Chapter 16

The Autonomic Nervous System and Higher-Order Functions

An Introduction to the ANS and Higher-Order Functions

- Somatic Nervous System (SNS)
  - Operates under conscious control
  - Seldom affects long-term survival
  - SNS controls skeletal muscles
- Autonomic Nervous System (ANS)
  - Operates without conscious instruction
  - ANS controls visceral effectors
  - Coordinates system functions
    - Cardiovascular, respiratory, digestive, urinary, reproductive

16-1 Autonomic Nervous System

- Organization of the ANS
  - Integrative centers
    - For autonomic activity in hypothalamus
    - Neurons comparable to upper motor neurons in SNS

16-1 Autonomic Nervous System

- Organization of the ANS
  - Visceral motor neurons
    - In brain stem and spinal cord, are known as **preganglionic neurons**
    - **Preganglionic fibers**
      - Axons of preganglionic neurons
      - Leave CNS and synapse on **ganglionic neurons**

16-1 Autonomic Nervous System

- Visceral Motor Neurons
  - **Autonomic ganglia**
    - Contain many ganglionic neurons
    - Ganglionic neurons innervate visceral effectors
      - Such as cardiac muscle, smooth muscle, glands, and adipose tissue
    - **Postganglionic fibers**
      - Axons of ganglionic neurons

16-1 Divisions of the ANS

- The Autonomic Nervous System
  - Operates largely outside our awareness
  - Has two divisions
    1. **Sympathetic division**
       - Increases alertness, metabolic rate, and muscular abilities
    2. **Parasympathetic division**
       - Reduces metabolic rate and promotes digestion

16-1 Divisions of the ANS

- **Sympathetic Division**
  - Kicks in only during exertion, stress, or emergency
  - "Fight or flight"
- **Parasympathetic Division**
  - Controls during resting conditions
  - "Rest and digest"

16-1 Divisions of the ANS

- Sympathetic and Parasympathetic Division
  1. Most often, these two divisions have opposing effects
     - If the sympathetic division causes excitation, the parasympathetic causes inhibition
  2. The two divisions may also work independently
     - Only one division innervates some structures
  3. The two divisions may work together, with each controlling one stage of a complex process

16-1 Divisions of the ANS

- Sympathetic Division
  - Preganglionic fibers (thoracic and superior lumbar; thoracolumbar) synapse in ganglia near spinal cord
  - Preganglionic fibers are short
  - Postganglionic fibers are long
  - Prepares body for crisis, producing a "fight or flight" response
    - Stimulates tissue metabolism
    - Increases alertness

16-1 Divisions of the ANS

- Seven Responses to Increased Sympathetic Activity
  1. Heightened mental alertness
  2. Increased metabolic rate
  3. Reduced digestive and urinary functions

4. Energy reserves activated
5. Increased respiratory rate and respiratory passageways dilate
6. Increased heart rate and blood pressure
7. Sweat glands activated

16-1 Divisions of the ANS

- Parasympathetic Division
  - Preganglionic fibers originate in brain stem and sacral segments of spinal cord; craniosacral
  - Synapse in ganglia close to (or within) target organs
  - Preganglionic fibers are long
  - Postganglionic fibers are short
  - Parasympathetic division stimulates visceral activity
  - Conserves energy and promotes sedentary activities
  -

16-1 Divisions of the ANS

- Five Responses to Increased Parasympathetic Activity
  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 digestive tract
  5. Urination and defecation stimulation

16-1 Divisions of the ANS

- **Enteric Nervous System** (**ENS**)
  - Third division of ANS
  - Extensive network in digestive tract walls
  - Complex visceral reflexes coordinated locally
  - Roughly 100 million neurons
  - All neurotransmitters are found in the brain

16-2 The Sympathetic Division

- The Sympathetic Division
  - Preganglionic neurons located between segments T_1 and L_2 of spinal cord
  - Ganglionic neurons in ganglia near vertebral column
  - Cell bodies of preganglionic neurons in lateral gray horns
  - Axons enter ventral roots of segments

16-2 The Sympathetic Division

- Ganglionic Neurons
  - Occur in three locations

1. *Sympathetic chain ganglia*
2. *Collateral ganglia*
3. *Adrenal medullae*

16-2 The Sympathetic Division

- **Sympathetic Chain Ganglia**
  - On both sides of vertebral column
  - Control effectors:
    - In body wall
    - Inside thoracic cavity
    - In head
    - In limbs

16-2 The Sympathetic Division

- **Collateral Ganglia**
  - Are anterior to vertebral bodies
  - Contain ganglionic neurons that innervate tissues and organs in abdominopelvic cavity

16-2 The Sympathetic Division

- **Adrenal Medullae** (*Suprarenal Medullae*)
  - Very short axons
  - When stimulated, release neurotransmitters into bloodstream (not at synapse)
  - Function as hormones to affect target cells throughout body

16-2 The Sympathetic Division

- Fibers in Sympathetic Division
  - Preganglionic fibers
    - Are relatively short
    - Ganglia located near spinal cord
  - Postganglionic fibers
    - Are relatively long, except at adrenal medullae

