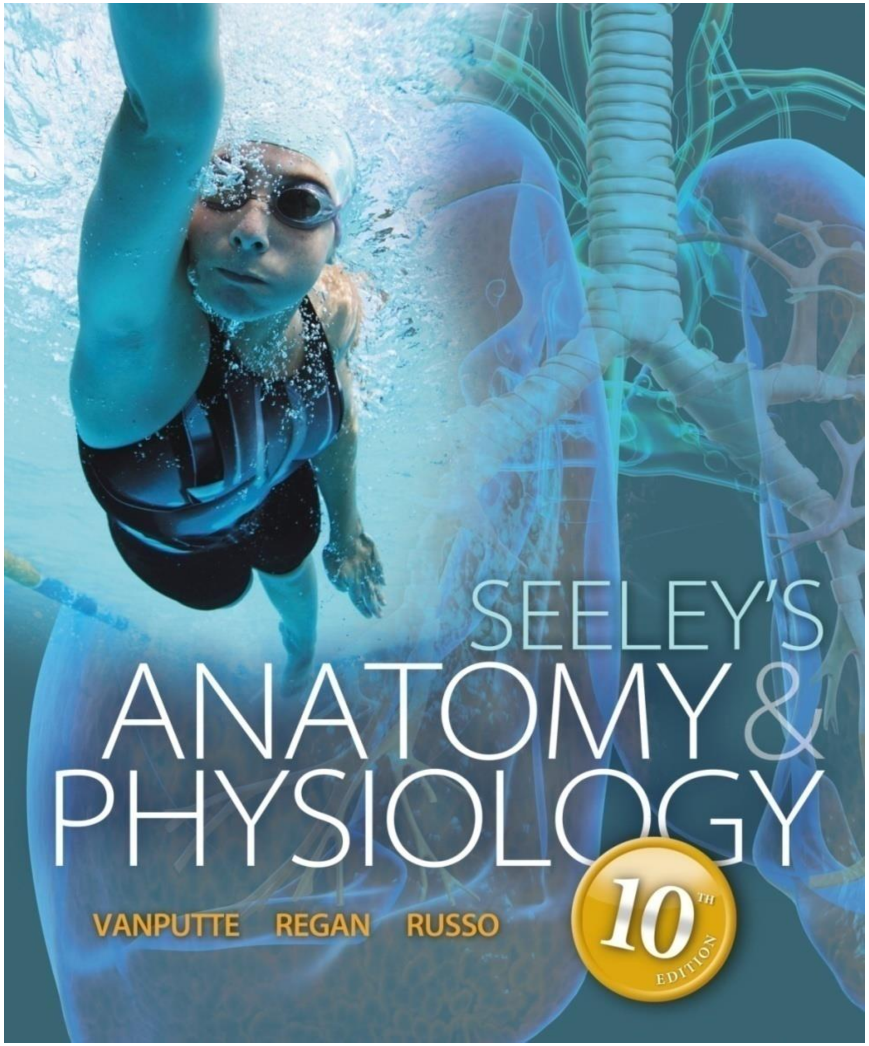


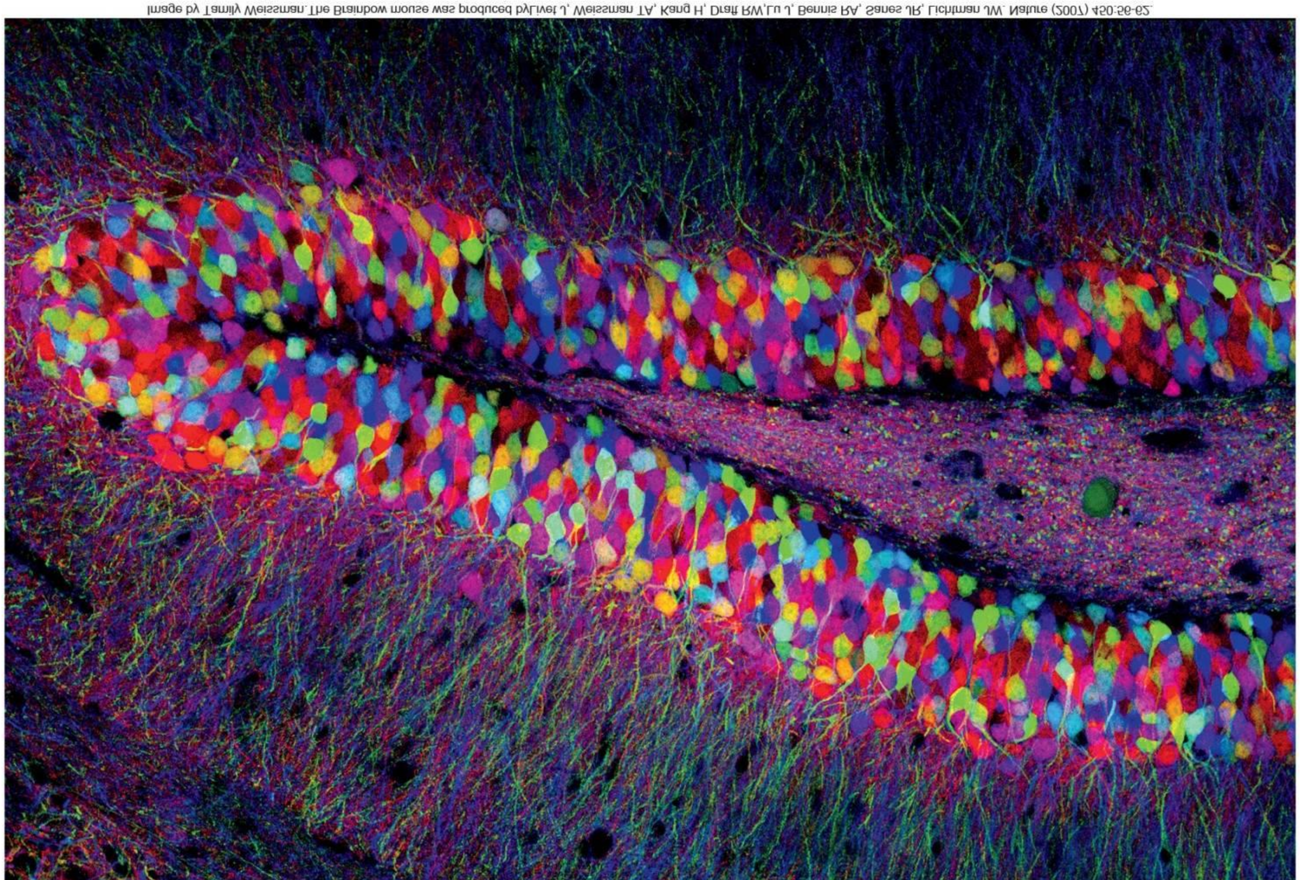
Chapter 14

APR Enhanced Lecture Slides

See separate PowerPoint slides for all figures and tables pre-inserted into PowerPoint without notes and animations.

Chapter 14
Integration of Nervous System Functions

Image by Tamily Weissman. The Brainbow mouse was produced by Livet J, Weissman TA, Kang H, Draft RW, Lu J, Bennis RA, Sanes JR, Lichtman JW. Nature (2007) 450:56-62.



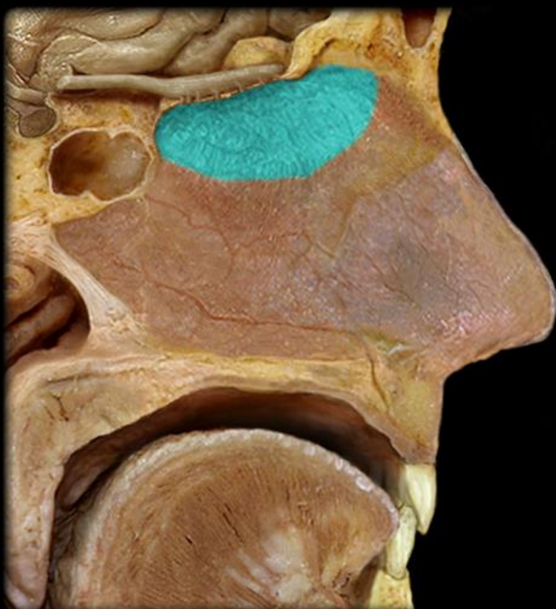
14.1 Sensation

- Means by which brain receives information about environment and body.
- **Sensation** (**perception**): conscious awareness of stimuli received by sensory receptors.
- Steps to sensation
  - Stimuli originating either inside or outside of the body must be detected by sensory receptors and converted into action potentials, which are propagated to the CNS by nerves.
  - Within the CNS, nerve tracts convey action potentials to the cerebral cortex and to other areas of the CNS.
  - Action potentials reaching the cerebral cortex must be translated so the person can be aware of the stimulus.

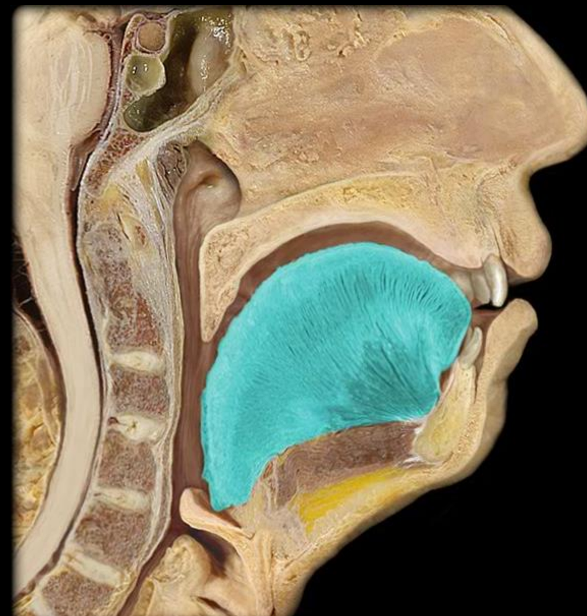
Types of Senses

- **General**: distributed over large part of body. Receptor generates an action potential called a generator potential that then travels to the brain. Called **primary receptors**.
  - **Somatic** (information about the body and environment): touch, pressure, temperature, proprioception, pain
  - **Visceral** (information about internal organs): pain and pressure
- **Special senses**: smell, taste, sight, hearing, balance. Receptor produces a receptor potential and the receptor then releases a neurotransmitter that binds to receptors on the membrane of a neuron which then travels to the brain. Called a **secondary receptor**.

