• The Nervous System
  – Includes all neural tissue in the body
• Neural Tissue
  – Contains two kinds of cells:
    • Neurons:
      – cells that send and receive signals
    • Neuroglia (glial cells):
      – cells that support and protect neurons
An Introduction to the Nervous System

• Organs of the Nervous System
  – **Brain** and **spinal cord**
  – **Sensory receptors** of sense organs (eyes, ears, etc.)
  – **Nerves** connect nervous system with other systems
8-1 The nervous system has anatomical and functional divisions
Overview of the Nervous System

Figure 8-1
8-2 Neurons are specialized for intercellular communication and are supported by cells called neuroglia
Neurons

• The Structure of Neurons
  – **Cell body** (soma)
  – Short, branched **dendrites**
  – Long, single **axon**
  – **Axon terminals**
Figure 8-2
Neurons

- **Structural Classifications of Neurons**
  - **Multipolar neurons:**
    - Common in the CNS
    - Include all skeletal muscle motor neurons
  - **Unipolar neurons:**
    - Found in sensory neurons of PNS
  - **Bipolar neurons:**
    - Found in special sensory organs (sight, smell, hearing)
Figure 8-3

(a) Multipolar neuron

(b) Unipolar neuron

(c) Bipolar neuron
Neurons

• Three Functional Classifications of Neurons
  – Sensory neurons:
    • Afferent neurons of PNS
  – Motor neurons:
    • Efferent neurons of PNS
  – Interneurons:
    • Association neurons
Neurons

• Three Types of Sensory Receptors
  – **Exteroceptors:**
    • External senses (touch, temperature, pressure)
    • Distance senses (sight, smell, hearing)
  – **Proprioceptors:**
    • Monitor position and movement (skeletal muscles and joints)
  – **Interoceptors:**
    • Monitor internal systems (digestive, respiratory, cardiovascular, urinary, reproductive)
    • Internal senses (taste, deep pressure, pain)
Neuroglia

- Half the volume of the nervous system
- Many types of neuroglia in CNS and PNS
Neuroglia

• Four Types of Neuroglia in the CNS
  – **Astrocytes**: large cell bodies with many processes
  – **Oligodendrocytes**: smaller cell bodies with fewer processes
  – **Microglia**: smallest and least numerous neuroglia with many fine-branched processes
  – **Ependymal cells**: cells with highly branched processes; contact neuroglia directly
Neuroglia

• Neuroglia of the Peripheral Nervous System

  – **Satellite cells:**
    • Also called *amphicytes*
    • Surround ganglia
    • Regulate environment around neuron

  – **Schwann cells:**
    • Also called *neurilemmocytes*
    • Form myelin sheath (*neurilemma*) around peripheral axons
    • One Schwann cell sheaths one segment of axon:
      – many Schwann cells sheath entire axon
Schwann Cells and Peripheral Axons

Figure 8-5

(a) Myelinated axon

(b) Unmyelinated axon
The Anatomical Organization of the Nervous System

Figure 8-6
8-3 In neurons, a change in the plasma membrane’s electrical potential may result in an action potential (nerve impulse)
The Membrane Potential

• Ion Movements and Electrical Signals
  – All plasma (cell) membranes produce electrical signals by ion movements
  – Transmembrane potential is particularly important to neurons
The Membrane Potential

- **Resting Potential**
  - The transmembrane potential of resting cell

- **Graded Potential**
  - Temporary, localized change in resting potential
  - Caused by stimulus

- **Action Potential**
  - Is an electrical impulse
  - Produced by graded potential
  - Propagates along surface of axon to synapse
The Membrane Potential

• Factors Responsible for the Membrane Potential
  – Concentration gradient of ions (Na\(^+\), K\(^+\))
  – Selectively permeable through channels
  – Maintains charge difference across membrane (resting potential – 70 mV)
  – Chemical gradients:
    • Concentration gradients of ions (Na\(^+\), K\(^+\))
  – Electrical gradients:
    • Separate charges of positive and negative ions
    • Result in potential difference
The Resting Membrane Potential

Figure 8-7
The Membrane Potential

• Changes in the membrane potential
  – Transmembrane potential rises or falls:
    • In response to temporary changes in membrane permeability
    • Resulting from opening or closing specific membrane channels
The Membrane Potential

• Sodium and Potassium Channels
  – Membrane permeability to Na\(^+\) and K\(^+\) determines transmembrane potential
  – They are either passive or active:
    • Passive channels (also called leak channels):
      – are always open
      – permeability changes with conditions
    • Active channels (also called gated channels):
      – open and close in response to stimuli
      – at resting potential, most gated channels are closed
The Membrane Potential

• Graded Potentials
  – Also called *local potentials*
  – Changes in transmembrane potential:
    • That cannot spread far from site of stimulation
  – Any stimulus that opens a gated channel:
    • Produces a graded potential
The Membrane Potential

• The Generation of an Action Potential
  – Propagated changes in transmembrane potential
  – Affect an entire excitable membrane
  – Link graded potentials at cell body with motor end plate actions
The Generation of an Action Potential

**Figure 8-8**
The Generation of an Action Potential

**STEP 2**

Activation of voltage-gated sodium channels and rapid depolarization

Figure 8-8
The Generation of an Action Potential

**STEP 3** Inactivation of sodium channels and activation of voltage-gated potassium channels

Figure 8-8
Figure 8-8
The Generation of an Action Potential

Figure 8-8

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Propagation of an Action Potential

• Propagation
  – Moves action potentials generated in axon hillock
  – Along entire length of axon
  – A series of repeated actions, not passive flow

• Two methods of propagating action potentials
  – Continuous propagation: unmyelinated axons
  – Saltatory propagation: myelinated axons
(a) Action potential propagation along an unmyelinated axon

Stimulus depolarizes membrane to threshold

EXTRACELLULAR FLUID

Na+

Plasma membrane

CYTOSOL

Local current

Repolarization (refractory period)
Figure 8-9

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8-4 At synapses, communication occurs among neurons or between neurons and other cells
Synapses