16-2 The Sympathetic Division

- Organization and Anatomy of the Sympathetic Division
  - Ventral roots of spinal segments T_1–L_2 contain sympathetic preganglionic fibers
    - Give rise to myelinated *white ramus*
    - Carry myelinated preganglionic fibers into sympathetic chain ganglion
    - May synapse at collateral ganglia or in adrenal medullae

16-2 The Sympathetic Division

- Sympathetic Chain Ganglia
  - Preganglionic fibers
    - One preganglionic fiber synapses on many ganglionic neurons
    - Fibers interconnect sympathetic chain ganglia
    - Each ganglion innervates particular body segment(s)

16-2 The Sympathetic Division

- Sympathetic Chain Ganglia
  - Postganglionic Fibers
    - Paths of unmyelinated postganglionic fibers depend on targets

16-2 The Sympathetic Division

- Sympathetic Chain Ganglia
  - Postganglionic fibers control visceral effectors
    - In body wall, head, neck, or limbs
    - Enter *gray ramus*
    - Return to spinal nerve for distribution
  - Postganglionic fibers innervate effectors
    - Sweat glands of skin
    - Smooth muscles in superficial blood vessels

16-2 The Sympathetic Division

- Sympathetic Chain Ganglia
  - Postganglionic fibers innervating structures in thoracic cavity form bundles
    - **Sympathetic nerves**

16-2 The Sympathetic Division

- Sympathetic Chain Ganglia
  - Each sympathetic chain ganglia contains:
    - 3 cervical ganglia
    - 10–12 thoracic ganglia
    - 4–5 lumbar ganglia
    - 4–5 sacral ganglia
    - 1 coccygeal ganglion

16-2 The Sympathetic Division

- Sympathetic Chain Ganglia
  - Preganglionic neurons
    - Limited to spinal cord segments T_1–L_2
    - White rami (myelinated preganglionic fibers)

        - Innervate neurons in:
            - Cervical, inferior lumbar, and sacral sympathetic chain ganglia

16-2 The Sympathetic Division

- Sympathetic Chain Ganglia
    - Chain ganglia provide postganglionic fibers
        - Through gray rami (unmyelinated postganglionic fibers)
        - To cervical, lumbar, and sacral spinal nerves

16-2 The Sympathetic Division

- Sympathetic Chain Ganglia
    - Only spinal nerves T_1–L_2 have white rami
    - Every spinal nerve has gray ramus
        - That carries sympathetic postganglionic fibers for distribution in body wall

16-2 The Sympathetic Division

- Sympathetic Chain Ganglia
    - Postganglionic sympathetic fibers
        - In head and neck leave superior cervical sympathetic ganglia
        - Supply the regions and structures innervated by cranial nerves III, VII, IX, X

16-2 The Sympathetic Division

- **Collateral Ganglia**
    - Receive sympathetic innervation via sympathetic preganglionic fibers
    - **Splanchnic nerves**
        - Formed by preganglionic fibers that innervate collateral ganglia
        - In dorsal wall of abdominal cavity
        - Originate as paired ganglia (left and right)
        - Usually fuse together in adults

16-2 The Sympathetic Division

- Collateral Ganglia
    - Postganglionic fibers
        - Leave collateral ganglia
        - Extend throughout abdominopelvic cavity
        - Innervate variety of visceral tissues and organs
            - Reduction of blood flow and energy by organs not vital to short-term survival
            - Release of stored energy reserves

16-2 The Sympathetic Division

- Collateral Ganglia
  - Preganglionic fibers from seven inferior thoracic segments
    - End at **celiac ganglion** or **superior mesenteric ganglion**
    - Ganglia embedded in network of autonomic nerves
  - Preganglionic fibers from lumbar segments
    - Form splanchnic nerves
    - End at **inferior mesenteric ganglion**

16-2 The Sympathetic Division

- Collateral Ganglia
  - Celiac ganglion
    - Pair of interconnected masses of gray matter
    - May form single mass or many interwoven masses
    - Postganglionic fibers innervate stomach, liver, gallbladder, pancreas, and spleen

16-2 The Sympathetic Division

- Collateral Ganglia
  - **Superior mesenteric ganglion**
    - Near base of *superior mesenteric artery*
    - Postganglionic fibers innervate small intestine and proximal 2/3 of large intestine

16-2 The Sympathetic Division

- Collateral Ganglia
  - **Inferior mesenteric ganglion**
    - Near base of *inferior mesenteric artery*
    - Postganglionic fibers provide sympathetic innervation to portions of:
      - Large intestine
      - Kidney
      - Urinary bladder
      - Sex organs

16-2 The Sympathetic Division

- Adrenal Medullae
  - Preganglionic fibers entering adrenal gland proceed to center (adrenal medulla)
  - Modified sympathetic ganglion
  - Preganglionic fibers synapse on *neuroendocrine cells*
  - Specialized neurons secrete hormones into bloodstream