Special Senses



Smell



Taste

Sight

Hearing

Balance

Types of Senses

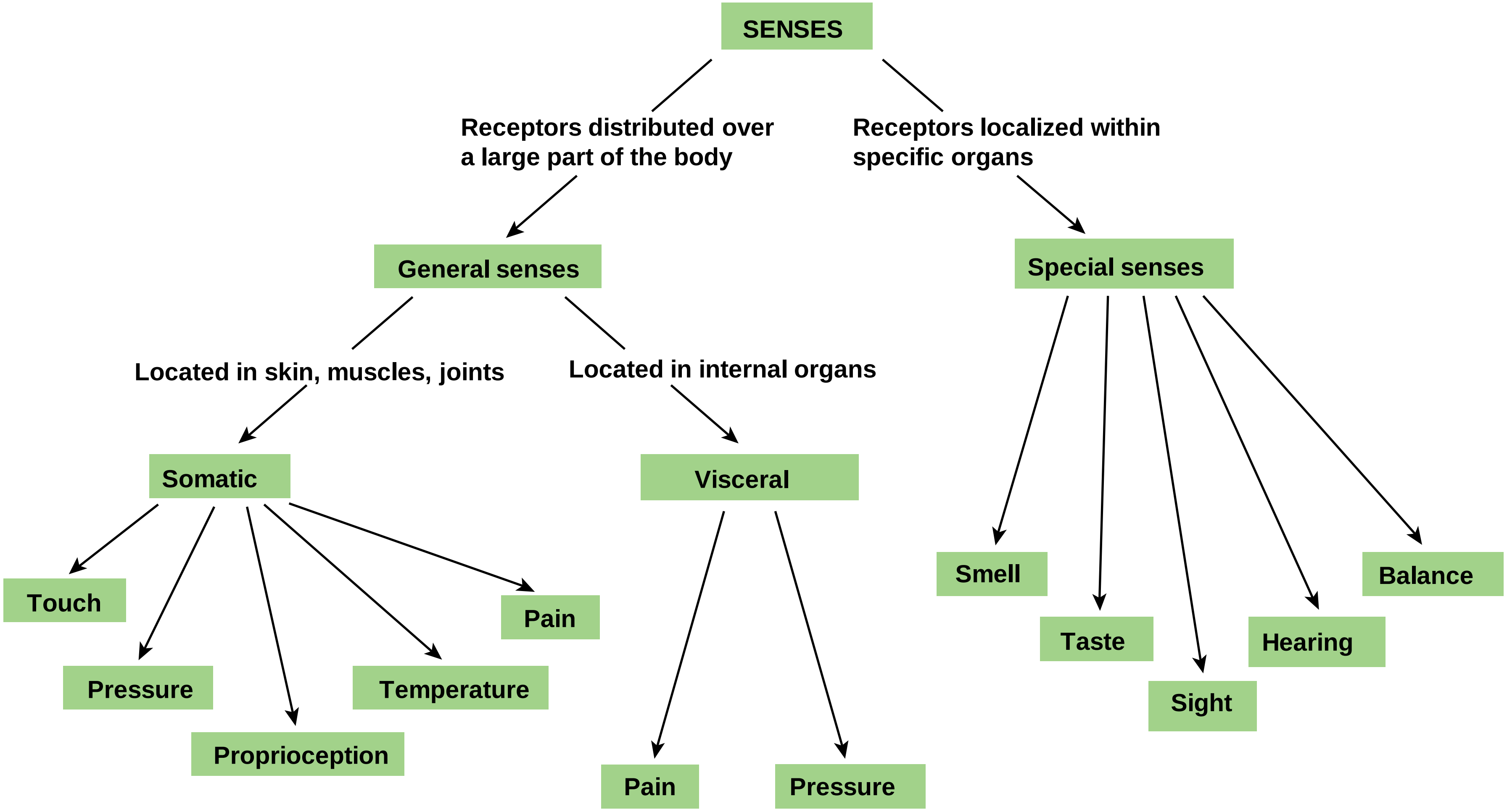


TABLE 14.1 Classification of the Senses

Types of Sense	Nerve Endings	Recept or Type	Initiation of Response
GENERAL SENSES			
Somatic			
Touch		Mechanoreceptors	Compression of receptors
Stroking	Meissner corpuscle		
	Hair follicle receptor		
Texture	Merkel disk		
Vibration	Pacinian corpuscle		
Skin stretch	Ruffini end organ		
Itch, tickle	Free nerve endings		
Pressure	Merkel disk	Mechanoreceptors	Compression of receptors
Proprioception	Pacinian corpuscle	Mechanoreceptors	Compression of receptors
Temperature	Free nerve endings	Thermoreceptors	Temperature around nerve endings
	Cold receptors		
	Warm receptors		
Pain	Free nerve endings	Nociceptors	Irritation of nerve endings (e.g., mechanical, chemical, or thermal)
Visceral			
Pain	Free nerve endings	Nociceptors	Irritation of nerve endings
Pressure	Pacinian corpuscle	Mechanoreceptors	Compression of receptors
SPECIALSENSES			
Smell	Specialized	Chemoreceptors	Binding of molecules to membrane receptors
Taste	Specialized	Chemoreceptors	Binding of molecules to membrane receptors
Sight	Specialized	Photoreceptors	Chemical change in receptors initiated by light
Hearing	Specialized	Mechanoreceptors	Bending of microvilli on receptor cells
Balance	Specialized	Mechanoreceptors	Bending of microvilli on receptor cells

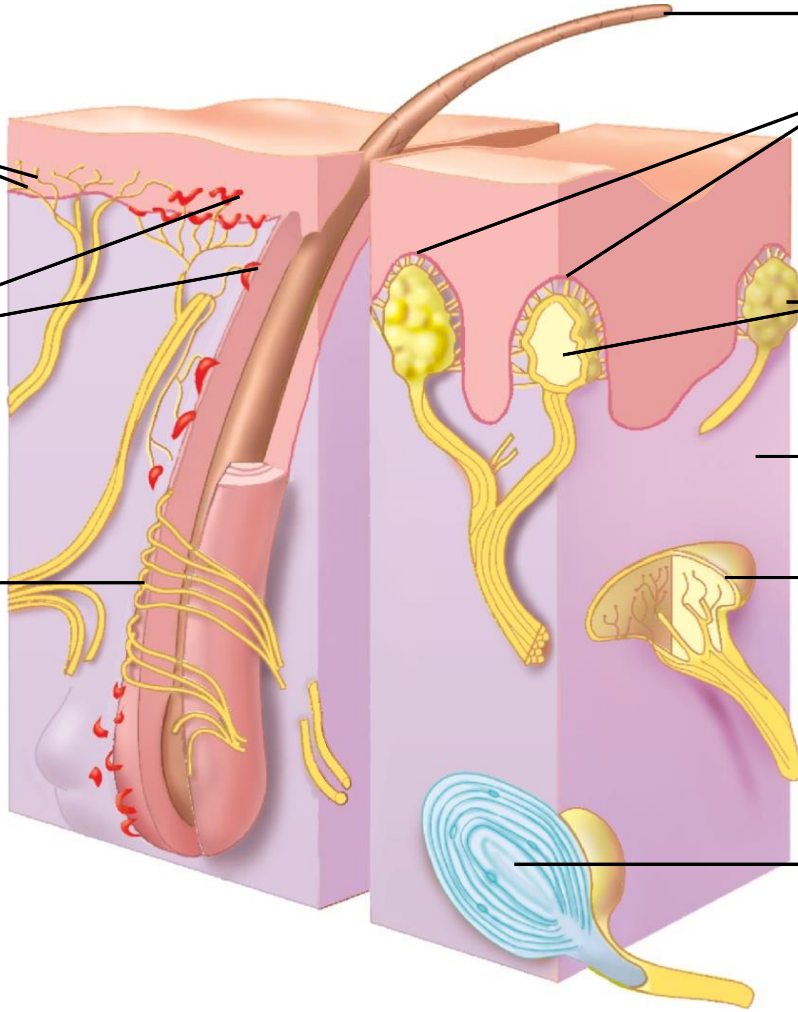
Types of Sensory Receptors

- **Mechanoreceptors**: compression, bending, stretching of cells. Touch, pressure, proprioception, hearing, and balance
- **Chemoreceptors**: chemicals become attached to receptors on their membranes. Smell and taste
- **Thermoreceptors**: respond to changes in temperature
- **Photoreceptors**: respond to light: vision
- **Nociceptors**: extreme mechanical, chemical, or thermal stimuli. Pain

Types of Receptors Based on Location

- **Exteroreceptors**: associated with skin
- **Visceroreceptors**: associated with organs
- **Proprioceptors**: associated with joints, tendons

Sensory Nerve Endings in Skin



Free Nerve Endings

- Simplest, most common sensory receptor
- Scattered through most of body; visceroceptors are of this type.
- Type responsible for temperature sensation
  - Cold: 10-15 times more numerous than warm
  - Warm
  - Pain: responds to extreme cold or heat