• Synaptic Activity

  – Action potentials (nerve impulses):
    • Are transmitted from presynaptic neuron
    • To postsynaptic neuron (or other postsynaptic cell)
The Structure of a Synapse

Figure 8-10a

Telodendrion
Synaptic knob
Mitochondrion
Synaptic vesicles
Presynaptic membrane
Endoplasmic reticulum
Postsynaptic membrane
Synaptic cleft

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Synapses

- **Chemical Synapses**
  - Are found in most synapses between neurons and all synapses between neurons and other cells
  - Cells not in direct contact
  - Action potential *may or may not* be propagated to postsynaptic cell, depending on:
    - Amount of neurotransmitter released
    - Sensitivity of postsynaptic cell
• Two Classes of Neurotransmitters

  – **Excitatory neurotransmitters:**
    * Cause depolarization of postsynaptic membranes
    * Promote action potentials

  – **Inhibitory neurotransmitters:**
    * Cause hyperpolarization of postsynaptic membranes
    * Suppress action potentials
• The Effect of a Neurotransmitter
  – On a postsynaptic membrane:
    • Depends on the receptor
    • Not on the neurotransmitter
  – For example, **acetylcholine** (ACh):
    • Usually promotes action potentials
    • But inhibits cardiac neuromuscular junctions
• Cholinergic Synapses
  – Any synapse that releases Ach:
    • All neuromuscular junctions with skeletal muscle fibers
    • Many synapses in CNS
    • All neuron-to-neuron synapses in PNS
    • All neuromuscular and neuroglandular junctions of ANS parasympathetic division
Synapses

- Events at a Cholinergic Synapse
  - Action potential arrives, depolarizes synaptic knob
  - Calcium ions enter synaptic knob, trigger exocytosis of ACh
  - ACh binds to receptors, depolarizes postsynaptic membrane
  - AChE breaks ACh into acetate and choline
Events at a Cholinergic Synapse

Figure 8-11
Events at a Cholinergic Synapse

Figure 8-11
Events at a Cholinergic Synapse

**Figure 8-11**

**STEP 3** 
ACh binds to receptors and depolarizes the postsynaptic membrane.

Initiation of action potential if threshold is reached.

Na⁺ Na⁺ Na⁺ Na⁺

Receptor
Events at a Cholinergic Synapse

Figure 8-11

Step 4: ACh is removed by AChE (acetylcholinesterase)

Propagation of action potential (if generated)
<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>An arriving action potential depolarizes the synaptic knob and the presynaptic membrane.</td>
</tr>
<tr>
<td>2</td>
<td>Calcium ions enter the cytoplasm of the synaptic knob. ACh release occurs through exocytosis of neurotransmitter vesicles.</td>
</tr>
<tr>
<td>3</td>
<td>ACh diffuses across the synaptic cleft and binds to receptors on the postsynaptic membrane. Sodium channels on the postsynaptic surface are activated, producing a graded depolarization. ACh release stops because calcium ions are removed from the cytoplasm of the synaptic knob.</td>
</tr>
<tr>
<td>4</td>
<td>The depolarization ends as ACh is broken down into acetate and choline by AChE. The synaptic knob reabsorbs choline from the synaptic cleft and uses it to resynthesize ACh.</td>
</tr>
</tbody>
</table>
Other Neurotransmitters

- At least 50 neurotransmitters other than ACh, including:
  - Some amino acids
  - Peptides
  - Prostaglandins
  - ATP
  - Some dissolved gases
Neurotransmitters and Neuromodulators

• Important Neurotransmitters

  – Other than acetylcholine:
    • Norepinephrine (NE)
    • Dopamine
    • Serotonin
    • Gamma aminobutyric acid (GABA)
Neuronal Pools

Figure 8-12

(a) Divergence

(b) Convergence
8-5 The brain and spinal cord are surrounded by three layers of membranes called the meninges
The Three Meningeal Layers

• The Dura Mater
  – Tough and fibrous
  – Cranially:
    • Fuses with periosteum of occipital bone
  – Caudally:
    • Tapers to dense cord of collagen fibers
    • Joins *filum terminale* in *coccygeal ligament*
  – The epidural space:
    • Between spinal dura mater and walls of vertebral canal
    • Contains loose connective and adipose tissue
    • Anesthetic injection site
The Three Meningeal Layers

• The Arachnoid Mater
  – Middle meningeal layer
  – Arachnoid membrane:
    • Simple squamous epithelia
    • Covers arachnoid mater
The Three Meningeal Layers

- **The Pia Mater**
  - Is the innermost meningeal layer
  - Is a mesh of collagen and elastic fibers
  - Is bound to underlying neural tissue
The Three Meningeal Layers

Figure 8-13
The spinal cord contains gray matter surrounded by white matter and connects to 31 pairs of spinal nerves.
Gross Anatomy of the Spinal Cord

• About 18 inches (45 cm) long
• 1/2 inch (14 mm) wide
• Ends between vertebrae L\textsubscript{1} and L\textsubscript{2}
• Bilateral symmetry
  – Grooves divide the spinal cord into left and right
  – Posterior median sulcus: on posterior side
  – Anterior median fissure: deeper groove on anterior side
• **Enlargements of the Spinal Cord**

  – Caused by:
    • Amount of gray matter in segment
    • Involvement with sensory and motor nerves of limbs

  – Cervical enlargement:
    • Nerves of shoulders and upper limbs

  – Lumbar enlargement:
    • Nerves of pelvis and lower limbs
Gross Anatomy of the Spinal Cord

- Gross Anatomy of the Spinal Cord
  - The distal end:
    - Conus medullaris:
      - thin, conical spinal cord below lumbar enlargement
    - Filum terminale:
      - thin thread of fibrous tissue at end of conus medullaris
      - attaches to coccygeal ligament
    - Cauda equina:
      - nerve roots extending below conus medullaris
Gross Anatomy of the Spinal Cord

Figure 8-14

Cervical spinal nerves
Thoracic spinal nerves
Lumbar spinal nerves
Sacral spinal nerves
Coccygeal nerve (Co.)