16-2 The Sympathetic Division

- Adrenal Medullae
  - Neuroendocrine cells
    - Secrete neurotransmitters *epinephrine* (E) and *norepinephrine* (NE)
    - Epinephrine
      - Also called *adrenaline*
      - Is 75–80 percent of secretory output
    - Remaining is norepinephrine (NE)
      - *Noradrenaline*

16-2 The Sympathetic Division

- Adrenal Medullae
  - Bloodstream carries neurotransmitters through body
  - Causing changes in metabolic activities of different cells including cells not innervated by sympathetic postganglionic fibers
  - Effects last longer
    - Hormones continue to diffuse out of bloodstream

16-2 The Sympathetic Division

- **Sympathetic Activation**
  - Change activities of tissues and organs by:
    - Releasing NE at peripheral synapses
      - Target specific effectors, smooth muscle fibers in blood vessels of skin
      - Are activated in reflexes
      - Do not involve other visceral effectors

16-2 The Sympathetic Division

- Sympathetic Activation
  - Changes activities of tissues and organs by:
    - Distributing E and NE throughout body in bloodstream
      - Entire division responds (sympathetic activation)
      - Are controlled by sympathetic centers in hypothalamus
      - Effects are not limited to peripheral tissues
      - Alters CNS activity

16-2 The Sympathetic Division

- Changes Caused by Sympathetic Activation
  - Increased alertness
  - Feelings of energy and euphoria
  - Change in breathing
  - Elevation in muscle tone

- Mobilization of energy reserves

16-3 Various Sympathetic Neurotransmitters

- Stimulation of Sympathetic Preganglionic Neurons
  - Releases ACh at synapses with ganglionic neurons
  - Excitatory effect on ganglionic neurons
- Ganglionic Neurons
  - Release neurotransmitters at specific target organs

16-3 Various Sympathetic Neurotransmitters

- Ganglionic Neurons
  - Axon terminals
    - Form branching networks of telodendria instead of synaptic terminals
    - Telodendria form sympathetic **varicosities**
      - Resemble string of pearls
      - Swollen segment packed with neurotransmitter vesicles
      - Pass along or near surface of effector cells
      - No specialized postsynaptic membranes
      - Membrane receptors on surfaces of target cells

16-3 Various Sympathetic Neurotransmitters

- Ganglionic Neurons
  - Axon terminals
    - Release NE at most varicosities
      - Called *adrenergic* neuron
    - Some ganglionic neurons release ACh instead
      - Are located in body wall, skin, brain, and skeletal muscles
      - Called *cholinergic* neurons

16-3 Various Sympathetic Neurotransmitters

- Sympathetic Stimulation and the Release of NE and E
  - Primarily from interactions of NE and E with two types of adrenergic membrane receptors
    1. **Alpha receptors** (NE more potent)
    2. **Beta receptors**
  - Activates enzymes on inside of cell membrane via G proteins

16-3 Various Sympathetic Neurotransmitters

- Sympathetic Stimulation and the Release of NE and E
  - Alpha-1 (α_1)
    - More common type of alpha receptor
    - Releases intracellular calcium ions from reserves in endoplasmic

reticulum
    - Has excitatory effect on target cell

16-3 Various Sympathetic Neurotransmitters

- Sympathetic Stimulation and the Release of NE and E
    - Alpha-2 (α_2)
        - Lowers cAMP levels in cytoplasm
        - Has inhibitory effect on the cell
        - Helps coordinate sympathetic and parasympathetic activities

16-3 Various Sympathetic Neurotransmitters

- Sympathetic Stimulation and the Release of NE and E
    - **Beta** (β) **receptors**
        - Affect membranes in many organs (skeletal muscles, lungs, heart, and liver)
        - Trigger metabolic changes in target cell
        - Stimulation increases intracellular cAMP levels

16-3 Various Sympathetic Neurotransmitters

- Three Main Types of Beta Receptors
    1. Beta-1 (β_1)
        - Increases metabolic activity
    2. Beta-2 (β_2)
        - Triggers relaxation of smooth muscles along respiratory tract
    3. Beta-3 (β_3)
        - Leads to *lipolysis*, the breakdown of triglycerides in adipocytes

16-3 Various Sympathetic Neurotransmitters

- Sympathetic Stimulation and the Release of ACh and NO
    - Cholinergic (ACh) sympathetic terminals
        - Innervate sweat glands of skin and blood vessels of skeletal muscles and brain
        - Stimulate sweat gland secretion and dilate blood vessels

16-3 Various Sympathetic Neurotransmitters

- Sympathetic Stimulation and the Release of ACh and NO
    - *Nitroxidergic* synapses
        - Release *nitric oxide* (NO) as neurotransmitter
        - Neurons innervate smooth muscles in walls of blood vessels in skeletal muscles and the brain
        - Produce vasodilation and increased blood flow

16-4 The Parasympathetic Division

- Autonomic Nuclei
  - Are contained in the mesencephalon, pons, and medulla oblongata
    - Associated with cranial nerves III, VII, IX, X
  - In lateral gray horns of spinal segments S_2–S_4

