Chapter 15: Neural Integration I: Sensory Pathways and the Somatic Nervous System

I. An Overview of Sensory Pathways and the Somatic Nervous System, p. 496

Figure 15-1

- Specialized cells called sensory receptors monitor specific conditions in the body or the external environment.

- When stimulated, a receptor passes information to the CNS in the form of action potentials along the axon of a sensory neuron.

- Sensory pathways deliver somatic and visceral sensory information to their final destinations inside the CNS using:
    1. nerves
    2. nuclei
    3. tracts

- Taken together, the receptors, sensory neurons and sensory pathways constitute the afferent division of the nervous system.

- Somatic sensory information is distributed to sensory processing centers in the brain.

- Visceral sensory information is distributed primarily to reflex centers in the brain stem and diencephalons.

II. Sensory Receptors and Their Classification, p. 496

- Sensory receptors are specialized cells or cell processes that provide your central nervous system with information about conditions inside or outside the body.

- <u>General senses</u> describes our sensitivity to:
    1. temperature
    2. pain
    3. touch
    4. pressure
    5. vibration
    6. proprioception

- The arriving information they send to the CNS reaches the primary sensory corex and our awareness.

- The arriving information is called a sensation and the conscious awareness of a sensation is called a perception.

- The special senses are:
    1. olfaction (smell)
    2. vision (sight)
    3. gestation (taste)
    4. equilibrium (balance)
    5. hearing

- Special sensory receptors are located in sense organs such as the eye or ear, where the receptors are protected by surrounding tissues.

Sensory Receptors, p. 497

- A sensory receptor detects an arriving stimulus and translates it into an action potential that can be conducted to the CNS.

- The translation process is called transduction.

The Detection of Stimuli, p. 497

- Each receptor has a characteristic sensitivity.

- The simplest receptors are the dendrites of sensory neurons.

- Free nerve endings are the branching tips of these dendrites that are not protected by accessory structures.

- Free nerve endings can be stimulated by many different stmuli.

- The area monitored by a single receptor cell is its receptive field.

Figure 15-2

- Whenever a sufficiently strong stimulus arrives in the receptive field, the CNS receives the information "stimulus arriving at receptor X."

- The larger the receptive field, the poorer your ability to localize a stimulus.

- An arriving stimulus can take many forms:
    1. physical force (such as pressure)
    2. dissolved chemical
    3. sound
    4. light

- Transduction begins when a stimulus changes the transmembrane potential of the receptor cell. This is called a receptor potential.

- A receptor potential large enough to produce an action potential is called a generator potential.

- Sensations of taste, hearing, equilibrium, and vision are provided by specialized receptor cells that communicate with sensory neurons across chemical synapses.

- The receptor potential develops in the receptor cell, and the generator potential appears later, in the sensory neuron.

The Interpretation of Sensory Information, p. 497

- Sensory information that arrives at the CNS is routed according to the location and nature of the stimulus.

- The link between peripheral receptor and cortical neuron is called a labeled line. Each labeled line consists of axons carrying information about one type of stimulus.

- The following characteristics of the stimulus are conveyed by the frequency and pattern of action potentials:
    1. strength
    2. duration
    3. variation

- The translation of complex sensory information into meaningful patterns of action potentials is called sensory coding.

- <u>Tonic receptors</u> are always active

- <u>Phasic receptors</u> are normally inactive, but become active for a short time whenever a change occurs in the conditions they are monitoring. They provide information about the intensity and rate of change of a stimulus.

Adaptation, p. 498

- <u>Adaptation</u> is a reduction in sensitivity in the presence of a constant stimulus. Your nervous system quickly adapts to stimuli that are painless and constant.

- Peripheral adaptation occurs when the level of receptor activity changes. The receptor responds strongly at first but then gradually declines.

- This response characteristic of phasic receptors are also called <u>fast-adapting receptors</u>.

- Tonic receptors show little peripheral adaptation and are called slow-adapting receptors. These receptors remind you of an injury long after the initial damage has occurred.

- Adaptation also occurs along sensory pathways inside the CNS. This process is known as central adaptation and generally involves the inhibition of nuclei along a sensory pathway.

- Peripheral adaptation reduces the amount of information that reaches the CNS. Central adaptation at the subconscious level further restricts the amount of detail that arrives at the cerebral cortex.

- Most of the incoming sensory information is processed in centers along the spinal cord or brain stem at the subconscious level. We are seldom consciously aware of either the stimuli or the responses.

- The reticular activating system in the mesencephalon helps focus our attention and heightens or reduces our awareness of arriving sensations. This adjustment can occur under conscious or subconscious direction.

- ***Key:*** **Stimulation of a receptor produces action potentials along the axon of a sensory neuron. The frequency and pattern of action potentials contains 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.**

The General Senses, p. 498

- Receptors for the general senses are scattered throughout the body and have a relatively simple structure. They can be divided into:
    1. exteroceptors – provide information about the external environment
    2. proprioceptors – report the positions of skeletal muscles and joints
    3. interoceptors – monitor visceral organs and functions

- A more detailed classification system divides the general sensory receptors 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)

- The difference between a somatic receptor and a visceral receptor is its location, not its structure.

- Proprioception is a purely somatic sensation. There are 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.

- The visceral organs have fewer pain, temperature, and touch receptors than elsewhere in the body. The sensory information received is poorly localized because the receptive fields are very large and may be widely separated.

- Only about 1% of the information provided by afferent fibers reaches the cerebral cortex and our awareness.