Merkel (Tactile) Disks

- Axonal branches end as flattened expansions associated with epithelial cells
- Basal layers of epidermis
- Associated with dome-shaped mounds of thickened epidermis in hairy skin
- Light touch and superficial pressure

Hair Follicle Receptors

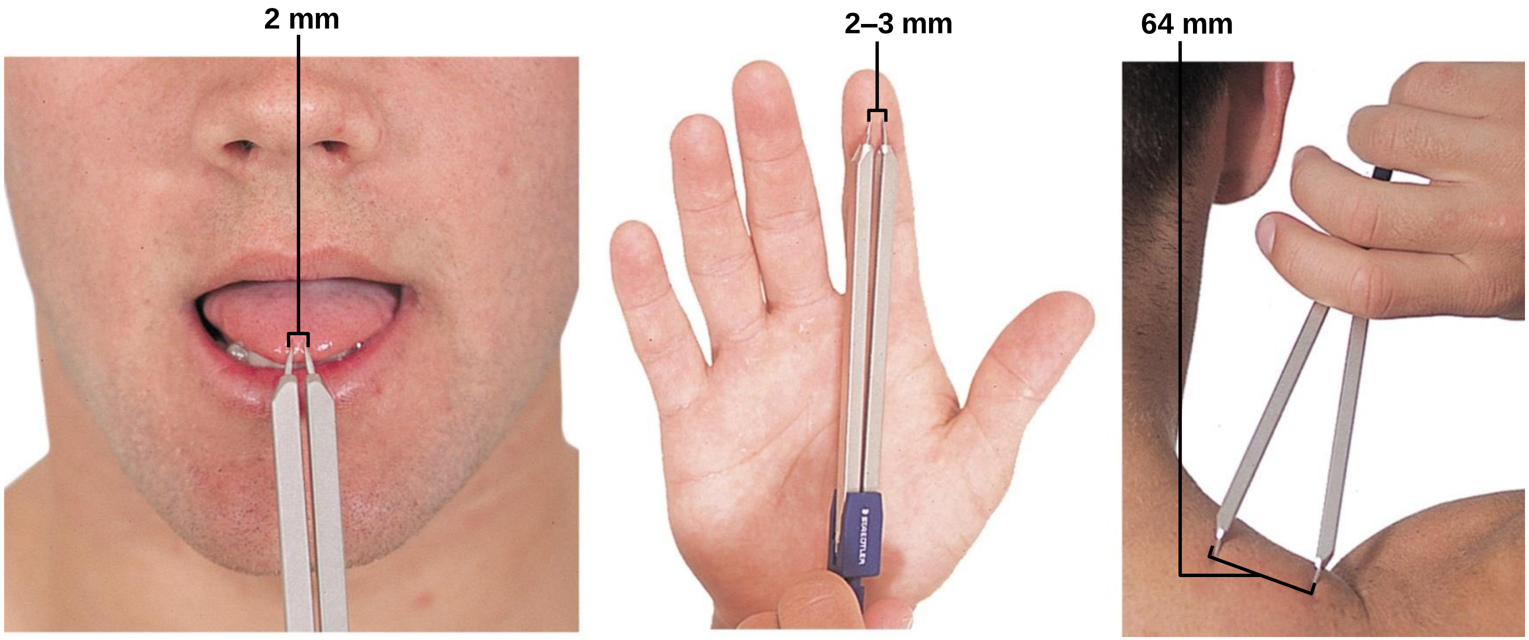
- Hair end organs
- Respond to slight bending of hair as occurs in light touch
- End organ receptor fields overlap; sensation not very localized, yet very sensitive

Pacinian Corpuscles

- Lamellated corpuscles
- Single dendrite to layers of corpuscles arranged like leaves of an onion
- Deep dermis or hypodermis
- Deep cutaneous pressure; vibration
- When associated with joints, involved in proprioception

Meissner (Tactile) Corpuscles

- Two-point discrimination
- Ability to detect simultaneous stimulations at two points on the skin.
- Used to determined texture of objects.
- Numerous and close together on tongue and fingertips



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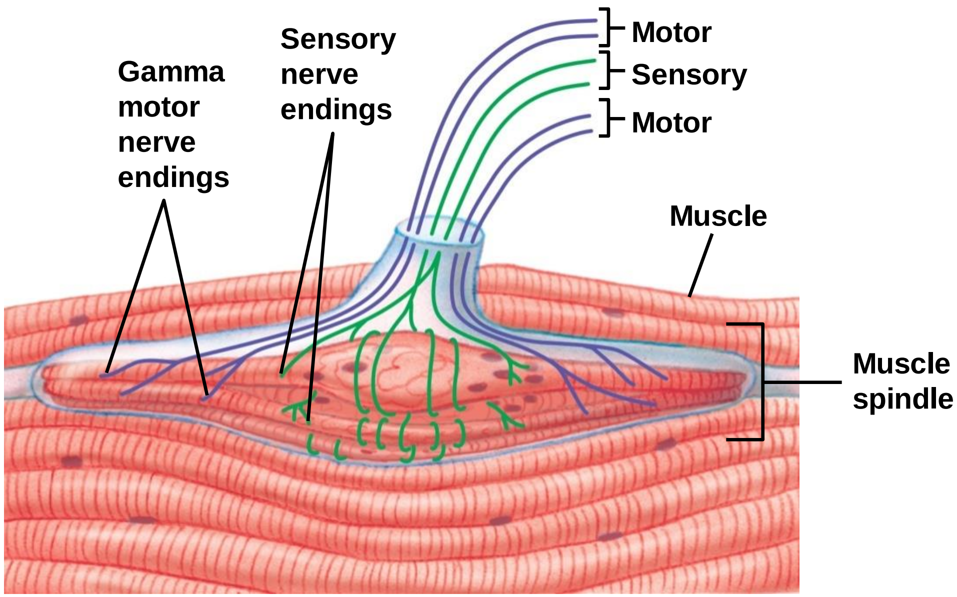
Ruffini End Organ

- Primarily in dermis of fingers
- Respond to continuous touch or pressure

Muscle Spindles



- 3-10 specialized skeletal muscle cells
- Provide information about length of muscles
- Involved in stretch reflex

Golgi Tendon Organ

- Proprioceptors associated with tendons
- Respond to increased tension on tendon

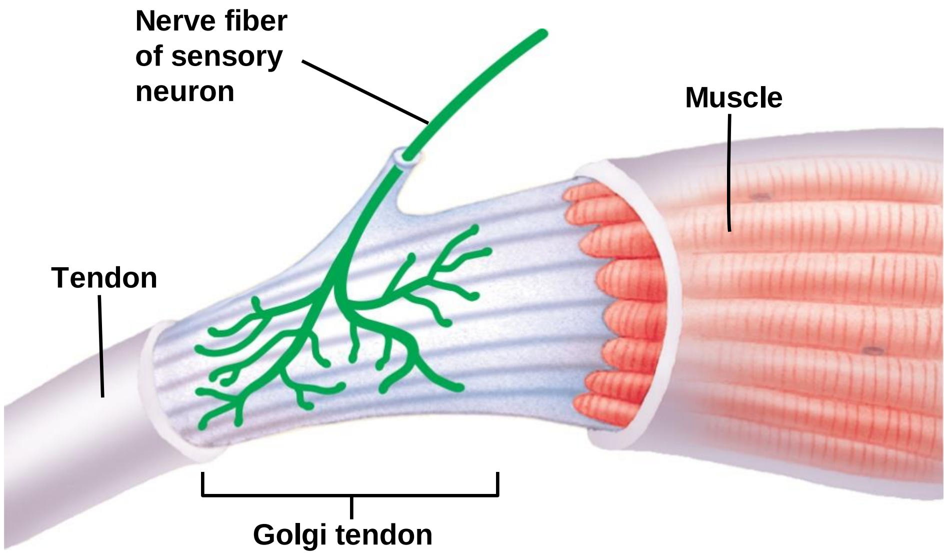


TABLE 14.2 Sensory Receptors

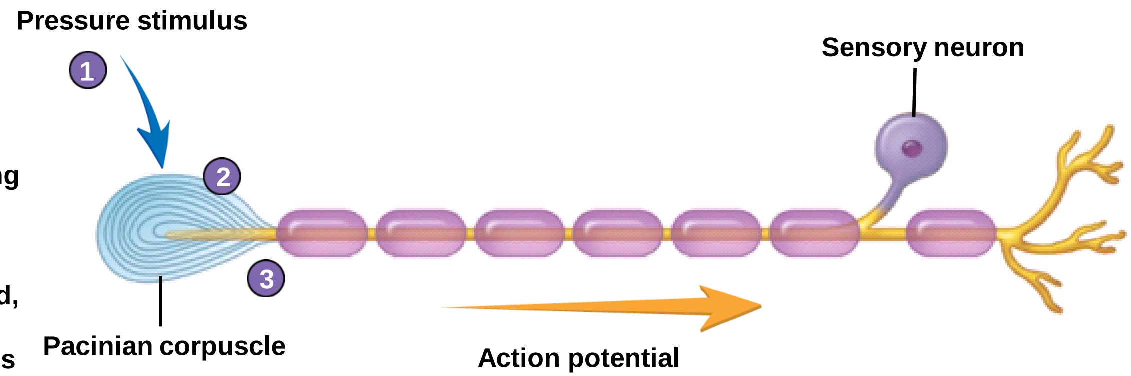
Type of Receptor	Structure	Function
Free nerve ending	Branching, no capsule	Pain, itch, tickle, temperature, joint movement, and proprioception
Merkel disk	Consists of flattened expansions at the end of axons; each expansion is associated with a Merkel cell	Light touch and superficial pressure
Hair follicle receptor	Wrapped around hair follicles or extending along the hair axis; each axon supplies several hairs, and each hair receives branches from several neurons, resulting in considerable overlap	Light touch; responds to very slight bending of the hair
Pacinian corpuscle	Onion-shaped capsule composed of several cell layers with a single central nerve process	Deep cutaneous pressure, vibration, and proprioception
Meissner corpuscle	Several branches of a single axon associated with specialized Schwann cells and surrounded by a connective tissue capsule	Two-point discrimination
Ruffini end organ	Branching axon with numerous small, terminal knobs surrounded by a connective tissue capsule	Continuous touch or pressure; responds to depression or stretch of the skin
Muscle spindle	Three to 10 striated muscle fibers enclosed by a loose connective tissue capsule, striated only at the ends, with sensory nerve endings in the center	Proprioception associated with detection of muscle stretch; important for control of muscle tone
Golgi tendon organ	Surrounds a bundle of tendon fasciculi and is enclosed by a delicate connective tissue capsule; nerve terminations are branched, with small swellings applied to individual tendon fasciculi	Proprioception associated with the stretch of a tendon; important for control of muscle contraction