16-4 The Parasympathetic Division

- Ganglionic Neurons in Peripheral Ganglia
  - **Terminal ganglion**
    - Near target organ
    - Usually paired
  - **Intramural ganglion**
    - Embedded in tissues of target organ
    - Interconnected masses
    - Clusters of ganglion cells

16-4 The Parasympathetic Division

- Organization and Anatomy of the Parasympathetic Division
  - Parasympathetic preganglionic fibers leave brain as components of cranial nerves
    - III (oculomotor)
    - VII (facial)
    - IX (glossopharyngeal)
    - X (vagus)
  - Parasympathetic preganglionic fibers leave spinal cord at sacral level

16-4 The Parasympathetic Division

- Oculomotor, Facial, and Glossopharyngeal Nerves
  - Control visceral structures in head
  - Synapse in *ciliary*, *pterygopalatine*, *submandibular*, and *otic ganglia*
  - Short postganglionic fibers continue to their peripheral targets

16-4 The Parasympathetic Division

- Vagus Nerve
  - Provides preganglionic parasympathetic innervation to structures in:
    - Neck
    - Thoracic and abdominopelvic cavities as distant as a distal portion of large intestine
  - Provides 75 percent of all parasympathetic outflow
  - Branches intermingle with fibers of sympathetic division

16-4 The Parasympathetic Division

- Sacral Segments of Spinal Cord
  - Preganglionic fibers carry sacral parasympathetic output
  - Do not join ventral roots of spinal nerves, instead form pelvic nerves
    - **Pelvic nerves** innervate intramural ganglia in walls of kidneys, urinary bladder, portions of large intestine, and the sex organs

16-4 The Parasympathetic Division

- Parasympathetic Activation
  - Centers on relaxation, food processing, and energy absorption
  - Localized effects, last a few seconds at most

16-4 The Parasympathetic Division

- Major Effects of Parasympathetic Division
  - Constriction of the pupils
    - To restrict the amount of light that enters the eyes
    - And focusing of the lenses of the eyes on nearby objects
  - Secretion by digestive glands
    - Including salivary glands, gastric glands, duodenal glands, intestinal glands, the pancreas (exocrine and endocrine), and the liver

16-4 The Parasympathetic Division

- Major Effects of Parasympathetic Division
  - Secretion of hormones
    - That promote the absorption and utilization of nutrients by peripheral cells
  - Changes in blood flow and glandular activity
    - Associated with sexual arousal
  - Increase in smooth muscle activity
    - Along the digestive tract

16-4 The Parasympathetic Division

- Major Effects of Parasympathetic Division
  - Stimulation and coordination of defecation
  - Contraction of the urinary bladder during urination
  - Constriction of the respiratory passageways
  - Reduction in heart rate and in the force of contraction

16-5 Parasympathetic Neurons Release ACh

- Neuromuscular and Neuroglandular Junctions
  - All release ACh as neurotransmitter

- Small, with narrow synaptic clefts
- Effects of stimulation are short lived
  - Inactivated by *acetylcholinesterase* (AChE) at synapse
  - ACh is also inactivated by tissue *cholinesterase* in surrounding *tissues*

16-5 Parasympathetic Neurons Release ACh

- Membrane Receptors and Responses
  - **Nicotinic receptors**
    - On surfaces of ganglion cells (sympathetic and parasympathetic)
      - Exposure to ACh causes excitation of ganglionic neuron or muscle fiber

16-5 Parasympathetic Neurons Release ACh

- Membrane Receptors and Responses
  - **Muscarinic receptors**
    - At cholinergic neuromuscular or neuroglandular junctions (parasympathetic)
    - At few cholinergic junctions (sympathetic)
    - G proteins
      - Effects are longer lasting than nicotinic receptors
      - Response reflects activation or inactivation of specific enzymes
      - Can be excitatory or inhibitory

16-5 Parasympathetic Neurons Release ACh

- Dangerous Environmental Toxins
  - Produce exaggerated, uncontrolled responses
  - *Nicotine*
    - Binds to *nicotinic* receptors
    - Targets autonomic ganglia and skeletal neuromuscular junctions
    - 50 mg ingested or absorbed through skin
    - Signs and symptoms:
      - Vomiting, diarrhea, high blood pressure, rapid heart rate, sweating, profuse salivation, convulsions
    - May result in coma or death

16-5 Parasympathetic Neurons Release ACh

- Dangerous Environmental Toxins
  - Produce exaggerated, uncontrolled responses
  - *Muscarine*
    - Binds to *muscarinic* receptors
    - Targets parasympathetic neuromuscular or neuroglandular junctions
    - Signs and symptoms:
      - Salivation, nausea, vomiting, diarrhea, constriction of respiratory

passages, low blood pressure, slow heart rate (bradycardia)