Nociceptors, p. 499

- Pain receptors, called <u>nociceptors</u>, are common in the following areas:
    1. superficial portions of the skin
    2. joint capsules
    3. within the periostea of bones
    4. around the walls of blood vessels

- Pain receptors are free nerve endings with large receptive fields.

Figure 15-2

- Nociceptors may be sensitive to:
    1. extremes of temperature
    2. mechanical damage
    3. dissolved chemicals, such as chemicals released by injured cells

- Very strong stimuli will excite all three receptor types, causing people to use similar descriptive terms such as "burning" to describe pain caused by acids, heat, or a deep cut.

- Stimulation of the nociceptor dendrites causes depolarization. When the initial segment of the axon reaches threshold, an action potential heads toward the CNS.

- Two types of axons carry painful sensations: Type A and Type C fibers.
    1. Myelinated Type A fibers carry sensations of <u>fast pain</u>, or prickling pain, such as that caused by an injection or deep cut. These sensations reach the CNS very quickly and often trigger somatic reflexes. They are also relayed to the primary sensory cortex and receive conscious attention.
    2. Type C fibers carry sensations of <u>slow pain</u>, or burning and aching pain. These sensations 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.

- Pain receptors are tonic receptors. The receptors continue to respond as long as the painful stimulus remains and the painful sensations stop only after tissue damage has ended.

- Central adaptation may reduce the perception of the pain while the receptors remain stimulated.

- Pain distribution and perception are extremely complex.

- The sensory neurons that bring pain sensations into the CNS release glutamate and/or substance P as neurotransmitters. These neurotransmitters produce facilitation of neurons along the pain pathways.
    1. The result is the level of pain experienced (especially chronic pain) can be out of proportion to the amount of painful stimuli or the apparent tissue damage.

- The level of pain felt by a person can be reduced by the release of endorphis and enkephalins within the CNS.

- Endorphis and enkephalins are neuromodulators whose release inhibits activity along pain pathways in the brain.

- These compounds are structurally similar to morphine and are found in:
    1. the limbic system
    2. hypothalamus
    3. reticular formation

- Endorphins bind to the presynaptic membrane and prevent the release of substance P, which reduces the conscious perception of pain even when the painful stimulus remains.

Thermoreceptors, p. 500

- Temperature receptors, or <u>thermoreceptors</u>, are free nerve endings located in:
    1. the dermis
    2. skeletal muscles
    3. the liver
    4. the hypothalamus

- Cold receptors are three or four times more numerous than warm receptors. No structural differences between cold and warm thermoreceptors has been found.

- Temperature sensations are conducted along the same pathways that carry pain sensations. They are sent to:
    1. the reticular formation
    2. the thalamus

3. the primary sensory cortex (to a lesser extent)

- Thermoreceptors are phasic receptors:
  1. they are very active when the temperature is changing
  2. but quickly adapt to a stable temperature

Mechanoreceptors, p. 500

- Mechanoreceptors are sensitive to stimuli that distort their cell membranes, which contain mechanically regulated ion channels whose gates open or close in response to:
  1. stretching
  2. compression
  3. twisting
  4. or other distortions of the membrane

- There are three classes of mechanoreceptors:
  1. Tactile receptors provide the sensations of touch, pressure, and vibration.
     a. Touch sensations provide information about shape or texture.
     b. Pressure sensations indicate the degree of mechanical distortion.
     c. Vibration sensations indicate a pulsing or oscillating pressure.
  2. Baroreceptors detect pressure changes in the walls of blood vessels and in portions of the digestive, reproductive, and urinary tracts.
  3. Proprioceptors monitor the positions of joints and muscles. They are the most structurally and functionally complex of the general sensory receptors.

Tactile Receptors, p. 500

- Fine touch and pressure receptors are extremely sensitive and have a relatively narrow receptive field. They provide detailed information about a source of stimulation, including:
  1. its exact location
  2. shape
  3. size
  4. texture
  5. movement

- Crude touch and pressure receptors have relatively large receptive fields, provide poor localization, and give little information about the stimulus.

- Tactile receptors range in complexity from free nerve endings to specialized sensory complexes with accessory cells and supporting structures.

Figure 15-3

- There are six types of tactile receptors in the skin:

  1. Free nerve endings sensitive to touch and pressure are situated between epidermal cells. Free nerve endings that provide touch sensations are tonic receptors with small receptive fields.

Figure 15-3a

  2. Nerve endings of the <u>root hair plexus</u> monitor distortions and movements across the body surface wherever hairs are located. These receptors adapt rapidly, so are best at detecting initial contact and subsequent movements.

Figure 15-3b

  3. <u>Tactile discs</u>, or Merkel's discs, are fine touch and pressure receptors. They are extremely sensitive to tonic receptors and have very small receptive fields.

Figure 15-3c

  4. <u>Tactile corpuscles</u>, or Meissner's corpuscles, perceive sensations of fine touch and pressure and low-frequency vibration. They adapt to stimulation within a second after contact.

     a. Tactile corpuscles are fairly large structures and are most abundant in the eyelids, lips, fingertips, nipples, and external genitalia.

Figure 15-3d

  5. <u>Lamellated corpuscles</u>, or pacinian corpuscles, are sensitive to deep pressure. They are fast-adapting receptors and are most sensitive to pulsing or high-frequency vibrating stimuli.