Responses of Sensory Receptors

- Graded potential: results from interaction of sensory receptor with stimulus
- Graded potential is called a **receptor** or **generator potential**
  - **Primary receptors**: axons conduct action potentials in response to receptor potential
  - **Secondary receptors**: cause release of neurotransmitters that bind to receptors on a neuron causing a receptor potential. Smell, taste, hearing, balance

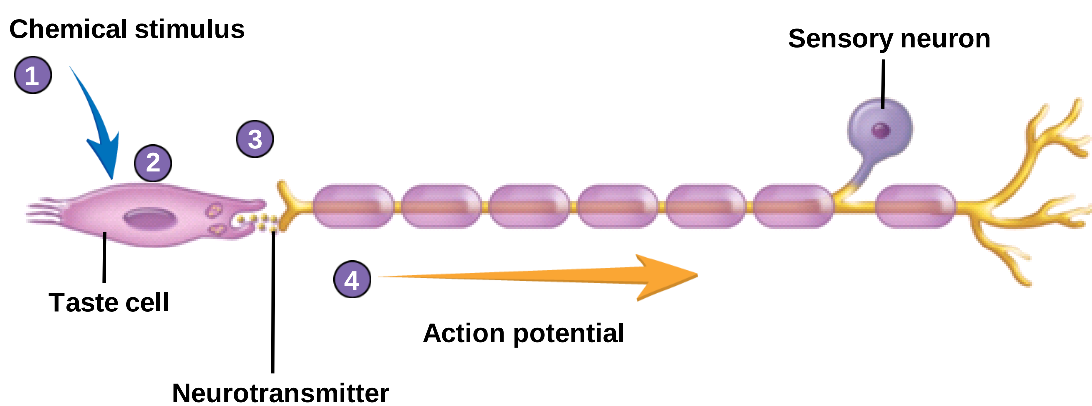
Primary vs. Secondary Receptors

1. **A mechanoreceptor (Pacinian corpuscle) is subjected to a pressure stimulus.**
2. **The sensory receptor responds by generating a graded potential, also known as the receptor potential.**
3. **When the graded potential reaches threshold, action potentials are generated in the axon. The action potentials are propagated towards the CNS.**



(a)

1. **A chemoreceptor (taste cell) is subjected to a chemical stimulus in the form of a salty substance.**
2. **The sensory receptor responds by generating a graded potential, also known as the receptor potential. In the case of taste cells, an action potential can also be generated.**
3. **The sensory receptor releases a neurotransmitter into the synaptic cleft, which in turn stimulates the sensory neuron.**
4. **When the stimulation reaches threshold, the neuron generates action potentials, which are propagated toward the CNS.**

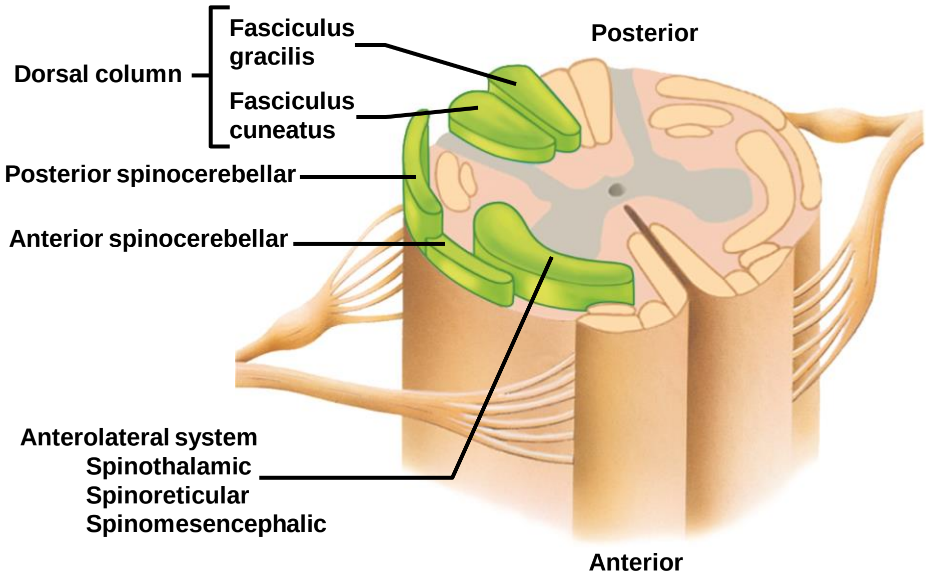


(b)

Responses of Sensory Receptors

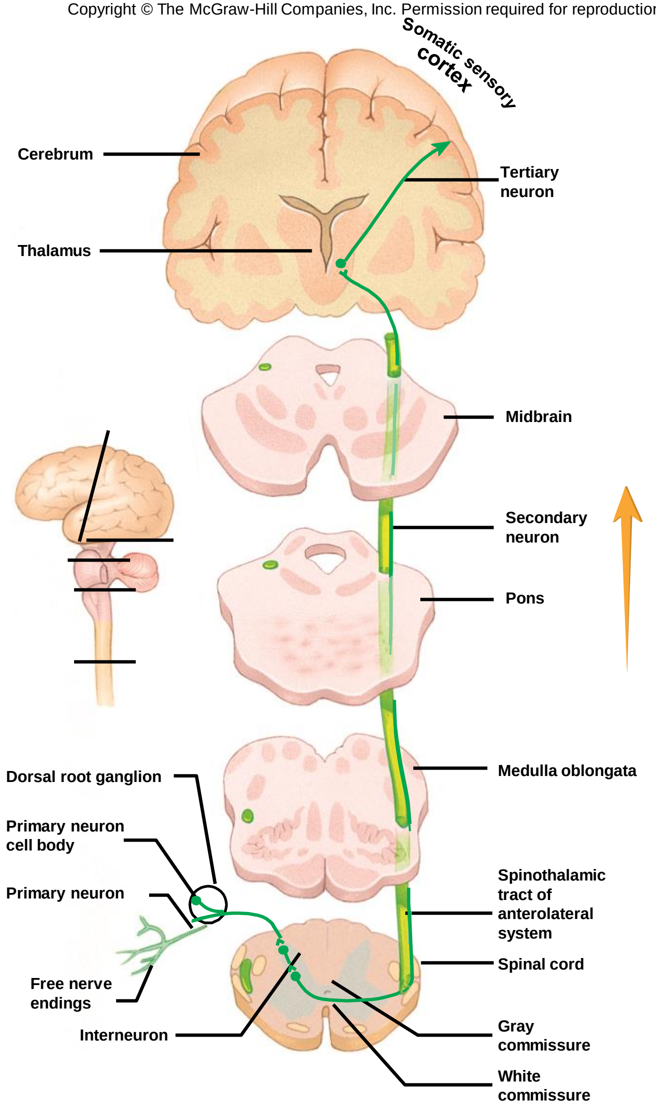
- **Accommodation** (**adaptation**): decreased sensitivity to a continued stimulus
- **Proprioceptors**: provide information about the precise position and the rate of movement of various body parts, the weight of an object being held in the hand and the range of movement of a joint.
  - **Slowly adapting (Tonic) receptors**: accommodate very slowly. Example: know where little finger is without looking
  - **Rapidly adapting (Phasic) receptors**: accommodate rapidly. Example: you know where hand is as it moves

Sensory Nerve Tracts



- Transmit action potentials from periphery to brain
- Each pathway involved with specific modality (type of information transmitted)
- First half of word indicates origin, second half indicates termination

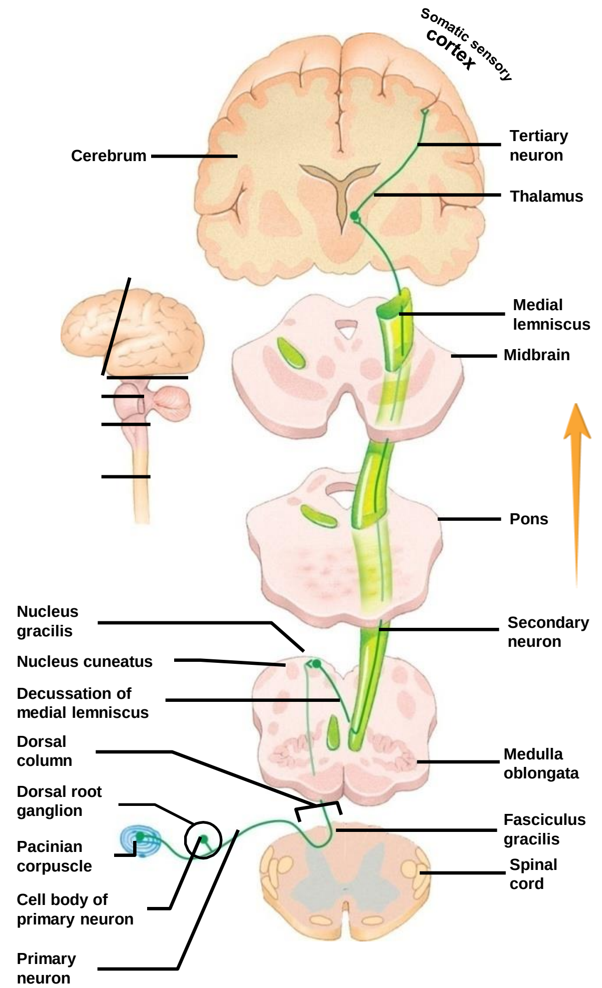
Anterolateral System: Spinothalamic Tract



