Chapter 15

Sensory Pathways and the Somatic Nervous System

An Introduction to Sensory Pathways and the Somatic Nervous System

- An Introduction to:
  - Sensory receptors
  - Sensory processing
  - Conscious and subconscious motor functions
- Focusing on the “general senses”

15-1 Sensory Information

- Afferent Division of the Nervous System
  - Receptors
  - Sensory neurons
  - Sensory pathways
- Efferent Division of the Nervous System
  - Nuclei
  - Motor tracts
  - Motor neurons

15-1 Sensory Information

- *Sensory Receptors*
  - Specialized cells that monitor specific conditions
    - In the body or external environment
  - When stimulated, a receptor passes information to the CNS
    - In the form of action potentials along the axon of a sensory neuron

15-1 Sensory Information

- *Sensory Pathways*
  - Deliver somatic and visceral sensory information to their final destinations inside the CNS using:
    - Nerves
    - Nuclei
    - Tracts

15-1 Sensory Information

- Somatic Motor Portion of the Efferent Division
  - Controls peripheral effectors
• Somatic Motor Commands
  o Travel from motor centers in the brain along somatic motor pathways of:
    ▪ Motor nuclei
    ▪ Tracts
    ▪ Nerves

15-1 Sensory Information
• Somatic Nervous System (SNS)
  o Motor neurons and pathways that control skeletal muscles

15-2 Sensory Receptors
• General Senses
  o Describe our sensitivity to:
    ▪ Temperature
    ▪ Pain
    ▪ Touch
    ▪ Pressure
    ▪ Vibration
    ▪ Proprioception

15-2 Sensory Receptors
• Sensation
  o The arriving information from these senses
• Perception
  o Conscious awareness of a sensation

15-2 Sensory Receptors
• Special Senses
  o Olfaction (smell)
  o Vision (sight)
  o Gustation (taste)
  o Equilibrium (balance)
  o Hearing

15-2 Sensory Receptors
• The Special Senses
  o Are provided by special sensory receptors
• Special Sensory Receptors
  o Are located in sense organs such as the eye or ear
  o Are protected by surrounding tissues
15-2 Sensory Receptors

The Detection of Stimuli
- Receptor specificity
  - Each receptor has a characteristic sensitivity
- Receptive field
  - Area is monitored by a single receptor cell
  - The larger the receptive field, the more difficult it is to localize a stimulus

The Interpretation of Sensory Information
- Arriving stimulus reaches cortical neurons via labeled line
  - Takes many forms (modalities)
    - Physical force (such as pressure)
    - Dissolved chemical
    - Sound
    - Light

Sensations
- Taste, hearing, equilibrium, and vision provided by specialized receptor cells
- Communicate with sensory neurons across chemical synapses

Adaptation
- Reduction in sensitivity of a constant stimulus
- Your nervous system quickly adapts to stimuli that are painless and constant

Tonic receptors
- Are always active
- Show little peripheral adaptation
- Are slow-adapting receptors
- Remind you of an injury long after the initial damage has occurred
Phasic receptors
- Are normally inactive
- Become active for a short time whenever a change occurs
- Provide information about the intensity and rate of change of a stimulus
- Are fast-adapting receptors

15-2 Sensory Receptors
- Adaptation
  - Stimulation of a receptor produces action potentials
    - Along the axon of a sensory neuron
  - The frequency and pattern of action potentials contain information
    - About the strength, duration, and variation of the stimulus
  - Your perception of the nature of that stimulus
    - Depends on the path it takes inside the CNS

15-3 Classifying Sensory Receptors
- Classifying Sensory Receptors
  - Exteroceptors provide information about the external environment
  - Proprioceptors report the positions of skeletal muscles and joints
  - Interoceptors monitor visceral organs and functions

15-3 Classifying Sensory Receptors
- Proprioceptors
  - Provide a purely somatic sensation
  - No proprioceptors in the visceral organs of the thoracic and abdominopelvic cavities
    - You cannot tell where your spleen, appendix, or pancreas is at the moment

15-3 Classifying Sensory Receptors
- General Sensory Receptors
  - Are divided into four types by the nature of the stimulus that excites them
    1. Nociceptors (pain)
    2. Thermoreceptors (temperature)
    3. Mechanoreceptors (physical distortion)
    4. Chemoreceptors (chemical concentration)

15-3 Classifying Sensory Receptors
- Nociceptors (Pain Receptors)
  - Are common
    - In the superficial portions of the skin
- In joint capsules
- Within the periosteum of bones
- Around the walls of blood vessels