     1. The concentric layers, separated by interstitial fluid, shield the dendrite from virtually every source of stimulation other than direct pressure.
     2. Lamellated corpuscles adapt quickly because distortion of the capsule soon relieves pressure on the sensory process.
     3. Somatic sensory information comes from lamellated corpuscles located throughout the dermis, especially in the fingers, mammary glands, and external genitalia; in the superficial and deep fasciae; and in joint capsules.
     4. Visceral sensory information comes from lamellated corpuscles in mesenteries, in the pancreas, and in the walls of the urethra and urinary bladder.

Figure 15-3e

  6. <u>Ruffini corpuscles</u> are also sensitive to pressure and distortion of the skin, but they are located in the reticular (deep) dermis. These receptors are tonic and show little if any adaptation.

Figure 15-3f

- Sensitivity to tactile sensations may be altered by:

  1. infection
  2. disease

3. damage to sensory neurons or pathways

- Mapping tactile responses can sometimes aid clinical assessment.
  1. Sensory losses with clear regional boundaries indicate trauma to spinal nerves.
  2. Regional sensitivity to light touch can be checked by gentle contact with a fingertip or slender wisp of cotton.
  3. Vibration receptors are tested by applying the base of a vibrating tuning fork to the skin.

- Tickle and itch sensations are closely related to the sensations of touch and pain. The receptors are free nerve endings and the information is carried by unmyelinated Type C fibers.
  1. Psychological factors are involved in the interpretation of tickle sensations and sensitivity differs greatly among individuals.
  2. Itching is more unpleasant than pain. Individuals with extreme itching will scratch even when pain is the result. The precise receptor mechanism is unknown.

Baroreceptors, p. 502

- Baroreceptors monitor change in pressure and consists of free nerve endings that branch within the elastic tissues in the wall of a distensible organ (such as a blood vessel). When the pressure changes, the movement distorts the dendritic branches and alters the rate of action potential generation.

- Baroreceptors respond immediately to a change in pressure, but they adapt rapidly.

- Baroreceptors monitor:
  1. blood pressure in the walls of major vessels, including the carotid artery and the aorta
  2. the degree of lung expansion
  3. various sites in the digestive and urinary tracts

Proprioceptors, p. 502

- Proprioceptors monitor:
  1. the position of joints
  2. the tension in tendons and ligaments
  3. the state of muscular contraction.

- There are three major groups of proprioceptors:
  1. Muscle spindles - monitor skeletal muscle length and trigger stretch reflexes.

2. Golgi tendon organs – are similar in function to Ruffini corpuscles, but are located at the junction between a skeletal muscle and its tendon. These receptors are stimulated by tension in the tendon and monitor the external tension developed during muscle contraction.
3. Receptors in joint capsules – these free nerve endings detect pressure, tension, and movement at the joint.

- Proprioceptors do not adapt to constant stimulation and each receptor continuously sends information to the CNS. Most proprioceptive information is processed at subconscious levels.

Chemoreceptors, p. 502

- Chemoreceptors respond only to water-soluble and lipid-soluble substances that are dissolved in the surrounding fluid. These receptors exhibit peripheral adaptation over a period of seconds, and central adaptation may also occur.

- The chemoreceptors in the general senses do not send information to the primary sensory cortex, so we are not consciously aware of these sensations.

- The arriving sensory information is routed to brain stem centers that deal with the autonomic control of respiratory and cardiovascular functions. Neurons in these respiratory centers respond to the concentration of hydrogen ions (pH) and levels of carbon dioxide molecules in the cerebrospinal fluid.

- Chemoreceptive neurons are also located in the carotid bodies, near the origin of the internal carotid arteries on each side of the neck, and in the aortic bodies, between the major branches of the aortic arch.
    1. These receptors monitor the Ph and the carbon dioxide and oxygen levels in arterial blood.

III. The Organization of Sensory Pathways, p. 503

- A first-order neuron is a sensory neuron that delivers sensations to the CNS. The cell body of a first-order general sensory neuron is located in the dorsal root ganglion or cranial nerve ganglion.

- In the CNS, the axon of that sensory neuron synapses on an interneuron known as a second-order neuron, may be located in the spinal cord or brain stem.

- If the sensation is to reach our awareness, the second-order neuron synapses on a third-order neuron in the thalamus.

- Somewhere along its length, the axon of the second-order neuron crosses over to the opposite side of the CNS.

1. As a result, the right side of the thalamus receives sensory information from the left side, and vice versa.

- The axons of the third-order neurons ascend without crossing over and synapse on neurons of the primary sensory cortex of the cerebral hemisphere.
    1. As a result, the right cerebral hemisphere receives sensory information from the left side of the body, and the left cerebral hemisphere receives sensations from the right side.

- Although it has no apparent functional benefit, crossover occurs along sensory and motor pathways in all vertebrates.

Somatic Sensory Pathways, p. 503

- Somatic sensory pathways carry sensory information from the skin and musculature of the body wall, head, neck, and limbs.

- There are three major somatic sensory pathways:
    1. the posterior column pathway
    2. the anterolateral pathway
    3. the spinocerebellar pathway

- These pathways utilize pairs of spinal tracts, symmetrically arranged on opposite sides of the spinal cord.

- All the axons within a tract share a common origin and destination.