16-6 Dual Innervation

- Sympathetic Division
  - Widespread impact
  - Reaches organs and tissues throughout body
- Parasympathetic Division
  - Innervates only specific visceral structures
- Sympathetic and Parasympathetic Division
  - Most vital organs receive instructions from both sympathetic and parasympathetic divisions
  - Two divisions commonly have opposing effects

16-6 Dual Innervation

- Anatomy of **Dual Innervation**
  - Parasympathetic postganglionic fibers accompany cranial nerves to peripheral destinations
  - Sympathetic innervation reaches same structures
    - By traveling directly from superior cervical ganglia of sympathetic chain

16-6 Dual Innervation

- Anatomy of Dual Innervation
  - *Autonomic plexuses*
    - Nerve networks in the thoracic and abdominopelvic cavities
      - Are formed by mingled sympathetic postganglionic fibers and parasympathetic preganglionic fibers
    - Travel with blood and lymphatic vessels that supply visceral organs

16-6 Dual Innervation

- Anatomy of Dual Innervation
  - **Cardiac plexus**
  - **Pulmonary plexus**
  - **Esophageal plexus**
  - **Celiac plexus**
  - **Inferior mesenteric plexus**
  - **Hypogastric plexus**

16-6 Dual Innervation

- **Cardiac** and **Pulmonary Plexuses**
  - Autonomic fibers entering thoracic cavity intersect
  - Contain:
    - Sympathetic and parasympathetic fibers for heart and lungs

        - Parasympathetic ganglia whose output affects those organs

16-6 Dual Innervation

- **Esophageal Plexus**
    - Contains:
        - Descending branches of vagus nerves
        - Splanchnic nerves leaving sympathetic chain
    - Parasympathetic preganglionic fibers of vagus nerve enter abdominopelvic cavity with esophagus
    - Fibers enter celiac plexus (solar plexus)

16-6 Dual Innervation

- **Celiac Plexus**
    - Associated with smaller plexuses, such as **inferior mesenteric plexus**
    - Innervates viscera within abdominal cavity

16-6 Dual Innervation

- **Hypogastric Plexus**
    - Contains:
        - Parasympathetic outflow of pelvic nerves
        - Sympathetic postganglionic fibers from inferior mesenteric ganglion
        - Splanchnic nerves from sacral sympathetic chain
    - Innervates digestive, urinary, and reproductive organs of pelvic cavity

16-6 Dual Innervation

- **Autonomic Tone**
    - Is an important aspect of ANS function
        - If nerve is inactive under normal conditions, can only increase activity
        - If nerve maintains background level of activity, can increase or decrease activity

16-6 Dual Innervation

- Autonomic Tone
    - Autonomic motor neurons
        - Maintain resting level of spontaneous activity
        - Background level of activation determines autonomic tone

16-6 Dual Innervation

- Autonomic Tone
    - Significant where dual innervation occurs
        - Two divisions have opposing effects

- More important when dual innervation does not occur

16-6 Dual Innervation

- The Heart Receives Dual Innervation
  - Two divisions have opposing effects on heart function
    1. Parasympathetic division
       - Acetylcholine released by postganglionic fibers slows heart rate
    2. Sympathetic division
       - NE released by varicosities accelerates heart rate
    - Balance between two divisions
      - Autonomic tone is present
      - Releases small amounts of both neurotransmitters continuously

16-6 Dual Innervation

- The Heart Receives Dual Innervation
  - Parasympathetic innervation dominates under resting conditions
    - Crisis accelerates heart rate by:
      - Stimulation of sympathetic innervation
      - Inhibition of parasympathetic innervation

16-6 Dual Innervation

- Autonomic Tone
  - Blood vessel dilates and blood flow increases
  - Blood vessel constricts and blood flow is reduced
  - Sympathetic postganglionic fibers release NE
    - Innervate smooth muscle cells in walls of peripheral vessels

16-6 Dual Innervation

- Autonomic Tone
  - Background sympathetic tone keeps muscles partially contracted
  - To increase blood flow:
    - Rate of NE release decreases
    - Sympathetic cholinergic fibers are stimulated
    - Smooth muscle cells relax
    - Vessels dilate and blood flow increases

16-7 Visceral Reflexes Regulate the ANS

- Somatic Motor Control
  - Centers in all portions of CNS
  - Lowest level regulatory control
    - Lower motor neurons of cranial and spinal visceral reflex arcs
  - Highest level

        - Pyramidal motor neurons of primary motor cortex
        - Operating with feedback from cerebellum and basal nuclei

16-7 Visceral Reflexes Regulate the ANS

- **Visceral Reflexes**
    - Provide automatic motor responses
    - Can be modified, facilitated, or inhibited by higher centers, especially hypothalamus
    - **Visceral reflex arc**
        - Receptor
        - Sensory neuron
        - Processing center (one or more interneurons)
            - All polysynaptic
        - Two visceral motor neurons

16-7 Visceral Reflexes Regulate the ANS

- Visceral Reflexes
    - **Long reflexes**
        - Autonomic equivalents of polysynaptic reflexes
        - Visceral sensory neurons deliver information to CNS along dorsal roots of spinal nerves
            - Within sensory branches of cranial nerves
            - Within autonomic nerves that innervate visceral effectors
        - ANS carries motor commands to visceral effectors
        - Coordinate activities of entire organ