15-3 Classifying Sensory Receptors
- Nociceptors
  - May be sensitive to:
    1. Temperature extremes
    2. Mechanical damage
    3. Dissolved chemicals, such as chemicals released by injured cells

15-3 Classifying Sensory Receptors
- Nociceptors
  - Are free nerve endings with large receptive fields
    - Branching tips of dendrites
    - Not protected by accessory structures
    - Can be stimulated by many different stimuli
    - Two types of axons - Type A and Type C fibers

15-3 Classifying Sensory Receptors
- Nociceptors
  - Myelinated Type A fibers
    - Carry sensations of fast pain, or prickling pain, such as that caused by an injection or a deep cut
    - Sensations reach the CNS quickly and often trigger somatic reflexes
    - Relayed to the primary sensory cortex and receive conscious attention

15-3 Classifying Sensory Receptors
- Nociceptors
  - Type C fibers
    - Carry sensations of slow pain, or burning and aching pain
    - Cause a generalized activation of the reticular formation and thalamus
    - You become aware of the pain but only have a general idea of the area affected

15-3 Classifying Sensory Receptors
- Thermoreceptors
  - Also called temperature receptors
  - Are free nerve endings located in:
    - The dermis
    - Skeletal muscles
    - The liver
- The hypothalamus

15-3 Classifying Sensory Receptors

- Thermoreceptors
  - Temperature sensations
    - Conducted along the same pathways that carry pain sensations
    - Sent to:
      - The reticular formation
      - The thalamus
      - The primary sensory cortex (to a lesser extent)

- Mechanoreceptors
  - Sensitive to stimuli that distort their plasma membranes
  - Contain *mechanically gated ion channels* whose gates open or close in response to:
    - Stretching
    - Compression
    - Twisting
    - Other distortions of the membrane

15-3 Classifying Sensory Receptors

- Three Classes of Mechanoreceptors
  1. Tactile receptors
     - Provide the sensations of touch, pressure, and vibration
     - Touch sensations provide information about shape or texture
     - Pressure sensations indicate degree of mechanical distortion
     - Vibration sensations indicate pulsing or oscillating pressure

15-3 Classifying Sensory Receptors

- Three Classes of Mechanoreceptors
  2. Baroreceptors
     - Detect pressure changes in the walls of blood vessels and in portions of the digestive, respiratory, and urinary tracts

15-3 Classifying Sensory Receptors

- Three Classes of Mechanoreceptors
  3. Proprioceptors
     - Monitor the positions of joints and muscles
     - The most structurally and functionally complex of general sensory receptors
15-3 Classifying Sensory Receptors

- **Tactile Receptors**
  - **Fine touch and pressure receptors**
    - Are extremely sensitive
    - Have a relatively narrow receptive field
    - Provide detailed information about a source of stimulation
      - Including its exact location, shape, size, texture, movement
  - **Crude touch and pressure receptors**
    - Have relatively large receptive fields
    - Provide poor localization
    - Give little information about the stimulus

15-3 Classifying Sensory Receptors

- **Six Types of Tactile Receptors in the Skin**
  1. **Free nerve endings**
     - Sensitive to touch and pressure
     - Situated between epidermal cells
     - Free nerve endings providing touch sensations are tonic receptors with small receptive fields

15-3 Classifying Sensory Receptors

- **Six Types of Tactile Receptors in the Skin**
  2. **Root hair plexus nerve endings**
     - Monitor distortions and movements across the body surface wherever hairs are located
     - Adapt rapidly, so are best at detecting initial contact and subsequent movements

15-3 Classifying Sensory Receptors

- **Six Types of Tactile Receptors in the Skin**
  3. **Tactile discs**
     - Also called *Merkel discs*
     - Fine touch and pressure receptors
     - Extremely sensitive tonic receptors
     - Have very small receptive fields

15-3 Classifying Sensory Receptors

- **Six Types of Tactile Receptors in the Skin**

© 2015 Pearson Education, Inc.
4. **Tactile corpuscles**  
   - Also called *Meissner’s corpuscles*  
   - Perceive sensations of fine touch, pressure, and low-frequency vibration  
   - Adapt to stimulation within 1 second after contact  
   - Fairly large structures  
   - Most abundant in the eyelids, lips, fingertips, nipples, and external genitalia

15-3 **Classifying Sensory Receptors**

- Six Types of Tactile Receptors in the Skin
  5. **Lamellated corpuscles**  
     - Also called *pacinian corpuscles*  
     - Sensitive to deep pressure  
     - Fast-adapting receptors  
     - Most sensitive to pulsing or high-frequency vibrating stimuli