Figure 15-4

- Tract names often give clues to their function.
    1. If the name of a tract begins with *spino-*, the tract must start in the spinal cord and end in the brain.
        a. It must therefore be an ascending tract that carries sensory information.
    2. The rest of the name indicates the tract's destination.
        a. A spinothalamic tract begins in the spinal cord and carries sensory information to the thalamus.
    3. If the name of a tract ends in *–spinal*, the tract ends in the spinal cord and starts in a higher center of the brain.
        a. It must therefore be a descending tract that carries motor commands.
    4. The first part of the name indicates the nucleus or cortical area of the brain where the tract originates.
        a. A corticospinal tract carries motor commands from the cerebral cortex to the spinal cord.

The Posterior Column Pathway, p. 504

- The posterior column pathway carries sensations of highly localized ("fine") touch, pressure, vibration, and proprioception.

Figure 15-5a

- This pathway, also known as the dorsal column/medial lemniscus, begins at a peripheral receptor and ends at the primary sensory cortex of the cerebral hemispheres.

- The spinal tracts involved are the left and right fasciculus gracilis and the left and right fasciculus cuneatus.
    1. On each side of the posterior median sulcus, the fasciculus gracilis is medial to the fasciculus cuneatus.

- The axons of the first-order neurons reach the CNS within the dorsal roots of spinal nerves and the sensory roots of cranial nerves.
    1. The axons ascending within the posterior column are organized according to the region innervated.
        a. Axons carrying sensations from the inferior half of the body ascend within the fasciculus gracilis and synapse in the nucleus gracilis of the medulla oblongata.
        b. Axons carrying sensations from the superior half of the trunk, upper limbs, and nick ascend in the fasciculus cuneatus and synapse in the nucleus cuneatus.

- Axons of the second-order neurons of the nucleus gracilis and nucleus cuneatus ascend to the thalamus.
    1. As they ascend, these axons cross over to the opposite side of the brain stem. This crossing of an axon is called decussation.
    2. Once on the opposite side of the brain, the axons enter a tract called the medial lemniscus.
    3. As it ascends, the medial lemniscus runs alongside a smaller tract that carries sensory information from the face, relayed from the sensory nuclei of the trigeminal nerve.

- The axons in these tracts synapse on third-order neurons in one of the ventral nuclei of the thalamus. These nuclei sort the arriving information according to:
    1. the nature of the stimulus
    2. the region of the body involved

- Processing in the thalamus determines whether you perceive a given sensation as fine touch, as pressure, or vibration.

- Our ability to determine precisely where on the body a specific stimulus originated depends on the projection of information from the thalamus to the primary sensory cortex.

- Sensory information from the toes arrives at one end of the primary sensory cortex, and information from the head arrives at the other.
    1. When neurons in one portion of your primary sensory cortex are stimulated, you become aware of sensations originating at a specific location.

- If your primary sensory cortex were damaged or the projection fibers were cut, you could detect a light touch but would be unable to determine its source.

- The same sensations are reported whether the cortical neurons are activated by axons ascending from the thalamus or by direct electrical stimulation.
    1. Researchers have electrically stimulated the primary sensory cortex in awake individuals during brain surgery and asked the subjects where they thought the stimulus originated.
    2. The results were used to create a functional map of the primary sensory cortex, called a <u>sensory homunculus</u>.

Figure 15-5

- The proportions of the sensory homunculus are quite different from those of any individual. These distortions occur because the area of sensory cortex devoted to a particular body region is not proportional to the region's size, but to the number of sensory receptors it contains.

The Anterolateral Pathway, p. 505

- The <u>anterolateral pathway</u> provides conscious sensations of poorly localized ("crude") touch, pressure, pain, and temperature.

- In this pathway, the axons of the first-order sensory neurons enter the spinal cord and synapse on second-order neurons within the posterior gray horns.

- The axons of these interneurons cross to the opposite side of the spinal cord before ascending.

- This pathway includes relatively small tracts that deliver sensations to reflex centers in the brain stem as well as larger tracts that carry sensations destined for the cerebral cortex.

- Sensations bound for the cerebral cortex ascend within the anterior or lateral spinothalamic tracts.

1. The anterior spinothalamic tracts carry crude touch and pressure sensations.

Figure 15-5b

2. The lateral spinothalamic tracts carry pain and temperature sensations.

Figure 15-5c

3. These tracts end at third-order neurons in the ventral nucleus group of the thalamus.
4. After the sensations have been sorted and processed, they are relayed to the primary sensory cortex.

- The perception that an arriving stimulus is painful rather than cold, hot, or vibrating depends on which second-order and third-order neurons are stimulated.

- The ability to localize that stimulus to a specific location in the body depends on the stimulation of an appropriate area of the primary sensory cortex.

- Any abnormality along the pathway can result in inappropriate sensations or inaccurate localization of the source.

1. An individual can experience painful sensations that are not real.
    a. A person may continue to experience pain in an amputated limb. This phantom limb pain is caused by activity in the sensory neurons or interneurons along the anterolateral pathway.
    b. These labeled lines and pathways are developmentally programmed, even people born without limbs can have phantom limb pain.
2. An individual can feel pain in an uninjured part of the body when the pain actually originates at another location.
    a. Strong visceral pain sensations arriving at a segment of the spinal cord can stimulate interneurons that are part of the anterolateral pathway.
    a. Activity in these interneurons leads to the stimulation of the primary sensory cortex, so the individual feels pain in a specific part of the body surface. This is called 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.

Figure 15-6

The Spinocerebellar Pathway, p. 506

- The cerebellum receives proprioceptive information about the position of skeletal muscles, tendons, and joints along the spinocerebellar pathway.