16-7 Visceral Reflexes Regulate the ANS

- Visceral Reflexes
    - **Short reflexes**
        - Bypass CNS
        - Involve sensory neurons and interneurons located within autonomic ganglia
        - Interneurons synapse on ganglionic neurons
        - Motor commands distributed by postganglionic fibers
        - Control simple motor responses with localized effects
        - One small part of target organ

16-7 Visceral Reflexes Regulate the ANS

- Visceral Reflexes
    - Regulating visceral activity
        - Most organs
            - Long reflexes most important
        - Digestive tract

- Short reflexes provide most control and coordination

16-7 Visceral Reflexes Regulate the ANS

- Visceral Reflexes
  - *Enteric nervous system*
    - Ganglia in the walls of digestive tract contain cell bodies of:
      - Visceral sensory neurons
      - Interneurons
      - Visceral motor neurons
    - Axons form extensive nerve nets
    - Control digestive functions independent of CNS

16-7 Visceral Reflexes Regulate the ANS

- Higher Levels of Autonomic Control
  - Simple reflexes from spinal cord provide rapid and automatic responses
  - Complex reflexes coordinated in medulla oblongata
    - Contains centers and nuclei involved in:
      - Salivation
      - Swallowing
      - Digestive secretions
      - Peristalsis
      - Urinary function
    - Regulated by hypothalamus

16-7 Visceral Reflexes Regulate the ANS

- The Integration of SNS and ANS Activities
  - Many parallels in organization and function
  - Integration at brain stem
  - Both systems under control of higher centers

16-8 Higher-Order Functions

- Higher-Order Functions Share Three Characteristics
  1. Require the cerebral cortex
  2. Involve conscious and unconscious information processing
  3. Are not part of programmed “wiring” of brain
     - Can adjust over time

16-8 Higher-Order Functions

- Memory
  - **Fact memories**
    - Are specific bits of information
  - **Skill memories**

        - Learned motor behaviors
        - Incorporated at unconscious level with repetition
        - Programmed behaviors stored in appropriate area of brain stem
        - Complex skill memories are stored and involve motor patterns in the basal nuclei, cerebral cortex, and cerebellum

16-8 Higher-Order Functions

- Memory
    - **Short-term memories**
        - Information that can be recalled immediately
        - Contain small bits of information
        - *Primary memories*

16-8 Higher-Order Functions

- Memory
    - **Long-term memories**
        - **Memory consolidation** – conversion from short-term to long-term memory
        - Two types of long-term memory
            1. *Secondary memories* fade and require effort to recall
            2. *Tertiary memories* are with you for life

16-8 Higher-Order Functions

- Brain Regions Involved in Memory Consolidation and Access
    - Amygdaloid body and hippocampus
    - Nucleus basalis
    - Cerebral cortex

16-8 Higher-Order Functions

- Amygdaloid Body and Hippocampus
    - Are essential to memory consolidation
    - Damage may cause:
        - Inability to convert short-term memories to new long-term memories
        - Existing long-term memories remain intact and accessible

16-8 Higher-Order Functions

- **Nucleus Basalis**
    - Cerebral nucleus near diencephalon
    - Plays uncertain role in memory storage and retrieval
    - Tracts connect with hippocampus, amygdaloid body, and cerebral cortex
    - Damage changes emotional states, memory, and intellectual functions

16-8 Higher-Order Functions

- Cerebral Cortex
  - Stores long-term memories
  - Conscious motor and sensory memories referred to association areas
  - Occipital and temporal lobes
    - Special portions crucial to memories of faces, voices, and words
    - A specific neuron may be activated by combination of sensory stimuli associated with particular individual; called “grandmother cells”

16-8 Higher-Order Functions

- Cerebral Cortex
  - Visual association area
  - Auditory association area
  - Speech center
  - Frontal lobes
  - Related information stored in other locations
    - If storage area is damaged, memory will be incomplete

16-8 Higher-Order Functions

- Cellular Mechanisms of Memory Formation and Storage
  - Involves anatomical and physiological changes in neurons and synapses
    - *Increased neurotransmitter release*
    - *Facilitation at synapses*
    - *Formation of additional synaptic connections*

16-8 Higher-Order Functions

- *Increased Neurotransmitter Release*
  - Frequently active synapse increases the amount of neurotransmitter it stores
  - Releases more on each stimulation
  - The more neurotransmitter released, the greater effect on postsynaptic neuron

16-8 Higher-Order Functions

- *Facilitation at Synapses*
  - Neural circuit repeatedly activated
  - Synaptic terminals begin continuously releasing neurotransmitter
  - Neurotransmitter binds to receptors on postsynaptic membrane
  - Produces graded depolarization
  - Brings membrane closer to threshold
  - Facilitation results affect all neurons in circuit