6. **Ruffini corpuscles**
   - Also sensitive to pressure and distortion of the skin  
   - Located in the reticular (deep) dermis  
   - Tonic receptors that show little if any adaptation

15-3 **Classifying Sensory Receptors**

- Six Types of Tactile Receptors in the Skin
  6. **Baroreceptors**
     - Monitor change in pressure  
     - Consist of free nerve endings that branch within elastic tissues  
       - In wall of distensible organ (such as a blood vessel)  
     - Respond immediately to a change in pressure, but adapt rapidly

15-3 **Classifying Sensory Receptors**

- **Proprioceptors**
  - Monitor:
    - Position of joints  
    - Tension in tendons and ligaments  
    - State of muscular contraction

15-3 **Classifying Sensory Receptors**

- Three Major Groups of Proprioceptors
  1. *Muscle spindles*
  2. *Golgi tendon organs*
3. **Receptors in joint capsules**

### 15-3 Classifying Sensory Receptors

- **Muscle Spindles**
  - Monitor skeletal muscle length
  - Trigger stretch reflexes

- **Golgi Tendon Organs**
  - Located at the junction between skeletal muscle and its tendon
  - Stimulated by tension in tendon
  - Monitor external tension developed during muscle contraction

### 15-3 Classifying Sensory Receptors

- **Receptors in Joint Capsules**
  - Free nerve endings detect pressure, tension, movement at the joint

### 15-3 Classifying Sensory Receptors

- **Chemoreceptors**
  - Respond only to water-soluble and lipid-soluble substances dissolved in surrounding fluid
  - Receptors exhibit peripheral adaptation over period of seconds
    - Central adaptation may also occur

### 15-3 Classifying Sensory Receptors

- Chemoreceptors
  - Receptors that monitor pH, carbon dioxide, and oxygen levels in arterial blood are located in:
    - **Carotid bodies**
      - Near the origin of the internal carotid arteries on each side of the neck
    - **Aortic bodies**
      - Between the major branches of the aortic arch

### 15-4 Sensory Pathways

- **First-Order Neuron**
  - Sensory neuron delivers sensations to the CNS
  - Cell body of a first-order general sensory neuron is located in dorsal root ganglion or cranial nerve ganglion

- **Second-Order Neuron**
  - Axon of the sensory neuron synapses on an interneuron in the CNS
  - May be located in the spinal cord or brain stem
15-4 Sensory Pathways

- **Third-Order Neuron**
  - If the sensation is to reach our awareness, the second-order neuron synapses
    - On a third-order neuron in the thalamus

15-4 Sensory Pathways

- **Somatic Sensory Pathways**
  - Carry sensory information from the skin and musculature of the body wall, head, neck, and limbs
  - Three major somatic sensory pathways
    1. *The spinothalamic pathway*
    2. *The posterior column pathway*
    3. *The spinocerebellar pathway*

15-4 Sensory Pathways

- **The Spinothalamic Pathway**
  - Provides conscious sensations of poorly localized (“crude”) touch, pressure, pain, and temperature
  - First-order neurons
    - Axons of first-order sensory neurons enter spinal cord
      - And synapse on second-order neurons within posterior gray horns

15-4 Sensory Pathways

- **The Spinothalamic Pathway**
  - Second-order neurons
    - Cross to the opposite side of the spinal cord before ascending
    - Ascend within the anterior or lateral *spinothalamic tracts*
      - The anterior tracts carry crude touch and pressure sensations
      - The lateral tracts carry pain and temperature sensations

15-4 Sensory Pathways

- **The Spinothalamic Pathway**
  - Third-order neurons
    - Synapse in ventral nucleus group of the thalamus
    - After the sensations have been sorted and processed, they are relayed to primary sensory cortex

15-4 Sensory Pathways

- **Feeling Pain (Lateral Spinothalamic Tract)**
  - An individual can feel pain in an *uninjured* part of the body when pain
actually originates at another location
  o Strong visceral pain
    ▪ Sensations arriving at segment of spinal cord can stimulate interneurons that are part of spinothalamic pathway
    ▪ Activity in interneurons leads to stimulation of primary sensory cortex, so an individual feels pain in specific part of body surface

15-4 Sensory Pathways
• Feeling Pain (Lateral Spinothalamic Tract)
  o Referred pain
    ▪ The pain of a heart attack is frequently felt in the left arm
    ▪ The pain of appendicitis is generally felt first in the area around the navel and then in the right, lower quadrant