Figure 15-7

- This information does not reach our awareness.

- The axons of first-order sensory neurons synapse on interneurons in the dorsal gray horns of the spinal cord.

- The axons of these second-order neurons ascend in one of the spinocerebellar tracts:
    1. The posterior spinocerebellar tracts contain axons that do not cross over to the opposite side of the spinal cord.
        a. These axons reach the cerebellar cortex via the inferior cerebellar peduncle of that side.
    2. The anterior spinocerebellar tracts are dominated by axons that have crossed over to the opposite side of the spinal cord, although they do contain a significant number of uncrossed axons as well.
        a. The sensations carried by the anterior spinocerebellar tracts reach the cerebellar cortex via the superior cerebellar peduncle.
        b. Many of the axons that cross over and ascend to the cerebellum then cross over again within the cerebellum, synapsing on the same side as the original stimulus.

- The information carried by the spinocerebellar pathway ultimately arrives at the Purkinje cells of the cerebellar cortex.
    1. Proprioceptive information from each part of the body is relayed to a specific portion of the cerebellar cortex.

Table 15-1

- ***Key:*** **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.**

Visceral Sensory Pathways, p. 507

- Visceral sensory information is collected by interoceptors monitoring visceral tissues and organs, primarily within the thoracic and abdominopelvic cavities. These interoceptors, which are not as numerous as they are in the somatic tissues, include:
    1. nociceptors
    2. thermoreceptors
    3. tactile receptors
    4. baroreceptors
    5. chemoreceptors

- The axons of the first-order neurons usually travel in company with autonomic motor fibers innervating the same visceral structures.

- Cranial nerves V, VII, IX, and X carry visceral sensory information from the mouth, palate, pharynx, larynx, trachea, esophagus, and associated vessels and glands.

- This information is delivered to the solitary nucleus, a large nucleus in the medulla oblongata.
    1. The solitary nucleus is a major processing and sorting center for visceral sensory information; it has extensive connections with the various cardiovascular and respiratory centers as well as with the reticular formation.

- The dorsal roots of spinal nerves T_1-L_2 carry visceral sensory information provided by receptors in organs located between the diaphragm and the pelvic cavity.

- The dorsal roots of spinal nerves S_2-S_4 carry visceral sensory information from organs in the inferior portion of the pelvic cavity, including:
    1. the last portion of the large intestine
    2. the urethra and base of the urinary bladder
    3. the prostate gland (males) or cervix of the uterus and adjacent portions of the vagina (females).

- The first-order neurons deliver the visceral sensory information to interneurons whose axons ascend within the anterolateral pathway.

- Most of the sensory information is delivered to the solitary nucleus, and because it never reaches the primary sensory cortex we remain unaware of these sensations.

IV. The Somatic Nervous System, p. 508

- Motor commands issued by the CNS are distributed by the somatic nervous system (SNS) and the autonomatic nervous system (ANS).
    1. The somatic nervous system, also called the somatic motor system, controls the contractions of skeletal muscles.
        a. The output of the SNS is under voluntary control.
    2. The autonomatic nervous system, also called the visceral motor system, controls visceral effectors, such as smooth muscle, cardiac muscle, and glands.

- Somatic motor pathways always involve at least two motor neurons:
    1. Upper motor neuron – cell body lies in a CNS processing center
    2. Lower motor neuron – cell body lies in a nucleus of the brain stem or spinal cord.

- The upper motor neuron synapses on the lower motor neuron, which in turn innervates a single motor unit in a skeletal muscle.

- Activity in the upper motor neuron may facilitate or inhibit the lower motor neuron.

- Activation of the lower motor neuron triggers a contraction in the innervated muscle.

- Only the axon of the lower motor neuron extends outside the CNS.

- Destruction of or damage to a lower motor neuron eliminates voluntary and reflex control over the innervated motor unit.

- Concious and subconscious motor commands control skeletal muscles by traveling over three integrated motor pathways:
    1. corticospinal pathway
    2. medial pathway
    3. lateral pathway

Figure 15-8

- Activity within these motor pathways is monitored and adjusted by the basal nuclei and cerebellum. Their output stimulates or inhibits activity of either:
    1. motor nuclei
    2. the primary motor cortex

The Corticospinal Pathway, p. 509

- The <u>corticospinal pathway</u>, sometimes called the pyramidal system, provides voluntary control over skeletal muscles.

Figure 15-9

- This system begins at the pyramidal cells of the primary motor cortex.
    1. The axons of these upper motor neurons descend into the brain stem and spinal cord to synapse on lower motor neurons that control skeletal muscles.

- In general, the corticospinal pathway is direct: The upper motor neurons synapse directly on the lower motor neurons. However, the corticospinal pathway also works indirectly, as it innervates centers of the medial and lateral pathways.

- The corticospinal pathway contains three pairs of descending tracts:
    1. coricobulbar tracts
    2. lateral corticospinal tracts
    3. anterior corticospinal tracts

-- These tracts enter the white matter of the internal capsule, descend into the brain stem, and emerge on either side of the mesencephalon as the cerebral peduncles.

The Corticobulbar Tracts, p. 509

- Axons in the corticobulbar tracts synapse on lower motor neurons in the motor nuclei of cranial nerves III, IV, V, VI, VII, IX, XI, and XII.

- The corticobulbar tracts provide conscious control over skeletal muscles that move the eye, jaw, and face, and some muscles of the neck and pharynx.