- Conveys pain, temperature, light touch, pressure, tickle, and itch
- Three neuron system
  - **Primary**: from periphery to posterior horn of spinal cord
  - Synapse with interneurons
  - **Secondary**: cross to opposite side, enter spinothalamic tract, ascend to thalamus
  - **Tertiary**: thalamus to somatic sensory cortex

Dorsal-Column/ Medial-Lemniscal System

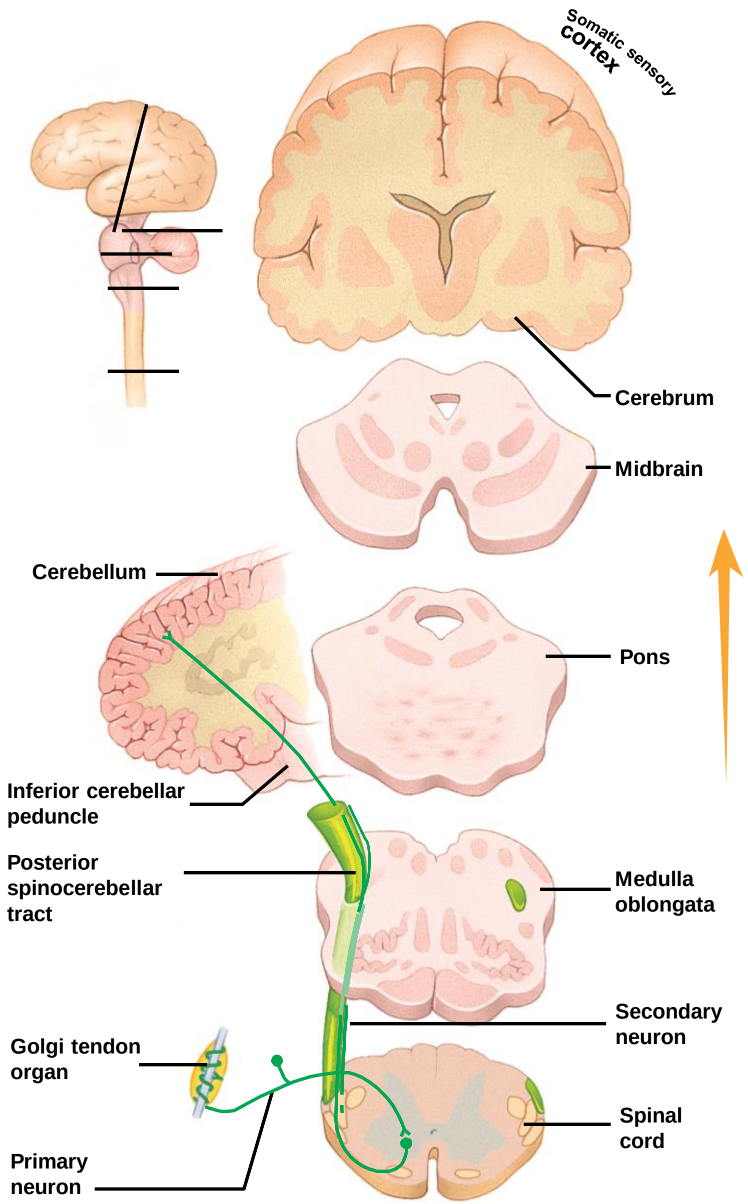
- Carries sensations of two-point discrimination, proprioception, pressure, vibration to cerebrum, and cerebellum
  - **Fasciculus gracilis**: sensations from inferior to midthoracic level
  - **Fasciculus cuneatus**: impulses from above midthorax
- Primary neurons have cell bodies in dorsal root ganglion. Axons enter spinal cord and ascend to the medulla oblongata without decussating where they synapse with secondary neurons.
- Secondary neurons: axons decussate and ascend to thalamus
- Tertiary neurons: project to somatic sensory cortex



Trigeminothalamic Tract

- Cranial nerve V
- Fibers join the spinothalamic tract in the brainstem
- Carries similar information to that of the spinothalamic and dorsal-column/medial-lemniscal system, but from the face, nasal cavity and oral cavity

Spinocerebellar System



- Carries proprioceptive information to cerebellum, most of which is unconscious
- Actual movements monitored and compared to cerebral information representing intended movement
- Posterior and anterior spinocerebellar tracts

Other Sensory Tracts

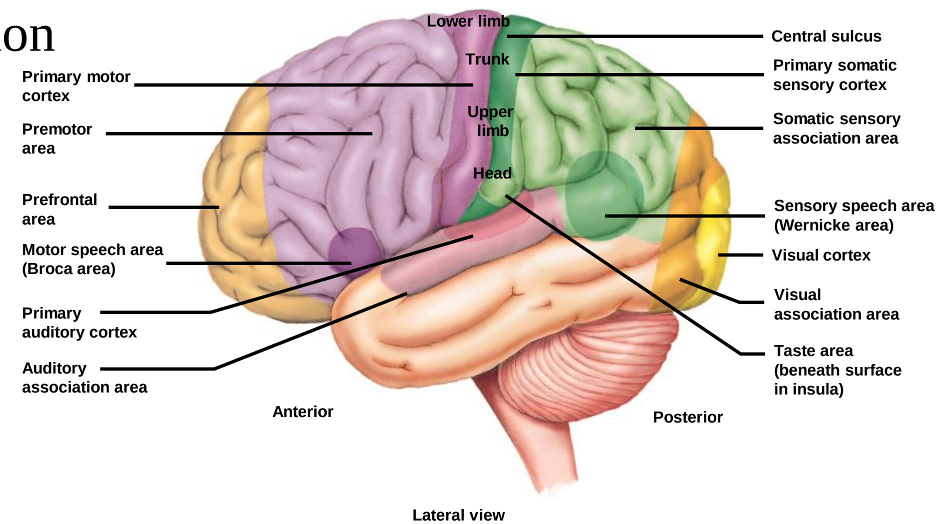
- **Spinoolivary**: contribute to coordination of movement associated with balance
- **Spinotectal**: involved in reflexes that turn the eyes and the head toward point of cutaneous stimulation

Descending Pathways Modifying Sensation

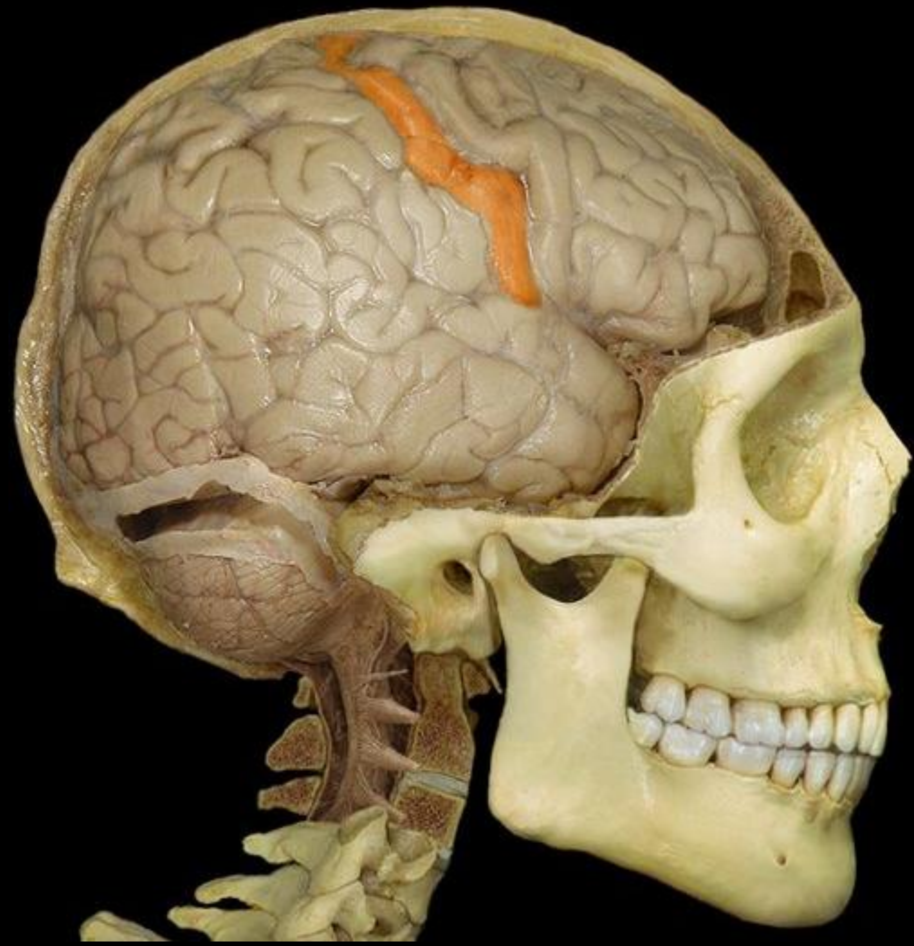
- Modification of sensation: cortex may reduce the conscious perception of sensations
- Corticospinal tracts send branches to ascending tracts and release neuromodulators such as endorphins