15-4 Sensory Pathways
• Posterior Column Pathway
  o Carries sensations of highly localized (“fine”) touch, pressure, vibration, and proprioception
  o Spinal tracts involved
    ▪ Left and right fasciculus gracilis
    ▪ Left and right fasciculus cuneatus

15-4 Sensory Pathways
• Posterior Column Pathway
  o Axons synapse
    ▪ On third-order neurons in one of the ventral nuclei of the thalamus
    ▪ Nuclei sort the arriving information according to:
      o The nature of the stimulus
      o The region of the body involved

15-4 Sensory Pathways
• Posterior Column Pathway
  o Processing in the thalamus
    ▪ Determines whether you perceive a given sensation as fine touch, as pressure, or as vibration
  o 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

15-4 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

15-4 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

15-4 Sensory Pathways
- The Spinocerebellar Pathway
  - Cerebellum receives proprioceptive information about position of:
    - Skeletal muscles
    - Tendons
    - Joints

15-4 Sensory Pathways
- The Spinocerebellar Tracts
  - The posterior spinocerebellar tracts
    - Contain second-order axons that do not cross over to the opposite side of the spinal cord
      - Axons reach cerebellar cortex via inferior cerebellar peduncle of that side

15-4 Sensory Pathways
- The Spinocerebellar Tracts
  - The anterior spinocerebellar tracts
    - Dominated by second-order axons that have crossed over to opposite side of spinal cord

15-4 Sensory Pathways
- The Spinocerebellar Tracts
  - Contain a significant number of uncrossed axons as well
    - Sensations reach the cerebellar cortex via superior cerebellar
15-4 Sensory Pathways

- Sensory Information
  - Most somatic sensory information
    - Is relayed to the thalamus for processing
  - A small fraction of the arriving information
    - Is projected to the cerebral cortex and reaches our awareness

15-4 Sensory Pathways

- Visceral Sensory Pathways
  - Collected by interoceptors monitoring visceral tissues and organs, primarily within the thoracic and abdominopelvic cavities
  - These interoceptors are not as numerous as in somatic tissues

15-4 Sensory Pathways

- Visceral Sensory Pathways
  - Interoceptors include:
    - Nociceptors
    - Thermoreceptors
    - Tactile receptors
    - Baroreceptors
    - Chemoreceptors

15-4 Sensory Pathways

- Visceral Sensory Pathways
  - Cranial Nerves V, VII, IX, and X
    - Carry visceral sensory information from mouth, palate, pharynx, larynx, trachea, esophagus, and associated vessels and glands

15-4 Sensory Pathways

- Visceral Sensory Pathways
  - Solitary nucleus
    - Large nucleus in the medulla oblongata
    - Major processing and sorting center for visceral sensory information
    - Extensive connections with the various cardiovascular and respiratory centers, reticular formation
15-5 Somatic Motor Pathways

- The Somatic Nervous System (SNS)
  - Also called the somatic motor system
    - Controls contractions of skeletal muscles (discussed next)
- The Autonomic Nervous System (ANS)
  - Also called the visceral motor system
    - Controls visceral effectors, such as smooth muscle, cardiac muscle, and glands (Ch. 16)

15-5 Somatic Motor Pathways

- Somatic Motor Pathways
  - Always involve at least two motor neurons
    1. Upper motor neuron
    2. Lower motor neuron

15-5 Somatic Motor Pathways

- Upper Motor Neuron
  - Cell body lies in a CNS processing center
  - Synapses on the lower motor neuron
  - Innervates a single motor unit in a skeletal muscle
    - Activity in upper motor neuron may facilitate or inhibit lower motor neuron

15-5 Somatic Motor Pathways

- Lower Motor Neuron
  - Cell body lies in a nucleus of the brain stem or spinal cord
  - Triggers a contraction in innervated muscle
    - Only axon of lower motor neuron extends outside CNS
    - Destruction of or damage to lower motor neuron eliminates voluntary and reflex control over innervated motor unit

15-5 Somatic Motor Pathways

- Conscious and Subconscious Motor Commands
  - Control skeletal muscles by traveling over three integrated motor pathways
    1. Corticospinal pathway
    2. Medial pathway
    3. Lateral pathway

15-5 Somatic 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

15-5 Somatic Motor Pathways
- The Corticospinal Pathway
  - Contains three pairs of descending tracts
    1. Corticobulbar tracts
    2. Lateral corticospinal tracts
    3. Anterior corticospinal tracts

15-5 Somatic Motor Pathways
- Corticobulbar Tracts
  - Provide conscious control over skeletal muscles that move the eye, jaw, face, and some muscles of neck and pharynx
  - Innervate motor centers of medial and lateral pathways