- The corticobulbar tracts also innervate the motor centers of the medial and lateral pathways.

The Corticospinal Tracts, p. 510

- Axons in the corticospinal tracts synapse on lower motor neurons in the anterior gray horns of the spinal cord.

- As they descend, the corticospinal tracts are visible along the ventral surface of the medulla oblongata as a pair of thick bands, the pyramids.

- Along the length of the pyramids, roughly 85% of the axons cross the midline (decussate) to enter the descending lateral corticospinal tracts on the opposite side of the spinal cord.

- The other 15% continue uncrossed along the spinal cord as the anterior corticospinal tracts.

- At the spinal segment it targets, an axon in the anterior corticospinal tract crosses over to the opposite side of the spinal cord in the anterior white commissure before synapsing on lower motor neurons in the anterior gray horns.

The Motor Homunculus, p. 510

- The activity of pyramidal cells in a specific portion of the primary motor cortex will result in the contraction of specific peripheral muscles.

- The identities of the stimulated muscles depend on the region of motor cortex that is active.

- As in the primary sensory cortex, the primary motor cortex corresponds point by point with specific regions of the body. The cortical areas have been mapped out in diagrammatic form, creating a motor homunculus.

Figure 15-9

- The proportions of the motor homunculus are quite different from those of the actual body, because the motor area devoted to a specific region of the cortex is proportional to the number of motor units involved in the region's control, not to its actual size.

- The homunculus provides an indication of the degree of fine motor control available.
    1. The hands, face, and tongue, all of which are capable of varied and complex movements, appear very large, while the trunk is relatively small.
    2. These proportions are similar to the sensory homunculus.

Figure 15-5

- The sensory and motor homunculi differ in other respects because some highly sensitive regions, such as the sole of the foot, contain few motor units, and some areas with an abundance of motor units, such as the eye muscles, are not particularly sensitive.

The Medial and Lateral Pathways, p. 511

- Several centers in the cerebrum, diencephalons, and brain stem may issue somatic motor commands as a result of processing performed at a subconscious level.

- These centers and their associated tracts were long known as the extrapyramidal system (EPS), because it was thought that they operated independently of, and in parallel with, the pyramidal system (corticospinal pathway). This classification is inaccurate and misleading because motor control is integrated at all levels through extensive feedback loops and interconnections.

- These nuclei and tracts are now grouped in terms of their primary functions:
    1. components of the medial pathway help control gross movements of the trunk and proximal limb muscles
    2. components of the lateral pathway help control the distal limb muscles that perform more precise movements.

- The medial and lateral pathways can modify or direct skeletal muscle contractions by stimulating, facilitating, or inhibiting lower motor neurons.

- The axons of upper motor neurons in the medial and lateral pathways synapse on the same lower motor neurons innervated by the corticospinal pathway.
    1. This means that the various motor pathways interact not only within the brain, through interconnections between the primary motor cortex and motor centers in the brain stem, but also through excitatory or inhibitory interactions at the level of the lower motor neuron.

The Medial Pathway, p. 511

- The medial pathway is primarily concerned with the control of muscle tone and gross movements of the neck, trunk, and proximal limb muscles.

- The upper motor neurons of the medial pathway are located in:
    1. the vestibular nuclei
    2. the superior and inferior colliculi
    3. the reticular formation

- The vestibular nuclei receive information, over the vestibulococlear nerve (VIII), from receptors in the inner ear that monitor the position and movement of the head.
    1. These nuclei respond to changes in the orientation of the head, sending motor commands that alter the muscle tone, extension, and position of the neck, eyes, head and limbs.
    2. The primary goal is to maintain posture and balance.
    3. The descending fibers of the spinal cord constitute the <u>vestibulospinal tracts</u>.

- The superior and inferior colliculi are located in the tectum, or roof of the mesencephalon.

Figure 14-8b

1. The colliculi receive visual (superior) and auditory (inferior) sensations.
2. Axons of upper motor neurons in the colliculi descend in the <u>tectospinal tracts</u>. These axons cross to the opposite side immediately, before descending to synapse on lower motor neurons in the brain stem or spinal cord.
3. Axons in the tectospinal tracts direct reflexive changes in the position of the head, neck, and upper limbs in response to bright lights, sudden movements, or loud noises.

- The reticular formation is a loosely organized network of neurons that extends throughout the brain stem.
    1. The reticular formation receives input from almost ever ascending and descending pathway. It also has extensive interconnections with the cerebrum, the cerebellum, and brain stem nuclei.
    2. Axons of the upper motor neurons in the reticular formation descend into the <u>reticulospinal tracts</u> without crossing to the opposite side.
    3. The effects of reticular formation stimulation are determined by the region stimulated.
        a. The stimulation of upper motor neurons in one portion of the reticular formation produces eye movements, whereas the stimulation of another portion activates respiratory muscles.

The Lateral Pathway, p. 511

- The lateral pathway is primarily concerned with the control of muscle tone and the more precise movements of the distal parts of the limbs.
    1. The upper motor neurons of the lateral pathway lie within the red nuclei of the mesencephalon.
    2. Axons of upper motor neurons in the red nuclei cross to the opposite side of the brain and descend into the spinal cord in the rubrospinal tracts.
        a. In humans, the rubrospinal tracts are small and extend only to the cervical spinal cord. There they provide motor control over distal muscles of the upper limbs.
        b. Normally their role is insignificant compared with that of the lateral corticospinal tract.
        c. The rubrospinal tracts can be important in maintaining motor control and muscle tone in the upper limbs if the lateral corticospinal tracts are damaged.