Dorsal root
Dorsal root ganglion
Central canal
Posterior median sulcus
Gray matter
White matter
Anterior median fissure
C3

Cervical enlargement
Posterior median sulcus
Lumbar enlargement
Inferior tip of spinal cord
Cauda equina

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Gross Anatomy of the Spinal Cord

• 31 Spinal Cord Segments
  – Based on vertebrae where spinal nerves originate
  – Positions of spinal segment and vertebrae change with age:
    • Cervical nerves:
      – are named for inferior vertebra
    • All other nerves:
      – are named for superior vertebra
Gross Anatomy of the Spinal Cord

• Roots
  – Two branches of spinal nerves:
    • Ventral root:
      – contains axons of motor neurons
    • Dorsal root:
      – contains axons of sensory neurons
  – Dorsal root ganglia:
    • contain cell bodies of sensory neurons
Gross Anatomy of the Spinal Cord

• The Spinal Nerve
  – Each side of spine:
    • Dorsal and ventral roots join
    • To form a spinal nerve
  – Mixed nerves:
    • Carry both afferent (sensory) and efferent (motor) fibers
Sectional Anatomy of the Spinal Cord

• **White matter**
  – Is superficial
  – Contains myelinated and unmyelinated axons

• **Gray matter**
  – Surrounds *central canal* of spinal cord
  – Contains neuron cell bodies, neuroglia, unmyelinated axons
  – Has projections (*gray horns*)
Sectional Anatomy of the Spinal Cord

• Organization of White Matter
  – **Posterior white columns**: lie between posterior gray horns and posterior median sulcus
  – **Anterior white columns**: lie between anterior gray horns and anterior median fissure
    • Anterior white commissure: area where axons cross from one side of spinal cord to the other
  – **Lateral white columns**: located on each side of spinal cord between anterior and posterior columns
Sectional Anatomy of the Spinal Cord

Figure 8-15a

(a) Sectional view of spinal cord
8-7 The brain has several principal structures, each with specific functions
An Introduction to the Brain

• The Adult Human Brain
  – Ranges from 750 cc to 2100 cc
  – Contains almost 97% of the body’s neural tissue
  – Average weight about 1.4 kg (3 lb)
The Brain

• Six Regions of the Brain
  – Cerebrum
  – Diencephalon
  – Midbrain
  – Pons
  – Medulla oblongata
  – Cerebellum

3D Peel-Away of the Brain
The Brain

- Cerebrum
  - Largest part of brain
  - Controls higher mental functions
  - Divided into left and right cerebral hemispheres
  - Surface layer of gray matter (neural cortex)
The Brain

• **Diencephalon**
  
  – Located under cerebrum and cerebellum
  
  – Links cerebrum with **brain stem**
  
  – Three divisions:
    
    • Left thalamus
    
    • Right thalamus
    
    • Hypothalamus
The Brain

• Diencephalon
  – Thalamus:
    • Relays and processes sensory information
  – Hypothalamus:
    • Hormone production
    • Emotion
    • Autonomic function
  – Pituitary gland:
    • Major endocrine gland
    • Connected to hypothalamus
    • Via infundibulum (stalk)
    • Interfaces nervous and endocrine systems
The Brain

- The Brain Stem
  - Processes information between:
    - Spinal cord and cerebrum or cerebellum
  - Includes:
    - Midbrain
    - Pons
    - Medulla oblongata
The Brain

• The Brain Stem
  – **Midbrain:**
    • Processes sight, sound, and associated reflexes
    • Maintains consciousness
  – **Pons:**
    • Connects cerebellum to brain stem
    • Is involved in somatic and visceral motor control
The Brain

• The Brain Stem

  – **Medulla oblongata:**
    
    • Connects brain to spinal cord
    
    • Relays information
    
    • Regulates autonomic functions:
      
      – heart rate, blood pressure, and digestion
The Brain

• **Cerebellum**
  – Second largest part of brain
  – Coordinates repetitive body movements
  – Two hemispheres
  – Covered with **cerebellar cortex**
Figure 8-16a
Figure 8-16b

The Brain

- Central sulcus
- Precentral gyrus
- Postcentral gyrus
- Frontal lobe of left cerebral hemisphere
- Lateral sulcus
- Parietal lobe
- Parieto-occipital sulcus
- Occipital lobe
- Temporal lobe
- CEREBELLUM
- PONS
- MEDULLA OBLONGATA

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The Brain

Figure 8-16c
Ventricles of the Brain

- Each cerebral hemisphere contains one large lateral ventricle:
  - Separated by a thin medial partition (septum pellucidum)

- Third ventricle:
  - Ventricle of the diencephalon
  - Lateral ventricles communicate with third ventricle:
    - via interventricular foramen (foramen of Monro)

- Fourth ventricle:
  - Extends into medulla oblongata
  - Connects with third ventricle:
    - aqueduct of midbrain
The Ventricles of the Brain

Figure 8-17
The Brain

- **Cerebrospinal Fluid**
  - **Subdural space:**
    - Between arachnoid mater and dura mater
  - **Subarachnoid space:**
    - Between arachnoid mater and pia mater
    - Contains collagen/elastin fiber network (arachnoid trabeculae)
    - Filled with cerebrospinal fluid (CSF)
  - **Cerebrospinal fluid (CSF):**
    - Carries dissolved gases, nutrients, and wastes
    - Spinal tap: withdraws CSF
The Cerebrum

• The Cerebrum
  – Is the largest part of the brain
  – Controls all conscious thoughts and intellectual functions
  – Processes somatic sensory and motor information
• Gray matter
  – In cerebral cortex and basal nuclei

• White matter
  – Deep to basal cortex
  – Around basal nuclei
The Cerebrum

• Structures of the Cerebrum
  – Gyri of neural cortex:
    • Increase surface area (number of cortical neurons)
  – Insula (island) of cortex:
    • Lies medial to lateral sulcus
  – Longitudinal fissure:
    • Separates cerebral hemispheres
  – Lobes:
    • Divisions of hemispheres
The Cerebrum