15-5 Somatic Motor Pathways
- Corticospinal Tracts
  - As they descend, lateral corticospinal tracts are visible along the ventral surface of medulla oblongata as a pair of thick bands, the pyramids
  - At spinal segment it targets, an axon in anterior corticospinal tract crosses over to opposite side of spinal cord in anterior white commissure before synapsing on lower motor neurons in anterior gray horns

15-5 Somatic 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

15-5 Somatic Motor Pathways
- The Corticospinal Pathway
  - Motor homunculus
    - 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

© 2015 Pearson Education, Inc.
These proportions are similar to the sensory homunculus

15-5 Somatic Motor Pathways
• The Medial and Lateral Pathways
  o Several centers in cerebrum, diencephalon, and brain stem may issue somatic motor commands as result of processing performed at subconscious level
  o 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

15-5 Somatic Motor Pathways
• The **Medial Pathway**
  o Primarily concerned with control of muscle tone and gross movements of neck, trunk, and proximal limb muscles
  o Upper motor neurons of medial pathway are located in:
    ▪ **Vestibular nuclei**
    ▪ **Superior and inferior colliculi**
    ▪ **Reticular formation**

15-5 Somatic Motor Pathways
• The **Medial Pathway**
  o Vestibular nuclei
    ▪ Receive information over the vestibulocochlear nerve (VIII) from receptors in inner ear that monitor position and movement of the head
    ▪ Primary goal is to maintain posture and balance
    ▪ Descending fibers of spinal cord constitute **vestibulospinal tracts**

15-5 Somatic Motor Pathways
• The **Medial Pathway**
  o Superior and inferior colliculi
    ▪ Are located in the roof of the mesencephalon, or the **tectum**
    ▪ Colliculi receive visual (superior) and auditory (inferior) sensations
    ▪ Axons of upper motor neurons in colliculi descend in **tectospinal tracts**
    ▪ These axons cross to opposite side, before descending to synapse on lower motor neurons in brain stem or spinal cord

15-5 Somatic Motor Pathways
• The Medial Pathway
Reticular formation
- Loosely organized network of neurons that extends throughout brain stem
- Axons of upper motor neurons in reticular formation descend into reticulospinal tracts without crossing to opposite side

15-5 Somatic Motor Pathways
- The Lateral Pathway
  - Primarily concerned with control of muscle tone and more precise movements of distal parts of limbs
  - Axons of upper motor neurons in red nuclei cross to opposite side of brain and descend into spinal cord in rubrospinal tracts

15-5 Somatic Motor Pathways
- The Basal Nuclei and Cerebellum
  - Responsible for coordination and feedback control over muscle contractions
    - Whether contractions are consciously or subconsciously directed

15-5 Somatic Motor Pathways
- The Basal Nuclei
  - Provide background patterns of movement involved in voluntary motor activities
    - Some axons extend to the premotor cortex, the motor association area that directs activities of the primary motor cortex
    - Alters the pattern of instructions carried by the corticospinal tracts
    - Other axons alter the excitatory or inhibitory output of the reticulospinal tracts

15-5 Somatic Motor Pathways
- The Cerebellum
  - Monitors:
    - Proprioceptive (position) sensations
    - Visual information from the eyes
    - Vestibular (balance) sensations from inner ear as movements are under way

15-5 Somatic Motor Pathways
- Levels of Processing and Motor Control
  - All sensory and motor pathways involve a series of synapses, one after the other
  - General pattern

© 2015 Pearson Education, Inc.
Spinal and cranial reflexes provide rapid, involuntary, preprogrammed responses that preserve homeostasis over short term

15-5 Somatic Motor Pathways
• Levels of Processing and Motor Control
  o Cranial and spinal reflexes
    ▪ Control the most basic motor activities

15-5 Somatic Motor Pathways
• Levels of Processing and Motor Control
  o Integrative centers in the brain
    ▪ Perform more elaborate processing
    ▪ As we move from medulla oblongata to cerebral cortex, motor patterns become increasingly complex and variable
  o Primary motor cortex
    ▪ Most complex and variable motor activities are directed by primary motor cortex of cerebral hemispheres

15-5 Somatic Motor Pathways
• Levels of Processing and Motor Control
  o Neurons of the primary motor cortex
    ▪ Innervate motor neurons in the brain and spinal cord responsible for stimulating skeletal muscles
  o Higher centers in the brain
    ▪ Can suppress or facilitate reflex responses
  o Reflexes
    ▪ Can complement or increase the complexity of voluntary movements