16-8 Higher-Order Functions

- *Formation of Additional Synaptic Connections*
  - Neurons repeatedly communicating
  - Axon tip branches and forms additional synapses on postsynaptic neuron
  - Presynaptic neuron has greater effect on transmembrane potential of postsynaptic neuron

16-8 Higher-Order Functions

- Cellular Mechanisms of Memory Formation and Storage
  - Basis of memory storage
    - Processes create anatomical changes
    - Facilitate communication along specific neural circuit
  - **Memory Engram**
    - Single circuit corresponds to single memory
    - Forms as result of experience and repetition

16-8 Higher-Order Functions

- Cellular Mechanisms of Memory Formation and Storage
  - Efficient conversion of short-term memory
    - Takes at least 1 hour
    - Repetition crucial
  - Factors of conversion
    - Nature, intensity, and frequency of original stimulus
    - Strong, repeated, and exceedingly pleasant or unpleasant events likely converted to long-term memories

16-8 Higher-Order Functions

- Cellular Mechanisms of Memory Formation and Storage
  - Drugs stimulate CNS
    - Caffeine and nicotine are examples
      - Enhance memory consolidation through facilitation

16-8 Higher-Order Functions

- Cellular Mechanisms of Memory Formation and Storage
  - Drugs stimulate CNS
    - *NMDA* (*N-methyl D-aspartate*) *Receptors*
      - Linked to consolidation
      - Chemically gated calcium channels
      - Activated by neurotransmitter *glutamate*
      - Gates open, calcium enters cell
      - Blocking NMDA receptors in hippocampus prevents long-term memory formation

16-8 Higher-Order Functions

- States of Consciousness
  - Many gradations of states
  - Degree of wakefulness indicates level of ongoing CNS activity
  - When abnormal or depressed, state of wakefulness is affected
  -

16-8 Higher-Order Functions

- States of Consciousness
  - **Deep sleep**
    - Also called *slow-wave* or *Non-REM* (*NREM*) sleep
    - Entire body relaxes
    - Cerebral cortex activity minimal
    - Heart rate, blood pressure, respiratory rate, and energy utilization decline up to 30 percent

16-8 Higher-Order Functions

- States of Consciousness
  - **Rapid eye movement** (**REM**) **sleep**
    - Active dreaming occurs
    - Changes in blood pressure and respiratory rate
    - Less receptive to outside stimuli than in deep sleep
    - Muscle tone decreases markedly
    - Intense inhibition of somatic motor neurons
    - Eyes move rapidly as dream events unfold

16-8 Higher-Order Functions

- States of Consciousness
  - Nighttime sleep pattern
    - Alternates between levels
    - Begins in deep sleep
    - REM periods average 5 minutes in length; increase to 20 minutes over 8 hours

16-8 Higher-Order Functions

- Sleep
  - Has important impact on CNS
  - Produces only minor changes in physiological activities of organs and systems
  - Protein synthesis in neurons increases during sleep
  - Extended periods without sleep lead to disturbances in mental function
  - 25 percent of the U.S. population experiences *sleep disorders*

16-8 Higher-Order Functions

- States of Consciousness
  - **Arousal** and the **reticular activating system** (**RAS**)
    - Awakening from sleep
    - Function of reticular formation
      - Extensive interconnections with sensory, motor, integrative nuclei, and pathways along brain stem
    - Determined by complex interactions between reticular formation and cerebral cortex

16-8 Higher-Order Functions

- **Reticular Activating System** (**RAS**)
  - Important brain stem component
  - Diffuse network in reticular formation
  - Extends from medulla oblongata to midbrain
  - Output of RAS projects to thalamic nuclei that influence large areas of cerebral cortex
  - When RAS inactive, so is cerebral cortex
  - Stimulation of RAS produces widespread activation of cerebral cortex

16-8 Higher-Order Functions

- Arousal and the Reticular Activating System
  - Ending sleep
    - Any stimulus activates reticular formation and RAS
    - Arousal occurs rapidly
    - Effects of single stimulation of RAS last less than a minute

16-8 Higher-Order Functions

- Arousal and the Reticular Activating System
  - Maintaining consciousness
    - Activity in cerebral cortex, basal nuclei, and sensory and motor pathways continue to stimulate RAS
      - After many hours, reticular formation becomes less responsive to stimulation
      - Individual becomes less alert and more lethargic
      - Neural fatigue reduces RAS activity

16-8 Higher-Order Functions

- Arousal and the Reticular Activating System
  - Regulation of sleep–wake cycles
    - Involves interplay between brain stem nuclei that use different neurotransmitters

        - Group of nuclei stimulates RAS with NE and maintains awake, alert state
        - Other group promotes deep sleep by depressing RAS activity with serotonin
        - "Dueling" nuclei located in brain stem

16-9 Brain Chemistry

- Brain Chemistry
    - Changes in normal balance between two or more neurotransmitters can profoundly affect brain function

16-9 Brain Chemistry

- *Huntington's Disease*
    - Destruction of ACh-secreting and GABA-secreting neurons in basal nuclei
    - Symptoms appear as basal nuclei and frontal lobes slowly degenerate
    - Difficulty controlling movements
    - Intellectual abilities gradually decline