• Structures of the Cerebrum
  – Central sulcus divides:
    • Anterior frontal lobe from posterior parietal lobe
  – Lateral sulcus divides:
    • Frontal lobe from temporal lobe
  – Parieto-occipital sulcus divides:
    • Parietal lobe from occipital lobe
The Cerebrum

• Motor and Sensory Areas of the Cortex
  – Central sulcus separates motor and sensory areas
  – **Motor areas:**
    • Precentral gyrus of frontal lobe:
      – directs voluntary movements
    • Primary motor cortex:
      – is the surface of precentral gyrus
    • Pyramidal cells:
      – are neurons of primary motor cortex
The Cerebrum

Motor and Sensory Areas of the Cortex

- Sensory areas:
  - Postcentral gyrus of parietal lobe:
    - receives somatic sensory information (touch, pressure, pain, vibration, taste, and temperature)
  - Primary sensory cortex:
    - surface of postcentral gyrus
The Cerebrum

• Special Sensory Cortexes
  – **Visual cortex:**
    • Information from sight receptors
  – **Auditory cortex:**
    • Information from sound receptors
  – **Olfactory cortex:**
    • Information from odor receptors
  – **Gustatory cortex:**
    • Information from taste receptors
The Cerebrum

• Association Areas
  – Sensory association areas:
    • Monitor and interpret arriving information at sensory areas of cortex
  – Somatic motor association area (premotor cortex):
    • Coordinates motor responses (learned movements)
The Cerebrum

• Sensory Association Areas
  – **Somatic sensory association area:**
    • Interprets input to primary sensory cortex (e.g., recognizes and responds to touch)
  – **Visual association area:**
    • Interprets activity in visual cortex
  – **Auditory association area:**
    • Monitors auditory cortex
The Cerebrum

- **General Interpretive Area**
  - Also called Wernicke area
  - Present in only one hemisphere
  - Receives information from all sensory association areas
  - Coordinates access to complex visual and auditory memories
The Cerebrum

• Other Integrative Areas

  – **Speech center:**
    • Is associated with general interpretive area
    • Coordinates all vocalization functions

  – **Prefrontal cortex of frontal lobe:**
    • Integrates information from sensory association areas
    • Performs abstract intellectual activities (e.g., predicting consequences of actions)
The Cerebrum

• Hemispheric Lateralization
  – Functional differences between left and right hemispheres
  – Each cerebral hemisphere performs certain functions that are not ordinarily performed by the opposite hemisphere
The Cerebrum

• The Left Hemisphere
  – In most people, the left brain (dominant hemisphere) controls:
    • Reading, writing, and math
    • Decision making
    • Speech and language

• The Right Hemisphere
  – Right cerebral hemisphere relates to:
    • Senses (touch, smell, sight, taste, hearing)
    • Recognition (faces, voice inflections)
Hemispheric Lateralization

Figure 8-20

- LEFT HAND
  - Prefrontal cortex
  - Speech center
  - Writing
  - Auditory cortex
  - General interpretive center (language and mathematical calculation)
  - Visual cortex (right visual field)

- RIGHT HAND
  - Prefrontal cortex
  - Anterior commissure
  - Analysis by touch
  - Auditory cortex
  - Spatial visualization and analysis
  - Visual cortex (left visual field)
Monitoring Brain Activity

- Brain activity is assessed by an electroencephalogram (EEG):
  - Electrodes are placed on the skull
  - Patterns of electrical activity (brain waves) are printed out
The Cerebrum

• Four Categories of Brain Waves
  – Alpha waves:
    • Found in healthy, awake adults at rest with eyes closed
  – Beta waves:
    • Higher frequency
    • Found in adults concentrating or mentally stressed
  – Theta waves:
    • Found in children
    • Found in intensely frustrated adults
    • May indicate brain disorder in adults
  – Delta waves:
    • During sleep
    • Found in awake adults with brain damage
### Brain Waves

#### Figure 8-21

<table>
<thead>
<tr>
<th>(a) Alpha waves</th>
<th>Alpha waves are characteristic of normal resting adults</th>
</tr>
</thead>
<tbody>
<tr>
<td>(b) Beta waves</td>
<td>Beta waves typically accompany intense concentration</td>
</tr>
<tr>
<td>(c) Theta waves</td>
<td>Theta waves are seen in children and in frustrated adults</td>
</tr>
<tr>
<td>(d) Delta waves</td>
<td>Delta waves occur in deep sleep and in certain pathological states</td>
</tr>
</tbody>
</table>

![EEG waves](Image)
The Cerebrum

• The Basal Nuclei
  – Also called cerebral nuclei
  – Are masses of gray matter
  – Are embedded in white matter of cerebrum
  – Direct subconscious activities
The Cerebrum

• Structures of Basal Nuclei
  – Caudate nucleus:
    • Curving, slender tail
  – Lentiform nucleus:
    • Globus pallidus
    • Putamen
The Cerebrum

• Functions of Basal Nuclei
  – Involved with:
    • The subconscious control of skeletal muscle tone
    • The coordination of learned movement patterns
      (walking, lifting)
The Basal Nuclei

Figure 8-22a
The Basal Nuclei

Figure 8-22b
The Limbic System

- The Limbic System
  - Is a functional grouping that:
    - Establishes emotional states
    - Links conscious functions of cerebral cortex with autonomic functions of brain stem
    - Facilitates memory storage and retrieval
The Limbic System

• Components of the Limbic System
  – **Amygdaloid body:**
    • Acts as interface between the limbic system, the cerebrum, and various sensory systems
  – **Limbic lobe of cerebral hemisphere:**
    • Cingulate gyrus
    • Dentate gyrus
    • Parahippocampal gyrus
    • Hippocampus
The Limbic System

• Components of the Limbic System
  – Fornix:
    • Tract of white matter
    • Connects hippocampus with hypothalamus
  – Anterior nucleus of the thalamus:
    • Relays information from mamillary body to cingulate gyrus
  – Reticular formation:
    • Stimulation or inhibition affects emotions (rage, fear, pain, sexual arousal, pleasure)
The Limbic System