Table 15-2

The Basal Nuclei and Cerebellum, p. 511

- The basal nuclei and cerebellum are responsible for coordination and feedback control over muscle contractions, whether those contractions are consciously or subconsciously directed.

The Basal Nuclei, p. 511

- The basal nuclei provide the background patterns of movement involved in voluntary motor activities.
    1. They may control muscles that determine the background position of the trunk or limbs.
    2. They may direct rhythmic cycles of movement, as in walking or running.

- These nuclei do not exert direct control over lower motor neurons. Instead they adjust the activities of upper motor neurons in the various motor pathways based on input from all portions of the cerebral cortex, as well as from the substantia nigra.

- The basal nuclei adjust or establish patterns of movement via two major pathways:
    1. One group of axons synapses on thalamic neurons, whose axons extend to the premotor cortex, the motor association area that directs activities of the primary motor cortex.
        a. This arrangement creates a feedback loop that changes the sensitivity of the pyramidal cells and alters the pattern of instructions carried by the corticospinal tracts.

2. A second group of axons synapses in the reticular formation, altering the excitatory or inhibitory output of the reticulospinal tracts.

- Two distinct populations of neurons exist:
    1. one that stimulates neurons by releasing acetylcholine (Ach)
    2. one that inhibits neurons through the release of gamma aminobutyric acid (GABA).

- Under normal conditions, the excitatory interneurons are kept inactive, and the tracs leaving the basal nuclei have an inhibitory effect on upper motor neurons.
    1. In Parkinson's disease, the excitatory neurons become more active, leading to problems with the voluntary control of movement.

- If the primary motor cortex is damaged, the individual loses the ability to exert fine control over skeletal muscles. However some voluntary movements can still be controlled by the basal nuclei. In effect, the medial and lateral pathways function as they usually do, but the corticospinal pathway cannot fine-tune the movements.
    1. After damage to the primary motor cortex, the basal nuclei can still receive information about planned movements from the prefrontal cortex and can perform preparatory movements of the trunk and limbs. But because the corticospinal pathway is inoperative, precise movements of the forearms, wrists, and hands cannot occur.
        a. An individual in this condition can stand, maintain balance, and even walk, but all movements are hesitant, awkward, and poorly controlled.

The Cerebellum, p. 512

- The cerebellum monitors proprioceptive (position) sensations, visual information from the eyes, and vestibular (balance) sensations from the inner ear as movements are under way.

- Axons within the spinocerebellar tracts deliver proprioceptive information to the cerebellar cortex.
    1. Visual information is relayed from the superior colliculi
    2. Balance information is relayed from the vestibular nuclei

- The output of the cerebellum affects upper motor neuron activity in the corticospinal, medial, and lateral pathways.

- All motor pathways send information to the cerebellum when motor commands are issued.
    1. As the movement proceeds, the cerebellum monitors proprioceptive and vestibular information and compares the arriving sensations with those experienced during previous movements.

2. It then adjusts the activities of the upper motor neurons involved.

- In general, any voluntary movement begins with the activation of far more motor units than are required, or even desirable. The cerebellum acts like a brake, providing the inhibition needed to minimize the number of motor commands used to perform the movement.

- The pattern and degree of inhibition changes from moment to moment, and this makes the movement efficient, smooth, and precisely controlled.

- The patterns of cerebellar activity are learned by trial and error, over many repetitions. Many of the basic patterns are established early in life:
    1. the fine balancing adjustments you make while standing and walking

- The ability to fine-tune a complex pattern of movement improves with practice, until the movements become fluid and automatic.

- When you concentrate on voluntary control, the rhythm and pattern of the movement usually fall apart as your primary motor cortex starts overriding the commands of the basal nuclei and cerebellum.

Levels of Processing and Motor Control, p. 513

- All sensory and motor pathways involve a series of synapses, one after the other.

- Along the way, the information is distributed to processing centers operating at the subconscious level.
    1. When you stumble, you often recover your balance even as you become aware that a problem exists.
    2. Long before your cerebral cortex could assess the situation, evaluate possible responses, and issue appropriate motor commands, monosynaptic and polysynaptic reflexes – perhaps adjusted by the brain stem and cerebellum – successfully prevented a fall.

- A general pattern: spinal and cranial reflexes provide rapid, involuntary, preprogrammed responses that preserve homeostasis over the short term.
    1. Voluntary responses are more complex and require more time to prepare and execute.

- Cranial and spinal reflexes control the most basic motor activities.

- Integrative centers in the brain perform more elaborate processing, and as we move from the medulla oblongata to the cerebral cortex, the motor patterns become increasingly complex and variable.

- The most complex and variable motor activities are directed by the primary motor cortex of the cerebral hemispheres.

- During development, the spinal and cranial reflexes are the first to appear. More complex reflexes and motor patterns develop as CNS neurons multiply, enlarge, and interconnect.
    1. This process proceeds relatively slowly, as billions of neurons establish trillions of synaptic connections.
    2. At birth, neither the cerebral nor the cerebellar cortex is fully functional.
    3. The behavior of newborn infants is directed primarily by centers in the diencephalons and brain stem.

- ***Key:*** **Neurons of the primary motor cortex innervate motor neurons in the brain and spinal cord responsible for stimulating skeletal muscles. Higher centers in the brain can suppress or facilitate reflex responses; reflexes can complement or increase the complexity of voluntary movements.**

SUMMARY
In Chapter 15 we learned about:

- ♣ The brain, spinal cord, and peripheral nerves continuously communicate with each other and with the internal and external environments.