Sensory and Association Areas of the Cerebral Cortex

- Sensory
  - **Primary somatic sensory cortex** (**general sensory area**): posterior to the central sulcus. Postcentral gyrus.
  - General sensory input: pain, pressure, temperature
  - **Taste area**: inferior end of postcentral gyrus
  - **Olfactory cortex**: inferior surface of frontal lobe
  - **Primary auditory cortex**: superior part of temporal lobe
  - **Visual cortex**: occipital lobe
- Association areas: process of recognition
  - **Somatic sensory**: posterior to primary somatic sensory cortex
  - **Visual association**: anterior to visual cortex: present visual information compared to past information



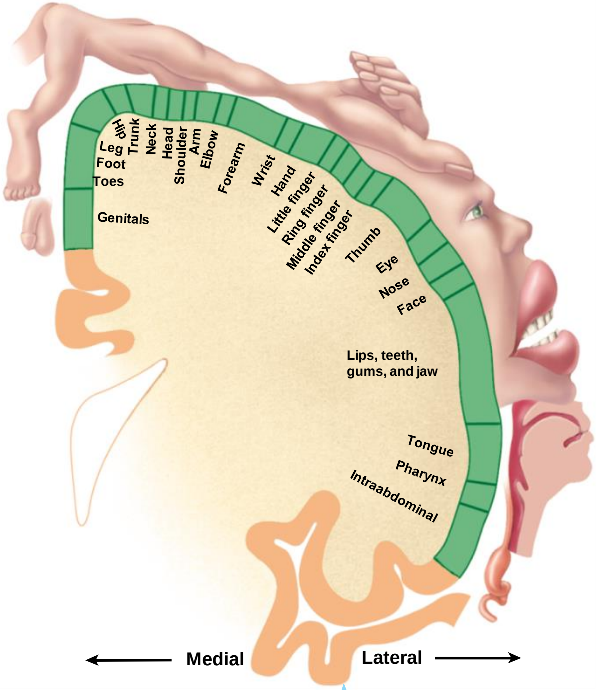
Precentral and Postcentral Gyrus

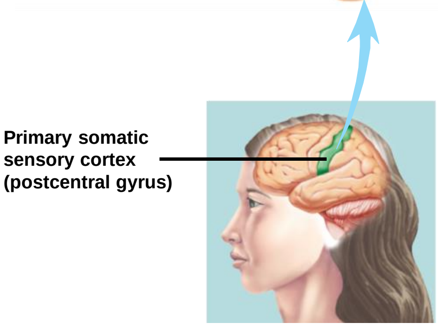


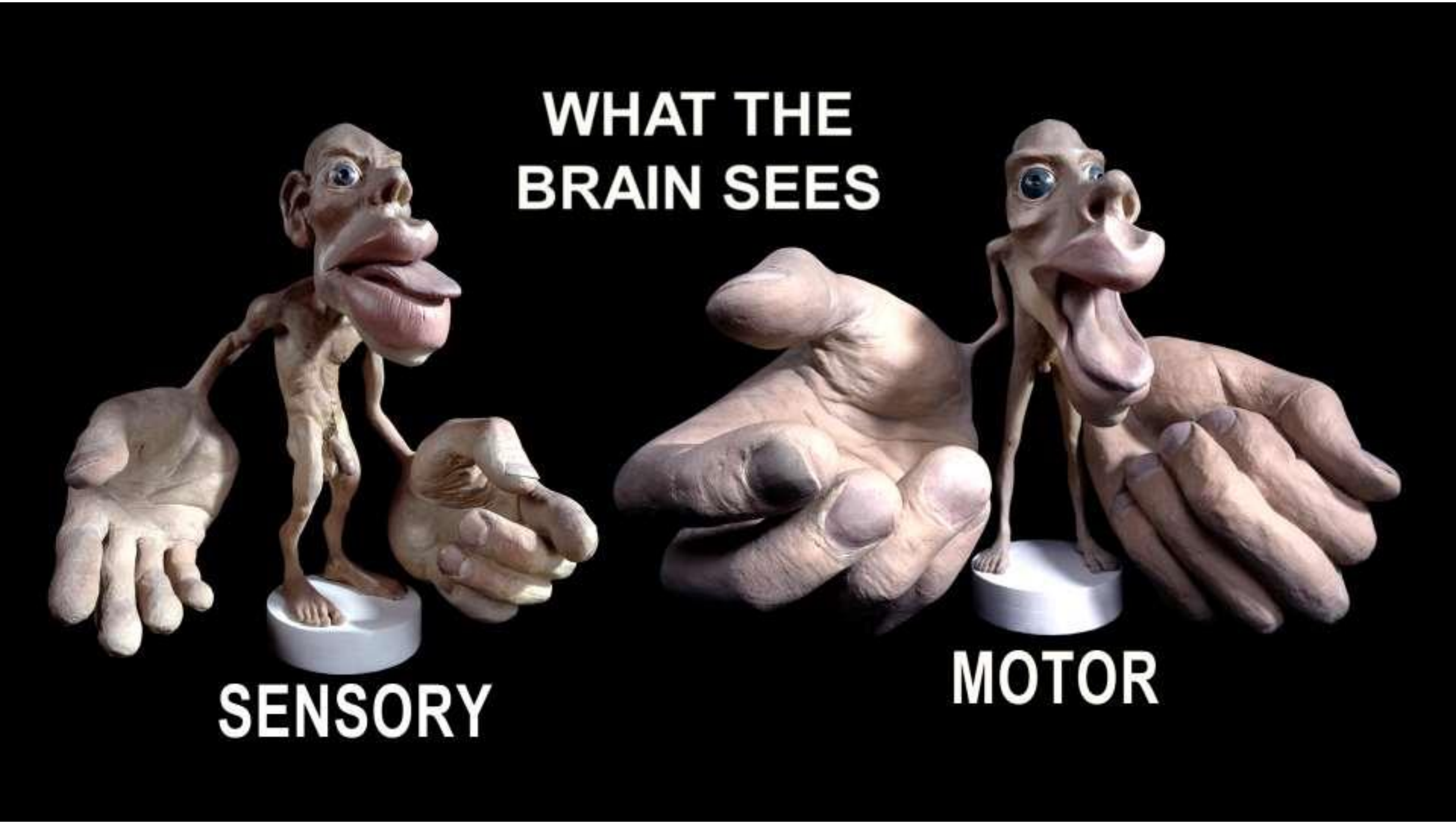
Primary Somatic Sensory Cortex
Postcentral Gyrus

Somatic Sensory Cortex: Homunculus

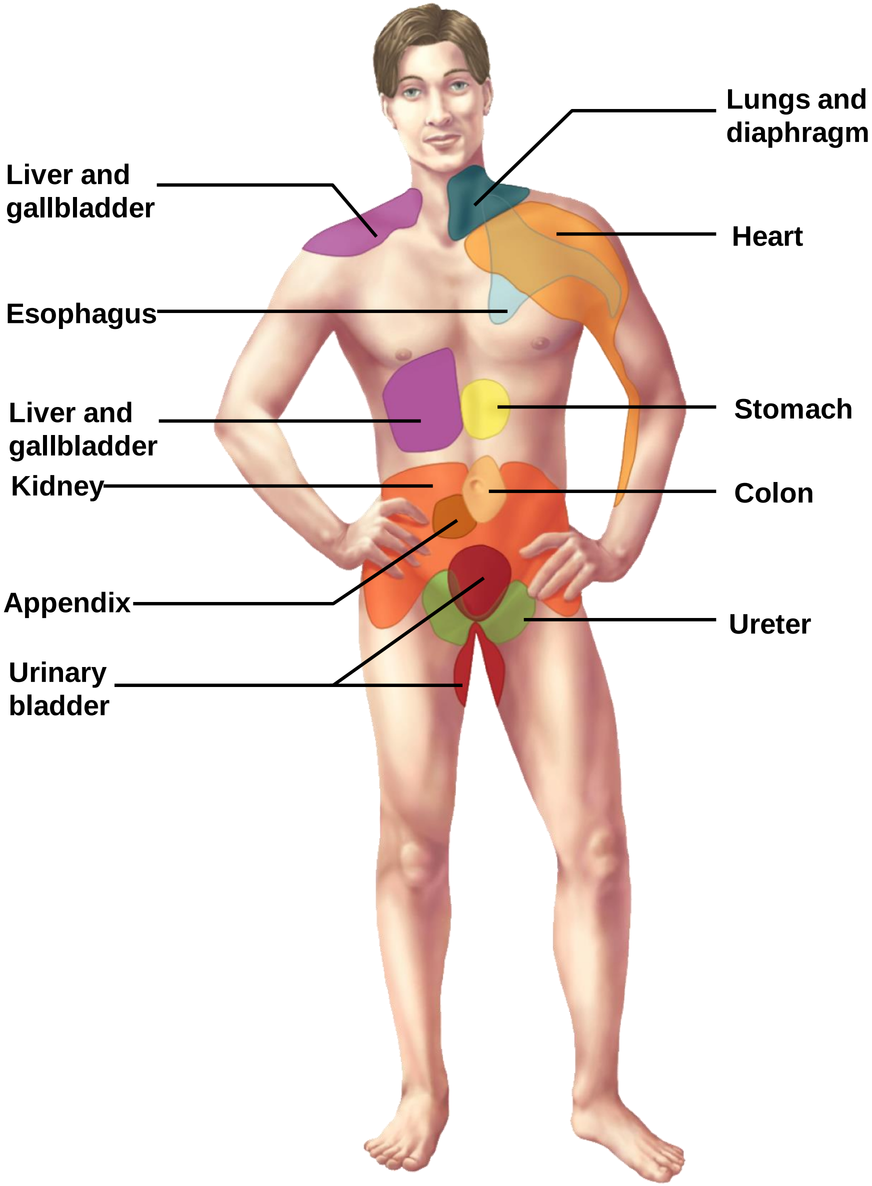
- Size of various regions related to the number of sensory receptors in that area of the body






WHAT THE
BRAIN SEES
SENSORY
MOTOR

Referred Pain



- Referred: sensation in one region of body that is not source of stimulus. Organ pain usually referred to the skin. Both the organ and that region of the skin input to the same spinal segment and converge on the same ascending neurons.