Figure 8-23

Corpus callosum
Hypothalamic nuclei
Olfactory tract
Hippocampus
Cingulate gyrus
Thalamic nuclei
Mamillary body
Amygdaloid body
The Diencephalon

- Integrates sensory information and motor commands
- Thalamus, epithalamus, and hypothalamus
  - The pineal gland:
    - Found in posterior epithalamus
    - Secretes hormone **melatonin**
The Midbrain

• Two pairs of sensory nuclei (corpora quadrigemina)
  – Superior colliculus (visual)
  – Inferior colliculus (auditory)

• Cerebral peduncles
  – Nerve fiber bundles on ventrolateral surfaces
  – Contain:
    • Descending fibers to cerebellum
    • Motor command fibers
The Pons

- Links cerebellum with mesencephalon, diencephalon, cerebrum, and spinal cord
  - Sensory and motor nuclei of cranial nerves V, VI, VII, and VIII
The Medulla Oblongata

• The Medulla Oblongata
  – Allows brain and spinal cord to communicate
  – Coordinates complex autonomic reflexes
  – Controls visceral functions
  – Nuclei in the medulla:
    • Autonomic nuclei: control visceral activities
    • Sensory and motor nuclei: of cranial nerves
    • Relay stations: along sensory and motor pathways
Figure 8-24
The PNS connects the CNS with the body’s external and internal environments.
Cranial Nerves

• 12 pairs connected to brain

• Four Classifications of Cranial Nerves
  – Sensory nerves: carry somatic sensory information, including touch, pressure, vibration, temperature, and pain
  – Special sensory nerves: carry sensations such as smell, sight, hearing, balance
  – Motor nerves: axons of somatic motor neurons
  – Mixed nerves: mixture of motor and sensory fibers
Cranial Nerves

• Cranial nerves are classified by primary functions

• May also have important secondary functions
  – Distributing autonomic fibers to peripheral ganglia
Cranial Nerves

Figure 8-25
Cranial Nerves

- **Olfactory Nerves (I)**
  - *Primary function:*
    - Special sensory (smell)

- **Optic Nerves (II)**
  - *Primary function:*
    - Special sensory (vision)

- **Oculomotor Nerves (III)**
  - *Primary function:*
    - Motor (eye movements)
Cranial Nerves

- **The Trochlear Nerves (IV)**
  - *Primary function:*
    - Motor (eye movements)

- **The Trigeminal Nerves (V)**
  - *Primary function:*
    - Mixed (sensory and motor) to face

- **The Abducens Nerves (VI)**
  - *Primary function:*
    - Motor (eye movements)
Cranial Nerves

• The Facial Nerves (VII)
  – *Primary function*:
    • Mixed (sensory and motor) to face

• The Vestibulocochlear Nerves (VIII)
  – *Primary function*: special sensory:
    • Vestibular branch:
      – balance and equilibrium
    • Cochlear branch:
      – hearing
Cranial Nerves

- The Glossopharyngeal Nerves (IX)
  - Primary function:
    - Mixed (sensory and motor) to head and neck

- The Vagus Nerves (X)
  - Primary function:
    - Mixed (sensory and motor)
    - Widely distributed in thorax and abdomen
Cranial Nerves

• The Accessory Nerves (XI)
  – Primary function
    • Motor to muscles of neck and upper back

• The Hypoglossal Nerves (XII)
  – Primary function
    • Motor (tongue movements)
<table>
<thead>
<tr>
<th>CRANIAL NERVES (NUMBER)</th>
<th>PRIMARY FUNCTION</th>
<th>INNERVATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olfactory (N I)</td>
<td>Special sensory</td>
<td>Olfactory epithelium</td>
</tr>
<tr>
<td>Optic (N II)</td>
<td>Special sensory</td>
<td>Retina of eye</td>
</tr>
<tr>
<td>Oculomotor (N III)</td>
<td>Motor</td>
<td>Inferior, medial, superior rectus, inferior oblique, and intrinsic muscles of eye</td>
</tr>
<tr>
<td>Trochlear (N IV)</td>
<td>Motor</td>
<td>Superior oblique muscle of eye</td>
</tr>
<tr>
<td>Trigeminal (N V)</td>
<td>Mixed</td>
<td>Sensory: orbital structures, nasal cavity, skin of forehead, eyelids, eyebrows, nose, lips, gums and teeth; cheek, palate, pharynx, and tongue Motor: chewing muscles (temporalis, masseter, pterygoids)</td>
</tr>
<tr>
<td>Abducens (N VI)</td>
<td>Motor</td>
<td>Lateral rectus muscle of eye</td>
</tr>
<tr>
<td>Facial (N VII)</td>
<td>Mixed</td>
<td>Sensory: taste receptors on the anterior 2/3 of tongue Motor: muscles of facial expression, lacrimal (tear) gland, and submandibular and sublingual salivary glands</td>
</tr>
<tr>
<td>Vestibulocochlear (Acoustic) (N VIII)</td>
<td>Special sensory</td>
<td>Cochlea (receptors for hearing) Vestibule (receptors for motion and balance)</td>
</tr>
<tr>
<td>Glossopharyngeal (N IX)</td>
<td>Mixed</td>
<td>Sensory: posterior 1/3 of tongue; pharynx and palate (part); receptors for blood pressure, pH, oxygen, and carbon dioxide concentrations Motor: pharyngeal muscles, parotid salivary glands</td>
</tr>
<tr>
<td>Vagus (N X)</td>
<td>Mixed</td>
<td>Sensory: pharynx; auricle and external acoustic meatus; diaphragm; visceral organs in thoracic and abdominopelvic cavities Motor: palatal and pharyngeal muscles and visceral organs in thoracic and abdominopelvic cavities</td>
</tr>
<tr>
<td>Accessory (Spinal Accessory) (N XI)</td>
<td>Motor</td>
<td>Voluntary muscles of palate, pharynx, and larynx (with vagus nerve); sternocleidomastoid and trapezius muscles</td>
</tr>
<tr>
<td>Hypoglossal (N XII)</td>
<td>Motor</td>
<td>Tongue muscles</td>
</tr>
</tbody>
</table>
Nerve Plexuses