- ♣ Information arrives via sensory receptors and ascends within the afferent division, while motor commands descend and are distributed by the efferent division.

- ♣ A sensory receptor is a specialized cell or cell process that monitors specific conditions within the body or in the external environment.
    1. Arriving information is called a sensation
    2. Awareness of a sensation is a perception

- ♣ The general senses are pain, temperature, physical distortion, and chemical detection.
    1. Receptors for these senses are distributed throughout the body.

- ♣ Special senses, located in specific sense organs, are structurally more complex.

- ♣ Each receptor cell monitors a specific receptive field.
    1. Tonic receptors are always active.
    2. Phasic receptors provide information about the intensity and rate of change of a stimulus.
    3. Adaptation is a reduction in sensitivity in the presence of a constant stimulus.
    4. Tonic receptors are slow-adapting receptors, while phasic receptors are fast-adapting receptors.

- Three types of nociceptor found in the body provide information on pain as related to extremes of:
    1. temperature
    2. mechanical damage
    3. dissolved chemicals.
        - Myelinated Type A fibers carry fast pain.
        - Slower, Type C fibers carry slow pain.

- Thermoreceptors are found in the dermis.

- Mechanoreceptors are sensitive to distortion of their membranes and include:
    1. tactile receptors
    2. baroreceptors
    3. proprioceptors

- There are six types of tactile receptors in the skin, and three types of proprioceptors.

- Chemoreceptors include carotid bodies and aortic bodies.

- Sensory neurons that deliver sensations to the CNS are referred to as first-order neurons.
    1. These synapse on second-order neurons in the brain stem or spinal cord.
    2. The next neuron in this chain is a third-order neuron, found in the thalamus.

- Three major somatic pathways carry sensory information from the skin and musculature of the body wall, head, neck, and limbs:
    1. the posterior column pathway
    2. the anterolateral pathway
    3. spinocerebellar pathway

- The posterior column pathway carries fine touch, pressure and proprioceptive sensations.
    1. The axons ascend within the fasciculus gracilis and fasciculus cuneatus and relay information to the thalamus via the medial lemniscus.
    2. Before the axons enter the medial lemniscus, they cross over to the opposite side of the brain stem. This crossing over is called decussation.

- The anterolateral pathway carries poorly localized sensations of touch, pressure, pain, and temperature.
    1. The axons involved decussate in the spinal cord and ascend within the anterior and lateral spinothalamic tracts to the ventral nuclei of the thalamus.

- ♣ The spinocerebellar pathway including the posterior and anterior spinocerebellar tracts, carries sensations to the cerebellum concerning the position of muscles, tendons, and joints.

- ♣ Visceral sensory pathways carry information collected by interoreceptors. Sensory information from cranial nerves V, VII, IX, and X is delivered to the solitary nucleus in the medulla oblongata.

- ♣ Dorsal roots of spinal nerves T_1-L_2 carry visceral sensory information from organs between the diaphragm and the pelvic cavity.

- ♣ Dorsal roots of spinal nerves S_2-S_4 carry sensory information from more inferior structures.

- ♣ Somatic motor (descending) pathways always involve an upper motor neuron (whose cell body lies in a CNS processing center) and a lower motor neuron (whose cell body is located in a nucleus of the brain stem or spinal cord).

- ♣ The neurons of the primary motor cortex are pyramidal cells.

- ♣ The corticospinal pathway provides voluntary skeletal muscle control.

- ♣ The corticobulbar tracts terminate at the cranial nerve nuclei.

- ♣ The corticospinal tracts synapse on lower motor neurons in the anterior gray horns of the spinal cord.
    1. The corticospinal tracts are visible along the medulla as a pair of thick bands, the pyramids, where most of the axons decussate to enter the descending lateral corticospinal tracts.
    2. Those that do not cross over enter the anterior corticospinal tracts.

- ♣ The corticospinal pathway provides a rapid, direct mechanism for controlling skeletal muscles.

- ♣ The medial and lateral pathways include several other centers that issue motor commands as a result of processing performed at a subconscious level.

- ♣ The medial pathway primarily controls gross movements of the neck, trunk, and proximal limbs. It includes the:
    1. vestibulospinal tracts
    2. tectospinal tracts
    3. reticulospinal tracts

- ♣ The vestibulospinal tracts carry information related to maintaining balance and posture.

- Commands carried by the tectospinal tracts change the position of the head, neck, and upper limbs in response to bright lights, sudden movements, or loud moises.

- Motor commands carried by the reticulospinal tracts vary according to the region stimulated.

- The lateral pathway consists of the rubrospinal tracts, which primarily control muscle tone and movements of the distal muscles of the upper limbs.

- The basal nuclei adjust the motor commands issued in other processing centers and provide background patterns of movement involved in voluntary motor activities.

- The cerebellum monitors proprioceptive sensations, visual information, and vestibular sensations.

- The integrative activities performed by neurons in the cortex and nuclei of the cerebellum are essential for the precise control of movements.

- Spinal and cranial reflexes provide rapid, involuntary, preprogrammed responses that preserve homeostasis.

- Voluntary responses are more complex and require more time to prepare and execute.

- During development, the spinal and cranial reflexes are first to appear. Complex reflexes develop over years, as the CNS matures and the brain grows in size and complexity.