories are stored in the visual association area, and memories of voluntary motor activity are stored in the premotor cortex.

• Special portions of the occipital and temporal lobes are crucial to the memories of faces, voices, and words.

• In at least some cases, a specific memory probably depends on the activity of a single neuron.
  1. For example, in one portion of the temporal lobe an individual neuron responds to the sound of one word and ignores others.

• A specific neuron may also be activated by the proper combination of sensory stimuli associated with a particular individual, such as your grandmother. As a result, these neurons are called “grandmother cells.”

• Information on one subject is parceled out to many different regions of the brain.

• Your memories of cows are stored in:
  1. the visual association area (what a cow looks like, that the letters c-o-w mean “cow”)
  2. the auditory association area (the “moo” sound and how the word cow sounds)
  3. the speech center (how to say the word cow)
  4. the frontal lobes (how big cows are, what they eat)
  5. Related information, such as how you feel about cows and what milk tastes like, is stored in other locations.
• If one of those storage areas is damaged, your memory will be incomplete in some way.

• How these memories are accessed and assembled on demand remains a mystery.

_Cellular Mechanisms of Memory Formation and Storage, p. 538_

• Memory consolidation at the cellular level involves anatomical and physiological changes in neurons and synapses.

• Research on animals, commonly those with relatively simple nervous systems, has indicated that the following mechanisms may be involved:
  1. **Increased Neurotransmitter Release.** A synapse that is frequently active increases the amount of neurotransmitter it stores, and it releases more with each stimulation. The more neurotransmitter released, the greater the effect on the postsynaptic neuron.
  2. **Facilitation at Synapses.** When a neural circuit is repeatedly activated, the synaptic terminals begin continuously releasing neurotransmitter in small quantities. The neurotransmitter binds to receptors on the postsynaptic membrane, producing a graded depolarization that brings the membrane closer to threshold. The facilitation that results affects all neurons in the circuit.
  3. **The Formation of Additional Synaptic Connections.** Evidence indicates that when one neuron repeatedly communicates with another, the axon tip branches and forms additional synapses on the postsynaptic neuron. As a result, the presynaptic neuron will have a greater effect on the transmembrane potential of the postsynaptic neuron.

• These processes create anatomical changes that facilitate communication along a specific neural circuit. This facilitated communication is thought to be the basis of memory storage.

• A single circuit that corresponds to a single memory has been called a memory engram. This definition is based on function rather than structure; we know too little about the organization and storage of memories to be able to describe the neural circuits involved.

• Memory engrams form as the result of experience and repetition.

• Repetition is crucial. Efficient conversion of a short-term memory into a memory engram takes time, usually at least an hour.

• Whether that conversion will occur depends on several factors, including the nature, intensity, and frequency of the original stimulus.
• Very strong, repeated, or exceedingly pleasant or unpleasant events are most likely to be converted to long-term memories.

• Drugs that stimulate the CNS, such as caffeine and nicotine, may enhance memory consolidation through facilitation.

• The hippocampus plays a key role in the consolidation of memories.

• The mechanism, which remains unknown, is linked to the presence of NMDA (N-methyl D-aspartate) receptors, which are chemically gated calcium channels.

• When activated by the neurotransmitter glycine, the gates open and calcium enters the cell.

• Blocking NMDA receptors in the hippocampus prevents long-term memory formation.

**Key:** Memory storage involves anatomical as well as physiological changes in neurons. The hippocampus is involved in the conversion of temporary, short-term memories into durable long-term memories.

*States of Consciousness, p. 540*

• The difference between a conscious individual and an unconscious one is obvious: A conscious individual is alert and attentive; an unconscious individual is not. But, there are many gradations of each state.

• Although “conscious” implies an awareness of and attention to external events and stimuli, a healthy conscious person can be nearly asleep, wide awake, or high-strung and jumpy.

• “Unconscious” can refer to conditions ranging from the deep, unresponsive state induced by anesthesia before major surgery, to deep sleep, to the light, drifting “nod.”

• The degree of wakefulness at any moment is an indication of the level of ongoing CNS activity.

• When you are asleep, you are unconscious but can still be awakened by normal sensory stimuli.

• Healthy individuals cycle between the alert, conscious state and sleep each day.

• When CNS function becomes abnormal or depressed, the state of wakefulness can be affected.
1. An individual in a coma, for example, is unconscious and cannot be awakened, even by strong stimuli. As a result, clinicians are quick to note any change in the responsiveness of comatose patients.