- Complex, interwoven networks of nerve fibers
- Formed from blended fibers of ventral rami of adjacent spinal nerves
- Control skeletal muscles of the neck and limbs
Peripheral Nerves and Nerve Plexuses

Figure 8-26

Cervical plexus

Brachial plexus

Phrenic nerve (extends to the diaphragm)

Axillary nerve

Musculocutaneous nerve

Radial nerve
Peripheral Nerves and Nerve Plexuses

Figure 8-26
<table>
<thead>
<tr>
<th>PLEXUS</th>
<th>MAJOR NERVE</th>
<th>DISTRIBUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cervical Plexus ($C_1-C_5$)</td>
<td>Phrenic nerve, Other branches</td>
<td>Diaphragm, Muscles of the neck; skin of upper chest, neck, and ears</td>
</tr>
<tr>
<td>Brachial Plexus ($C_3-T_1$)</td>
<td>Axillary nerve, Musculocutaneous nerve, Median nerve, Radial nerve, Ulnar nerve</td>
<td>Deltoid and teres minor muscles; skin of shoulder, Flexor muscles of arm and forearm; skin on lateral surface of forearm, Flexor muscles of forearm and hand; skin over lateral surface of hand, Extensor muscles of arm, forearm, and hand; skin over posterolateral surface of the arm, Flexor muscles of forearm and small digital muscles; skin over medial surface of hand</td>
</tr>
<tr>
<td>Lumbosacral Plexus</td>
<td>Femoral nerve, Obturator nerve, Saphenous nerve</td>
<td>Flexors and adductors of hip, extensors of knee; skin over medial surfaces of thigh, leg, and foot, Adductors of hip; skin over medial surface of thigh, Skin over medial surface of leg</td>
</tr>
<tr>
<td>Lumbar Plexus ($T_{12}-L_4$)</td>
<td>Gluteal nerve, Sciatic nerve</td>
<td>Adductors and extensors of hip; skin over posterior surface of thigh, Flexors of knee and ankle, flexors and extensors of toes; skin over anterior and posterior surfaces of leg and foot</td>
</tr>
</tbody>
</table>
Reflexes are rapid, automatic responses to stimuli.
Reflexes

- Automatic responses coordinated within spinal cord
- Through interconnected sensory neurons, motor neurons, and interneurons
- Produce simple and complex reflexes
Reflexes

- **Neural Reflexes**
  - Rapid, automatic responses to specific stimuli
  - Basic building blocks of neural function
  - One neural reflex produces one motor response
  - Reflex arc:
    - The wiring of a single reflex
    - Beginning at receptor
    - Ending at peripheral effector
    - Generally opposes original stimulus (negative feedback)
Reflexes

• Five Steps in a Neural Reflex
  – Step 1: Arrival of stimulus, activation of receptor:
    • Physical or chemical changes
  – Step 2: Activation of sensory neuron:
    • Graded depolarization
  – Step 3: Information processing by postsynaptic cell:
    • Triggered by neurotransmitters
  – Step 4: Activation of motor neuron:
    • Action potential
  – Step 5: Response of peripheral effector:
    • Triggered by neurotransmitters
Reflexes

Figure 8-28

**STEP 1**
Arrival of stimulus and activation of receptor

**STEP 2**
Activation of a sensory neuron

**STEP 3**
Information processing in CNS

**STEP 4**
Activation of a motor neuron

**STEP 5**
Response by effector

**KEY**
- Sensory neuron (stimulated)
- Excitatory interneuron
- Motor neuron (stimulated)
• **Monosynaptic Reflexes**
  
  – A stretch reflex
  
  – Have least delay between sensory input and motor output:
    
    • For example, *stretch reflex* (such as patellar reflex)
  
  – Completed in 20–40 msec
  
  – Receptor is muscle spindle
A Stretch Reflex

**Figure 8-29**

**STEP 1**
Stretching of muscle tendon stimulates muscle spindles

**Muscle spindle** (stretch receptor)

**REFLEX ARC**

**SPINAL CORD**

**STEP 2**
Activation of motor neuron produces reflex muscle contraction
• Withdrawal Reflexes
  – Move body part away from stimulus (pain or pressure)
    • For example, **flexor reflex**:
      – pulls hand away from hot stove
  – Strength and extent of response:
    • Depends on intensity and location of stimulus
A Flexor Reflex

Figure 8-30
• Reflex behaviors are automatic
  – But processing centers in brain can facilitate or inhibit reflex motor patterns based in spinal cord
8-10 Separate pathways carry sensory and motor commands
Sensory Pathways

• Deliver somatic and visceral sensory information to their final destinations inside the CNS using
  – Nerves
  – Nuclei
  – Tracts
Sensory Pathways

• Somatic Sensory Pathways

  – Posterior column pathway:
    • Carries sensations of highly localized ("fine") touch, pressure, vibration, and proprioception
    • Spinal tracts involved:
      – left and right **fasciculus gracilis**
      – left and right **fasciculus cuneatus**
Sensory Pathways

• Posterior Column Pathway
  – Axons synapse
    • On third-order neurons in one of the ventral nuclei of the thalamus
    • Nuclei sort the arriving information according to:
      – the nature of the stimulus
      – the region of the body involved
Sensory Pathways

• Posterior Column Pathway
  – Processing in the thalamus:
    • Determines whether you perceive a given sensation as fine touch, as pressure, or as vibration
  – Ability to determine stimulus:
    • Precisely where on the body a specific stimulus originated depends on the projection of information from the thalamus to the primary sensory cortex
Sensory Pathways

• Posterior Column Pathway

– Sensory information:

• From toes arrives at one end of the primary sensory cortex

• From the head arrives at the other:

  – when neurons in one portion of your primary sensory cortex are stimulated, you become aware of sensations originating at a specific location
Sensory Pathways

• Posterior Column Pathway

  – Sensory homunculus:
    • Functional map of the primary sensory cortex
    • Distortions occur because area of sensory cortex devoted to particular body region is not proportional to region’s size, but to number of sensory receptors it contains
The Posterior Column Pathway

Figure 8-31

KEY
- Axon of first-order neuron
- Second-order neuron
- Third-order neuron

Sensory homunculus of left cerebral hemisphere
Nuclei in thalamus
MIDBRAIN
Nucleus in medulla oblongata
MEDULLA OBLONGATA
SPINAL CORD
Dorsal root ganglion

Fine-touch, vibration, pressure, and proprioception sensations from right side of body
Motor Pathways

• The Corticospinal Pathway
  – Sometimes called the **pyramidal system**
  – Provides voluntary control over skeletal muscles:
    • System begins at pyramidal cells of primary motor cortex
    • Axons of these upper motor neurons descend into brain stem and spinal cord to synapse on lower motor neurons that control skeletal muscles
  – Contains three pairs of descending tracts:
    • Corticobulbar tracts
    • Lateral corticospinal tracts
    • Anterior corticospinal tracts
Motor Pathways

• The Corticospinal Pathway
  – Corticospinal tracts:
    • As they descend, lateral corticospinal tracts are visible along the ventral surface of medulla oblongata as pair of thick bands, the pyramids
    • At spinal segment it targets, an axon in anterior corticospinal tract crosses over to the opposite side of the spinal cord in anterior white commissure before synapsing on lower motor neurons in anterior gray horns
Motor Pathways

• The Corticospinal Pathway
  – **Motor homunculus:**
    • Primary motor cortex corresponds point by point with specific regions of the body
    • Cortical areas have been mapped out in diagrammatic form
    • Homunculus provides indication of degree of fine motor control available:
      – hands, face, and tongue, which are capable of varied and complex movements, appear very large, while trunk is relatively small
      – these proportions are similar to the sensory homunculus
The Corticospinal Pathway

Figure 8-32
Motor Pathways

• The Medial and Lateral Pathways
  – Several centers in cerebrum, diencephalon, and brain stem may issue somatic motor commands as result of processing performed at a subconscious level
  – These nuclei and tracts are grouped by their primary functions:
    • Components of **medial pathway** help control gross movements of trunk and proximal limb muscles
    • Components of **lateral pathway** help control distal limb muscles that perform more precise movements
<table>
<thead>
<tr>
<th>PATHWAY</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SENSORY</strong></td>
<td></td>
</tr>
<tr>
<td>Posterior column pathway</td>
<td>Delivers highly localized sensations of fine touch, pressure, vibration, and proprioception to the primary sensory cortex</td>
</tr>
<tr>
<td>Spinothalamic pathway</td>
<td>Delivers poorly localized sensations of touch, pressure, pain, and temperature to the primary sensory cortex</td>
</tr>
<tr>
<td>Spinocerebellar pathway</td>
<td>Delivers proprioceptive information concerning the positions of muscles, bones, and joints to the cerebellar cortex</td>
</tr>
<tr>
<td><strong>MOTOR</strong></td>
<td></td>
</tr>
<tr>
<td>Corticospinal pathway</td>
<td>Provides conscious control of skeletal muscles throughout the body</td>
</tr>
<tr>
<td>Medial and lateral pathways</td>
<td>Provides subconscious regulation of skeletal muscle tone, controls reflexive skeletal muscle responses to equilibrium sensations and to sudden or strong visual and auditory stimuli</td>
</tr>
</tbody>
</table>
The autonomic nervous system, composed of the sympathetic and parasympathetic divisions, is involved in the unconscious regulation of body functions.
An Introduction to the ANS

- **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
Figure 8-33a

(a) Somatic nervous system
Autonomic Nervous System

(b) Autonomic nervous system

Figure 8-33b
Divisions of the ANS

• The autonomic nervous system
  – Operates largely outside our awareness
  – Has two divisions:
    • **Sympathetic division:**
      – increases alertness, metabolic rate, and muscular abilities
    • **Parasympathetic division:**
      – reduces metabolic rate and promotes digestion
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”
The Sympathetic Division

• Ganglionic Neurons
  – Occur in three locations:
    • Sympathetic chain ganglia
    • Collateral ganglia
    • Suprarenal medullae
The Sympathetic Division

• Ganglionic Neurons
  – Sympathetic chain ganglia:
    • Are on both sides of vertebral column
    • Control effectors:
      – in body wall
      – inside thoracic cavity
      – in head
      – in limbs
The Sympathetic Division

• Ganglionic Neurons
  – Collateral ganglia:
    • Are anterior to vertebral bodies
    • Contain ganglionic neurons that innervate tissues and organs in abdominopelvic cavity
The Sympathetic Division

• Ganglionic Neurons
  – Suprarenal (adrenal) medullae:
    • Very short axons
    • When stimulated, release neurotransmitters into bloodstream (not at synapse)
    • Function as hormones to affect target cells throughout body
The Sympathetic Division

Figure 8-34

KEY
- Preganglionic neurons
- Ganglionic neurons

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The Sympathetic Division

Figure 8-34

KEY
- Preganglionic neurons
- Ganglionic neurons
The Sympathetic Division

Figure 8-34

Splanchnic nerve

Collateral ganglion

Liver and gallbladder
Stomach
Spleen
Pancreas
Large intestine
Small intestine
Suprarenal medulla
Kidney

Uterus
Ovary
Penis
Scrotum
Urinary bladder
The Sympathetic Division

Figure 8-34

**KEY**
- Preganglionic neurons
- Ganglionic neurons

Postganglionic fibers to spinal nerves (innervating skin, blood vessels, sweat glands, arrector pili muscles, adipose tissue)

Sympathetic chain ganglia

Spinal cord
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 $S_2$–$S_4$
The Parasympathetic Division