Phantom and Chronic Pain

- **Phantom**: occurs in people who have appendage amputated or structure removed such as a tooth. Gate control theory of pain-- in uninjured limb, pressure and touch sensation inhibits pain (thus the success of massage in pain relief). These sensations are lost with amputations and thus their inhibitory effect.
- **Chronic**: not a response to immediate direct tissue injury. Cerebrum and thalamus may malfunction and misinterpret discomfort as pain. Brain as a whole may not properly regulate how much pain stimulation is allowed to penetrate to the cerebral cortex. Migraine, back pain. Associated with depression, frustration, helplessness, hopelessness.

14.2 Control of Skeletal Muscles

- Motor system: maintains posture and balance; moves limbs, trunk, head, eyes; facial expression, speech.
- Reflexes: movements that occur without conscious thought
- **Voluntary movements**: consciously activated to achieve a specific goal
- Two neurons: upper and lower
  - **Upper motor neurons**: directly or through interneurons connect to lower
  - **Lower motor neurons**: axons leave the CNS, extend through PNS to skeletal muscles. Cell bodies in anterior horns of spinal cord and in cranial nerve nuclei of brainstem

Three Steps to Voluntary Movements

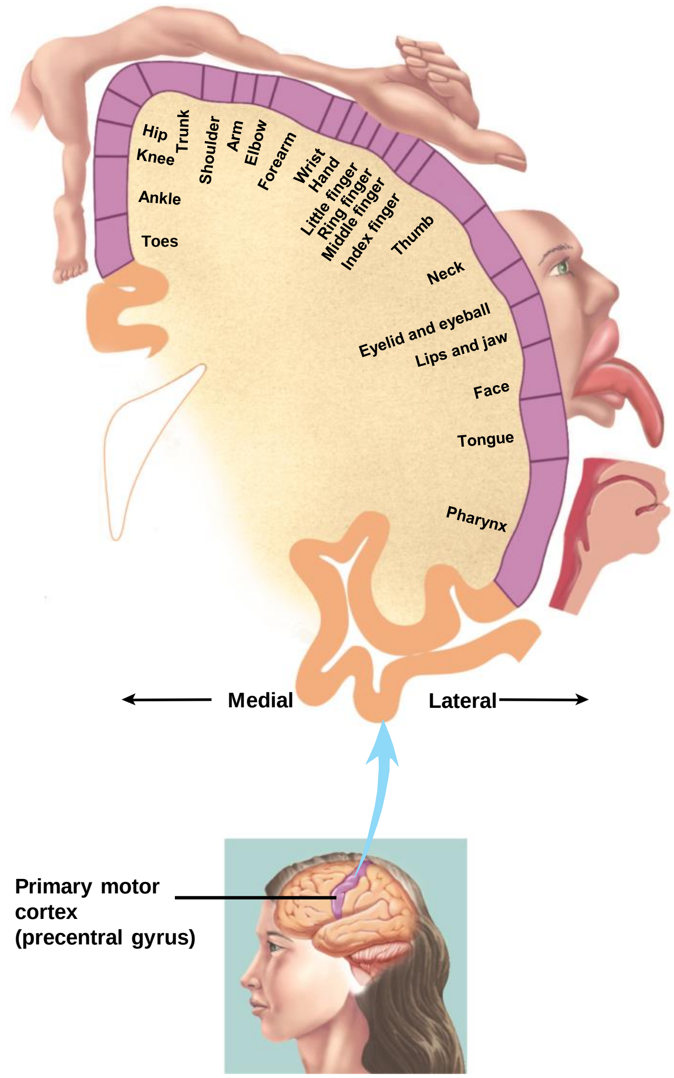
1. The initiation of most voluntary movement begins in the premotor areas of the cerebral cortex and results in the stimulation of upper motor neurons.
2. The axons of the upper motor neurons form the descending nerve tracts. They stimulate lower motor neurons which stimulate skeletal muscles to contract.
3. The cerebral cortex interacts with the basal nuclei and cerebellum in the planning, coordination and execution of movements.

Motor Areas of the Cerebral Cortex

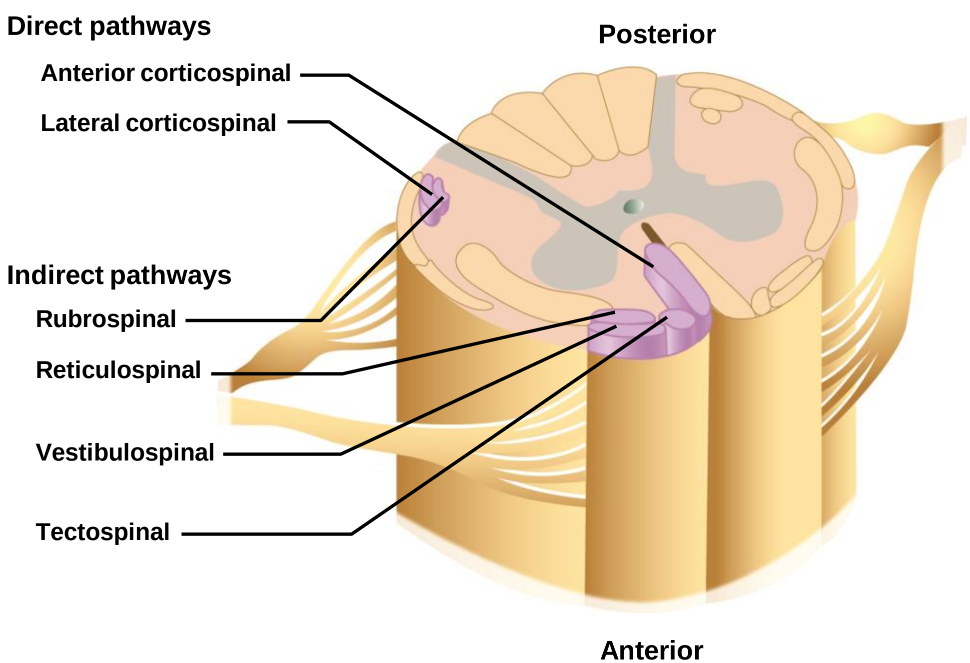
- **Precentral gyrus** (primary motor cortex, primary motor area): 30% of upper motor neurons. Another 30% in premotor area, rest in somatic sensory cortex
- **Premotor area**: anterior to primary motor cortex. Motor functions organized before initiation
- **Prefrontal area**: motivation, foresight to plan and initiate movements, emotional behavior, mood