16-9 Brain Chemistry

- *Lysergic Acid Diethylamide* (*LSD*)
    - Powerful hallucinogenic drug
    - Activates serotonin receptors in brain stem, hypothalamus, and limbic system

16-9 Brain Chemistry

- Serotonin
    - Compounds that enhance effects also produce hallucinations (LSD)
    - Compounds that inhibit or block action cause severe depression and anxiety
    - Variations in levels affect sensory interpretation and emotional states

16-9 Brain Chemistry

- Serotonin
    - *Fluoxetine* (*Prozac*)
        - Slows removal of serotonin at synapses
        - Increases serotonin concentrations at postsynaptic membrane
        - Classified as selective serotonin reuptake inhibitors (SSRIs)
        - Other SSRIs
            - *Celexa*, *Luvox*, *Paxil*, and *Zoloft*

16-9 Brain Chemistry

- Parkinson's Disease
  - Inadequate dopamine production causes motor problems
  - Dopamine
    - Secretion stimulated by amphetamines, or "speed"
    - Large doses can produce symptoms resembling *schizophrenia*
    - Important in nuclei that control intentional movements
    - Important in other centers of diencephalon and cerebrum

16-10 Effects of Aging on the Nervous System

- Effects of Aging
  - Anatomical and physiological changes begin after maturity (age 30)
  - Accumulate over time
  - 85 percent of people over age 65 have changes in mental performance and CNS function

16-10 Effects of Aging on the Nervous System

- Common Age-related Anatomical Changes in the Nervous System
  - *Reduction in Brain Size and Weight*
  - *Reduction in Number of Neurons*
  - *Decrease in Blood Flow to Brain*
  - *Changes in Synaptic Organization of Brain*
  - *Intracellular and Extracellular Changes in CNS Neurons*

16-10 Effects of Aging on the Nervous System

- *Reduction in Brain Size and Weight*
  - Decrease in volume of cerebral cortex
  - Narrower gyri and wider sulci
  - Larger subarachnoid space
- *Reduction in Number of Neurons*
  - Brain shrinkage linked to loss of cortical neurons
  - No neuronal loss in brain stem nuclei

16-10 Effects of Aging on the Nervous System

- *Decrease in Blood Flow to Brain*
  - *Arteriosclerosis*
    - Fatty deposits in walls of blood vessels
    - Reduces blood flow through arteries
    - Increases chances of rupture
  - *Cerebrovascular accident* (*CVA*), or stroke
    - May damage surrounding neural tissue

16-10 Effects of Aging on the Nervous System

- *Changes in Synaptic Organization of Brain*
  - Number of dendritic branches, spines, and interconnections decreases
  - Synaptic connections lost
  - Rate of neurotransmitter production declines

16-10 Effects of Aging on the Nervous System

- *Intracellular and Extracellular Changes in CNS Neurons*
  - Neurons in brain accumulate abnormal intracellular deposits
  - **Lipofuscin**
    - Granular pigment with no known function
  - **Neurofibrillary tangles**
    - Masses of neurofibrils form dense mats inside cell body and axon

16-10 Effects of Aging on the Nervous System

- *Intracellular and Extracellular Changes in CNS Neurons*
  - **Plaques**
    - Extracellular accumulations of fibrillar proteins
    - Surrounded by abnormal dendrites and axons

16-10 Effects of Aging on the Nervous System

- *Intracellular and Extracellular Changes in CNS Neurons*
  - Plaques and tangles
    - Contain deposits of several peptides
    - Primarily two forms of **amyloid** ß (Aß) protein
    - Appear in brain regions specifically associated with memory processing

16-10 Effects of Aging on the Nervous System

- Anatomical Changes
  - Linked to functional changes
  - Neural processing becomes less efficient with age
  - Memory consolidation more difficult
  - Secondary memories harder to access

16-10 Effects of Aging on the Nervous System

- Sensory Systems
  - Hearing, balance, vision, smell, and taste become less acute
  - Reaction times slowed
  - Reflexes weaken or disappear
- Motor Control
  - Precision decreases
  - Takes longer to perform

16-10 Effects of Aging on the Nervous System

- Incapacitation
  - 85 percent of elderly population develops changes that do *not* interfere with abilities
  - Some individuals become incapacitated by progressive CNS changes

16-10 Effects of Aging on the Nervous System

- **Senility**
  - Also called *senile dementia*
  - Degenerative changes
    - Memory loss
    - Anterograde amnesia (lose ability to store new memories)
    - Emotional disturbances
    - Alzheimer's disease is most common

16-10 Nervous System Integration

- The Nervous System
  - Monitors all other systems
  - Issues commands that adjust their activities
  - Like conductor of orchestra

16-10 Nervous System Integration

- Neural Tissue
  - Extremely delicate
  - Extracellular environment must maintain homeostatic limits
  - If regulatory mechanisms break down, neurological disorders appear