- Ganglionic Neurons in Peripheral Ganglia
  - Near target organ
  - Embedded in tissues of target organ
  - Usually paired
The Parasympathetic Division

Figure 8-35
The Parasympathetic Division

Figure 8-35
The Parasympathetic Division

• **Parasympathetic Activation**
  – Centers on relaxation, food processing, and energy absorption
  – Localized effects, last a few seconds at most
<table>
<thead>
<tr>
<th>STRUCTURE</th>
<th>SYMPATHETIC EFFECTS</th>
<th>PARASYMPATHETIC EFFECTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>EYE</td>
<td>Dilation of pupil</td>
<td>Constriction of pupil</td>
</tr>
<tr>
<td></td>
<td>Focusing for distance vision</td>
<td>Focusing for near vision</td>
</tr>
<tr>
<td>Tear Glands</td>
<td>None (not innervated)</td>
<td>Secretion</td>
</tr>
<tr>
<td>SKIN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweat glands</td>
<td>Increases secretion</td>
<td>None (not innervated)</td>
</tr>
<tr>
<td>Arrector pili muscles</td>
<td>Contraction, erection of hairs</td>
<td>None (not innervated)</td>
</tr>
<tr>
<td>CARDIOVASCULAR SYSTEM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blood vessels</td>
<td>Vasoconstriction and vasodilation</td>
<td>None (not innervated)</td>
</tr>
<tr>
<td>Heart</td>
<td>Increases heart rate, force of contraction, and blood pressure</td>
<td>Decreases heart rate, force of contraction, and blood pressure</td>
</tr>
<tr>
<td>STRUCTURE</td>
<td>SYMPATHETIC EFFECTS</td>
<td>PARASYMPATHETIC EFFECTS</td>
</tr>
<tr>
<td>------------------------</td>
<td>-------------------------------------------------------------------------------------</td>
<td>---------------------------------------</td>
</tr>
<tr>
<td><strong>SUPRARENAL GLANDS</strong></td>
<td>Secretion of epinephrine and norepinephrine by suprarenal medullae</td>
<td>None (not innervated)</td>
</tr>
<tr>
<td><strong>RESPIRATORY SYSTEM</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Airways</td>
<td>Increases diameter</td>
<td>Decreases diameter</td>
</tr>
<tr>
<td>Respiratory rate</td>
<td>Increases rate</td>
<td>Decreases rate</td>
</tr>
<tr>
<td><strong>DIGESTIVE SYSTEM</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General level of activity</td>
<td>Decreases activity</td>
<td>Increases activity</td>
</tr>
<tr>
<td>Liver</td>
<td>Glycogen breakdown, glucose synthesis and release</td>
<td>Glycogen synthesis</td>
</tr>
<tr>
<td>STRUCTURE</td>
<td>SYMPATHETIC EFFECTS</td>
<td>PARASYMPATHETIC EFFECTS</td>
</tr>
<tr>
<td>---------------------------</td>
<td>--------------------------------------------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>SKELETAL MUSCLES</td>
<td>Increases force of contraction, glycogen breakdown</td>
<td>None (not innervated)</td>
</tr>
<tr>
<td>ADIPOSE TISSUE</td>
<td>Lipid breakdown, fatty acid release</td>
<td>None (not innervated)</td>
</tr>
<tr>
<td>URINARY SYSTEM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kidneys</td>
<td>Decreases urine production</td>
<td>Increases urine production</td>
</tr>
<tr>
<td>Urinary bladder</td>
<td>Constricts sphincter, relaxes urinary bladder</td>
<td>Tenses urinary bladder, relaxes sphincter to</td>
</tr>
<tr>
<td></td>
<td></td>
<td>eliminate urine</td>
</tr>
<tr>
<td>REPRODUCTIVE SYSTEM</td>
<td>Increased glandular secretions; ejaculation in males</td>
<td>Erection of penis (males) or clitoris (females)</td>
</tr>
</tbody>
</table>
8-12 Aging produces various structural and functional changes in the nervous system
Aging and the Nervous System

- Anatomical and physiological changes begin after maturity (age 30)
- Accumulate over time
- 85% of people over age 65 have changes in mental performance and CNS function
Aging and 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
8-13 The nervous system is closely integrated with other body systems
The Nervous System in Perspective

Functional
the Nervous System and Other Systems
The Integumentary System provides sensations of touch, pressure, pain, vibration, and temperature; hair provides some protection and insulation for skull and brain; protects peripheral nerves.

The Nervous System controls contraction of arrector pili muscles and secretion of sweat glands.
The Skeletal System provides calcium for neural function; protects brain and spinal cord.

The Nervous System controls skeletal muscle contractions that produce bone thickening and maintenance, and determine bone position.
The Muscular System

- The Muscular System’s facial muscles express emotional state; intrinsic laryngeal muscles permit communication; muscle spindles provide proprioceptive sensations.

- The Nervous System controls skeletal muscle contractions; coordinates respiratory and cardiovascular activities.
The Endocrine System

The Endocrine System’s
Many hormones affect CNS neural metabolism; the reproductive hormones and thyroid hormone influence CNS development.

The Nervous System controls pituitary gland and many other endocrine organs; secretes ADH and oxytocin.
The Cardiovascular System’s capillaries maintain the blood-brain barrier when stimulated by astrocytes; blood vessels (with ependymal cells) produce CSF.

The Nervous System modifies heart rate and blood pressure; astrocytes stimulate maintenance of blood-brain barrier.
The Lymphoid System defends against infection and assists in tissue repairs.

The Respiratory System provides oxygen and eliminates carbon dioxide.

The Nervous System controls the pace and depth of respiration.
The Digestive System provides nutrients for energy production and neurotransmitter synthesis.

The Nervous System regulates digestive tract movement and secretion.
The Urinary System

The Urinary System eliminates metabolic wastes; regulates body fluid pH and electrolyte concentrations.

The Nervous System adjusts renal pressure and controls urination.
The Reproductive System’s sex hormones affect CNS development and sexual behaviors.

The Nervous System controls sexual behaviors and sexual function.