Sleep, p. 540

- Two general levels of sleep are recognized, each typified by characteristic patterns of brain wave activity:

**Figure 16-14a**

1. In deep sleep, also called slow wave or non-REM (NREM) sleep, your entire body relaxes, and activity at the cerebral cortex is at a minimum. Heart rate, blood pressure, respiratory rate, and energy utilization decline by up to 30 percent.

2. During rapid eye movement (REM) sleep, active dreaming occurs, accompanied by changes in blood pressure and respiratory rate. Although the EEG resembles that of the awake state, you become even less receptive to outside stimuli than in deep sleep, and muscle tone decreases markedly. Intense inhibition of somatic motor neurons probably prevents you from physically producing the responses you envision while dreaming. The neurons controlling the eye muscles escape this inhibitory influence, and your eyes move rapidly as dream events unfold.

- Periods of REM and deep sleep alternate throughout the night, beginning with a period of deep sleep that lasts about an hour and a half.

**Figure 16-14b**

- Rapid eye movement periods initially average about 5 minutes in length, but they gradually increase to about 20 minutes over an eight-hour night.

- Each night we probably spend less than two hours dreaming, but variation among individuals is significant.

  1. For example, children devote more time to REM sleep than do adults, and extremely tired individuals have very short and infrequent REM periods.

- Sleep produces only minor changes in the physiological activities of other organs and systems, and none of these changes appear to be essential to normal function.

- The significance of sleep must lie in its impact on the CNS, but the physiological or biochemical basis remains to be determined.

- We do know that protein synthesis in neurons increases during sleep.

- Extended periods without sleep will lead to a variety of disturbances in mental function.
• Roughly 25 percent of the U.S. population experiences some form of sleep disorder.
  1. Examples of such disorders include abnormal patterns or duration of REM sleep or unusual behaviors performed while sleeping, such as sleepwalking.
  2. In some cases, these problems begin to affect the individual’s conscious activities. Slowed reaction times, irritability, and behavioral changes may result.

_Arousal and the Reticular Activating System_, p. 540

• **Arousal**, or awakening from sleep, appears to be one of the functions of the reticular formation.

• The reticular formation is especially well suited for providing “watchdog” services, because it has extensive interconnections with the sensory, motor, and integrative nuclei and pathways all along the brain stem.

• Your state of consciousness is determined by complex interactions between the reticular formation and the cerebral cortex.

• One of the most important brain stem components is a diffuse network in the reticular formation known as the **reticular activating system (RAS)**. This network extends from the medulla oblongata to the mesencephalon.

**Figure 16-15**

• The output of the RAS projects to thalamic nuclei that influence large areas of the cerebral cortex.

• When the RAS is inactive, so is the cerebral cortex; stimulation of the RAS produces a widespread activation of the cerebral cortex.

• The mesencephalic portion of the RAS appears to be the “headquarters” of the system.

• Stimulation of this area produces the most pronounced and long-lasting effects on the cerebral cortex.

• Stimulating other portions of the RAS seems to have an effect only to the degree that it changes the activity of the mesencephalic region.

• The greater the stimulation to the mesencephalic region of the RAS, the more alert and attentive the individual will be to incoming sensory information.
• The thalamic nuclei associated with the RAS may also play an important role in focusing attention on specific mental processes.

• Sleep may be ended by any stimulus sufficient to activate the reticular formation and RAS.

• Arousal occurs rapidly, but the effects of a single stimulation of the RAS last less than a minute.

• Thereafter, consciousness can be maintained by positive feedback, because activity in the cerebral cortex, basal nuclei, and sensory and motor pathways will continue to stimulate the RAS.

• After many hours of activity, the reticular formation becomes less responsive to stimulation.

• The individual becomes less alert and more lethargic.

• The precise mechanism remains unknown, but neural fatigue probably plays a relatively minor role in the reduction of RAS activity.

• Evidence suggests that the regulation of awake–asleep cycles involves interplay between brain stem nuclei that use different neurotransmitters.

• One group of nuclei stimulates the RAS with norepinephrine and maintains the awake, alert state. The other group, which depresses RAS activity with serotonin, promotes deep sleep.

• These “dueling” nuclei are located in the brain stem.

**Key:** An individual’s state of consciousness is variable and complex, ranging from energized and “hyper” to unconscious and comatose. During deep sleep, all metabolic functions are significantly reduced; during REM sleep, muscular activities are inhibited while cerebral activity is similar to that seen in awake individuals. Sleep disorders result in abnormal reaction times, mood swings, and behaviors. Awakening occurs when the reticular activating system becomes active; the greater the level of activity, the more alert the individual.

**VII. Brain Chemistry and Behavior, p. 541**

• Changes in the normal balance between two or more neurotransmitters can profoundly affect brain function.
1. For example, the interplay between populations of neurons releasing serotonin and norepinephrine appears to be involved in the regulation of awake–asleep cycles.

2. Another example concerns Huntington’s disease. The primary problem in this inherited disease is the destruction of ACh-secreting and GABA-secreting neurons in the basal nuclei.
   • The reason for this destruction is unknown.
   • Symptoms appear as the basal nuclei and frontal lobes slowly degenerate.
   • An individual with Huntington’s disease has difficulty controlling movements, and intellectual abilities gradually decline.

   • In many cases, the importance of a specific neurotransmitter has been revealed during the search for a mechanism for the effects of administered drugs. Here are two examples:
     1. Lysergic acid diethylamide (LSD) is a powerful hallucinogenic drug that activates serotonin receptors in the brain stem, hypothalamus, and limbic system.
        • Compounds that merely enhance the effects of serotonin also produce hallucinations, whereas compounds that inhibit serotonin production or block its action cause severe depression and anxiety.
        • The most effective anti-depressive drug now in widespread use, fluoxetine (Prozac), slows the removal of serotonin at synapses, causing an increase in serotonin concentrations at the postsynaptic membrane.
        • Such drugs are classified as selective serotonin reuptake inhibitors (SSRIs).
        • Other important SSRIs include Celexa, Luvox, Paxil, and Zoloft.
        • It is now clear that an extensive network of tracts delivers serotonin to nuclei and higher centers throughout the brain, and variations in serotonin levels affect sensory interpretation and emotional states.
     2. Inadequate dopamine production causes the motor problems of Parkinson’s disease.
        • Amphetamines, or “speed,” stimulate dopamine secretion and, in large doses, can produce symptoms resembling those of schizophrenia, a psychological disorder marked by pronounced disturbances of mood, thought patterns, and behavior.
        • Dopamine is thus important not only in the nuclei involved in the control of intentional movements, but in many other centers of the diencephalon and cerebrum.
• Anatomical and physiological changes begin shortly after maturity (probably by age 30) and accumulate over time.

• Although an estimated 85 percent of people above age 65 lead relatively normal lives, they exhibit noticeable changes in mental performance and in CNS function.

• Common age-related anatomical changes in the nervous system include the following:
  1. **A Reduction in Brain Size and Weight.** This reduction results primarily from a decrease in the volume of the cerebral cortex. The brains of elderly individuals have narrower gyri and wider sulci than do those of young people, and the subarachnoid space is larger.
  2. **A Reduction in the Number of Neurons.** Brain shrinkage has been linked to a loss of cortical neurons, although evidence indicates that neuronal loss does not occur (at least to the same degree) in brain stem nuclei.
  3. **A Decrease in Blood Flow to the Brain.** With age, fatty deposits gradually accumulate in the walls of blood vessels. Just as a clog in a drain reduces water flow, these deposits reduce the rate of blood flow through arteries. (This process, called arteriosclerosis, affects arteries throughout the body.) Even if the reduction in blood flow is not sufficient to damage neurons, it increases the chances that the affected vessel wall will rupture, damaging the surrounding neural tissue and producing symptoms of a cerebrovascular accident (CVA), or stroke.
  4. **Changes in the Synaptic Organization of the Brain.** In many areas, the number of dendritic branches, spines, and interconnections appears to decrease. Synaptic connections are lost, and the rate of neurotransmitter production declines.
  5. **Intracellular and Extracellular Changes in CNS Neurons.** Many neurons in the brain accumulate abnormal intracellular deposits, including lipofuscin and neurofibrillary tangles.
    - **Lipofuscin** is a granular pigment with no known function.
    - **Neurofibrillary tangles** are masses of neurofibrils that form dense mats inside the cell body and axon.
    - **Plaques** are extracellular accumulations of fibrillar proteins, surrounded by abnormal dendrites and axons.
    - Both plaques and tangles contain deposits of several peptides—primarily two forms of amyloid (Aβ) protein—and appear in brain regions such as the hippocampus, specifically associated with memory processing.
    - The significance of these histological abnormalities is unknown.
    - Evidence indicates that they appear in all aging brains, but when present in excess, they seem to be associated with clinical abnormalities.

• These anatomical changes are linked to functional changes.
• In general, neural processing becomes less efficient with age.

• Memory consolidation typically becomes more difficult, and secondary memories, especially those of the recent past, become harder to access.

• The sensory systems of the elderly—hearing, balance, vision, smell, and taste—become less acute.
- Lights must be brighter, sounds louder, and smells stronger before they are perceived.
- Reaction times are slowed, and reflexes—even some withdrawal reflexes—waken or disappear.
- The precision of motor control decreases, and it takes longer to perform a given motor pattern than it did 20 years earlier.

• For roughly 85 percent of the elderly population, these changes do not interfere with their abilities to function in society.

• But for as yet unknown reasons, some elderly individuals become incapacitated by progressive CNS changes.

• These degenerative changes, which can include memory loss, anterograde amnesia, emotional disturbances, are often lumped together under the general heading of senile dementia, or senility.

• By far the most common and incapacitating form of senile dementia is Alzheimer’s disease.

IX. Integration with Other Systems, p. 543

• Every moment of your life, billions of neurons in your nervous system are exchanging information across trillions of synapses and performing the most complex integrative functions in the body.

• As part of this process, the nervous system monitors all other systems and issues commands that adjust their activities.

• The significance and impact of these commands varies greatly from one system to another.
  1. The normal functions of the muscular system, for example, simply cannot be performed without instructions from the nervous system.
  2. By contrast, the cardiovascular system is relatively independent—the nervous system merely coordinates and adjusts cardiovascular activities to meet the circulatory demands of other systems.
Neural tissue is extremely delicate, and the characteristics of the extracellular environment must be kept within narrow homeostatic limits.

When homeostatic regulatory mechanisms break down under the stress of genetic or environmental factors, infection, or trauma, symptoms of neurological disorders appear.

Literally hundreds of disorders affect the nervous system.

These disorders can be roughly categorized into the following groups:
1. Infections, which include diseases such as rabies and polio
2. Congenital disorders, such as spina bifida and hydrocephalus
3. Degenerative disorders, such as Parkinson’s disease and Alzheimer’s disease
4. Tumors of neural origin
5. Trauma, such as spinal cord injuries and concussions
6. Toxins, such as heavy metals and the neurotoxins found in certain seafoods
7. Secondary disorders, which are problems resulting from dysfunction in other systems; examples include strokes and several demyelination disorders

A standard physical examination includes a neurological component, which the physician uses to check the general status of the CNS and PNS.

In neurological examinations, physicians attempt to trace the source of a specific problem by evaluating the sensory, motor, behavioral, and cognitive functions of the nervous system.

SUMMARY
In Chapter 16 we learned about:

♣ Coordination of the system functions by the autonomic nervous system (ANS).
♣ The functions of preganglionic neurons in the CNS.
♣ The sympathetic division.
♣ The functions of preganglionic and postganglionic fibers.
Collateral ganglia and splanchnic nerves.

The celiac ganglion

Sympathetic activation.

The roles of neurotransmitters acetylcholine (Ach) norepinephrine (NE) and epinephrine (E).

Sympathetic ganglionic neurons and telodendria.

The two types of sympathetic receptors: alpha receptors and beta receptors.

Adrenergic, cholinergic and nitroxidergic postganglionic fibers.

Sympathetic chain ganglia, collateral ganglia and adrenal medullae.

The parasympathetic division (food processing, energy absorption).

Muscarinic and nicotinic receptors.

The autonomic plexuses (nerve networks): cardiac, pulmonary, esophageal, celiac, inferior mesenteric, and hypogastric plexuses.

Physiological and functional differences between sympathetic and parasympathetic divisions.

Visceral reflex arcs of the ANS: long reflexes (with interneurons) or short reflexes (bypassing the CNS).

Brain stem control of sympathetic and parasympathetic divisions of the ANS.

Parallel organization of SNS and ANS.

Memory: short term or long term.

Memory consolidation.

Consciousness, unconsciousness and sleep.

Age-related changes in the nervous system.