Primary Motor Cortex
Precentral Gyrus

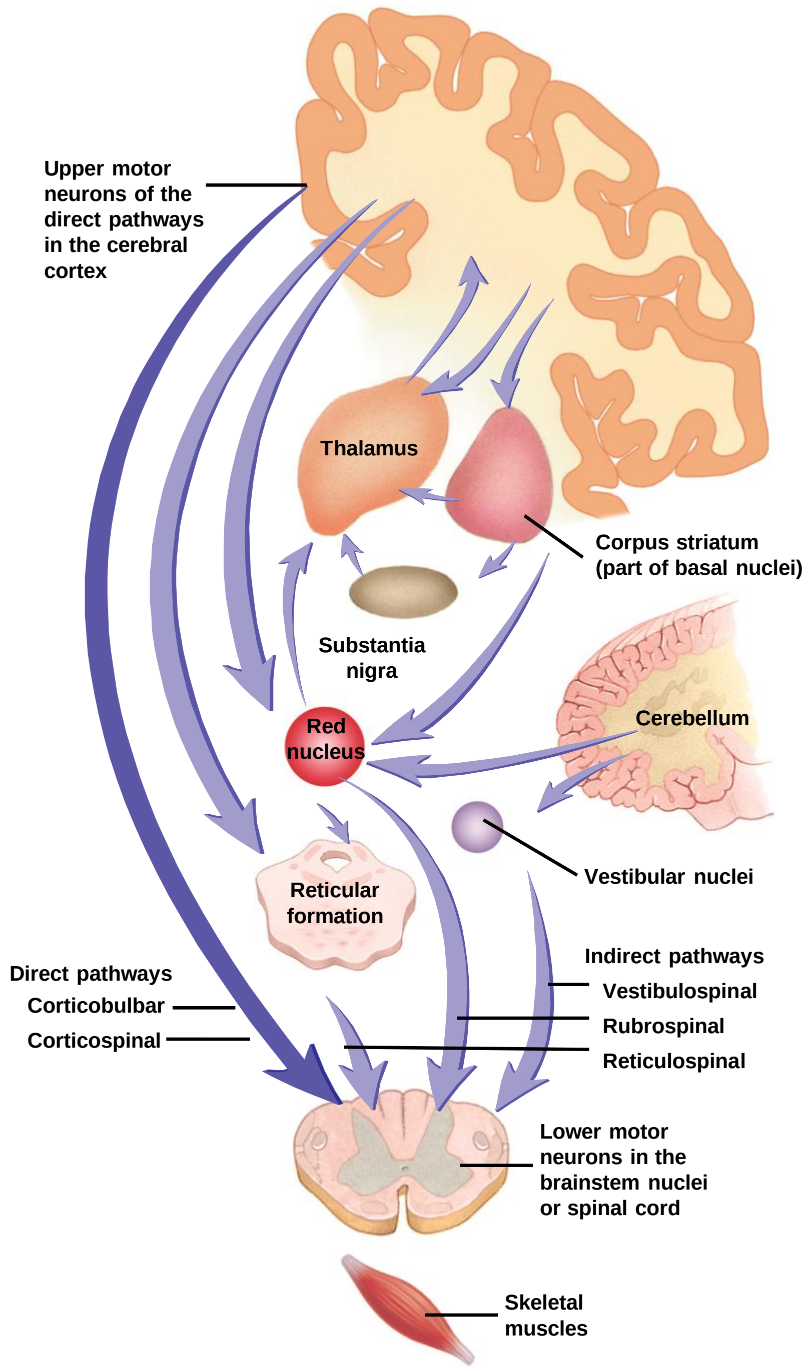
Topography of the Primary Motor Cortex



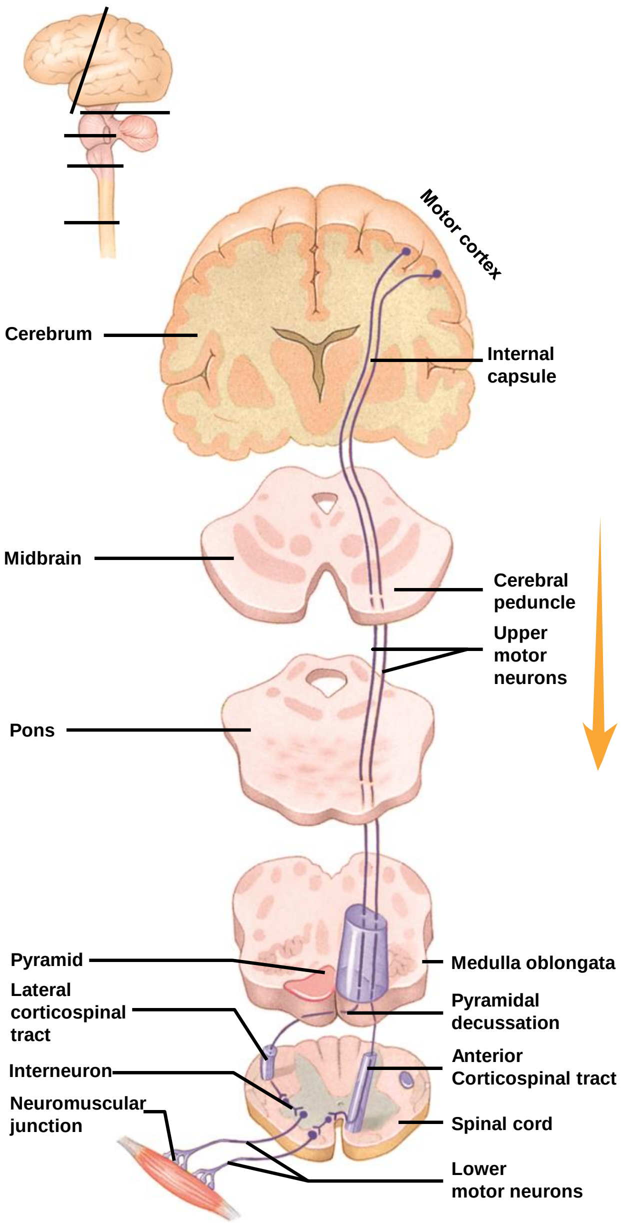
Motor Nerve Tracts



- **Direct pathways** (**pyramidal system**): maintenance of muscle tone, controlling speed and precision of skilled movements
- **Indirect pathways** (**extrapyramidal system**): less precise movements.


Upper motor neurons of the direct pathways in the cerebral cortex
Thalamus
Corpus striatum (part of basal nuclei)
Substantia nigra
Red nucleus
Cerebellum
Vestibular nuclei
Reticular formation
Direct pathways
Corticobulbar
Corticospinal
Indirect pathways
Vestibulospinal
Rubrospinal
Reticulospinal
Lower motor neurons in the brainstem nuclei or spinal cord
Skeletal muscles

Direct Pathways



- Control muscle tone and conscious fine, skilled movements in the face and distal limbs
- Direct synapse of upper motor neurons of cerebral cortex with lower motor neurons in brainstem or spinal cord
- Tracts
  - **Corticospinal**: direct control of movements below the head
  - **Corticobulbar**: direct control of movements in head and neck

Corticospinal Tracts

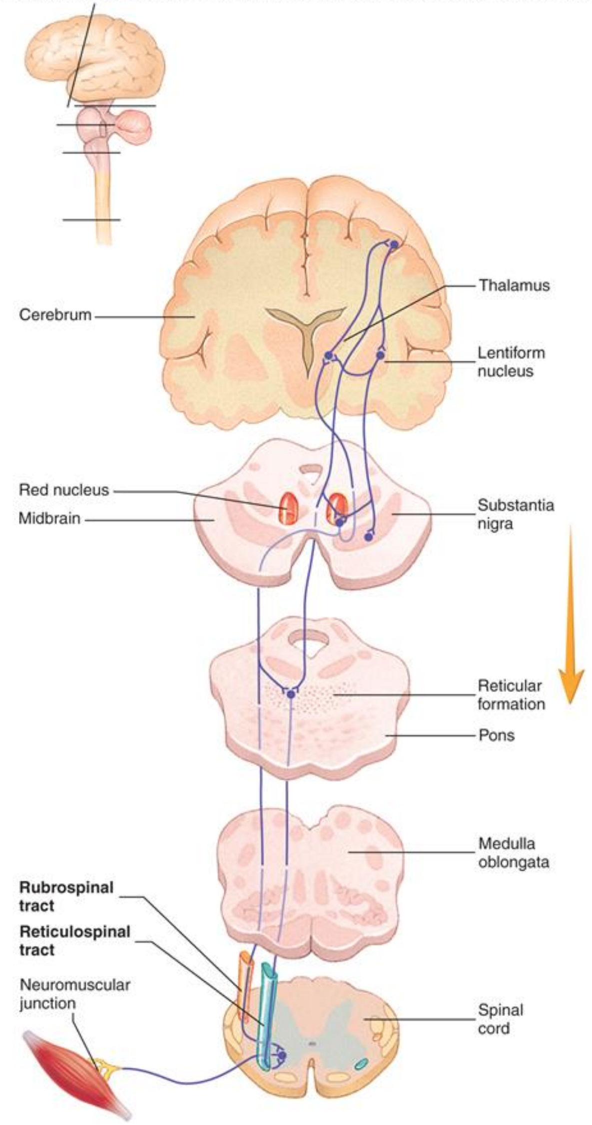
- Axons of upper motor neurons descend through internal capsules and cerebral peduncles to pyramids of medulla oblongata
- 75-85% decussate and descend in the **lateral corticospinal tracts**. Supply all levels of body
- Remaining fibers descend uncrossed in **anterior corticospinal tracts** but decussate near level of synapse with lower neurons. Supply neck; upper limbs

Corticobulbar Tracts

- Innervate the head
- Upper neurons enter the cranial nerve nuclei after forming the reticular formation
- Lower motor neurons control eye and tongue movement, mastication, facial expression, palatine, pharyngeal, and laryngeal movements

Indirect Pathways

- Control conscious and unconscious muscle movements in trunk and proximal limbs.
- Synapse in some intermediate nucleus rather than directly with lower motor neurons.
- Tracts
  - **Rubrospinal**: upper neurons synapse in red nucleus. Similar to comparator function of cerebellum. Regulates fine motor control of muscles in distal part of upper limb.
  - **Vestibulospinal**: influence neurons innervating extensor muscles in trunk and proximal portion of lower limbs; help maintain upright posture.
  - **Reticulospinal**: maintenance of posture.

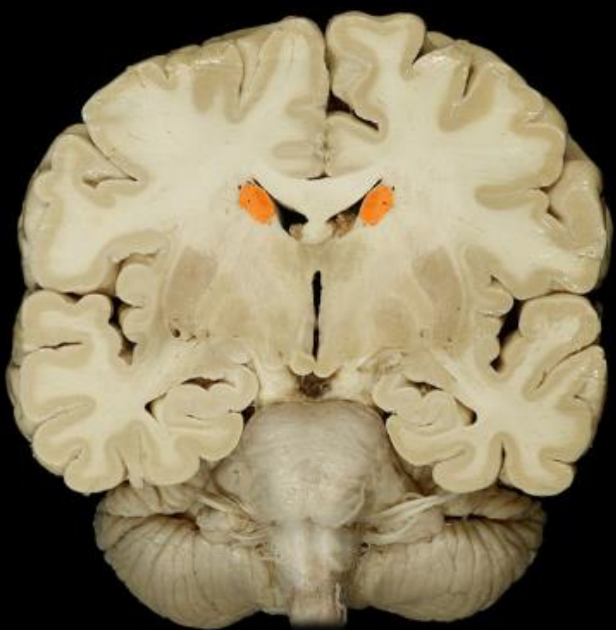


Basal Nuclei

- Important in planning, organizing, coordinating movements and posture
- Feedback loops among basal nuclei, thalamus, and cerebral cortex
  - Stimulatory: facilitate muscle activity like rising from a chair
  - Inhibitory: inhibit activity in antagonistic muscles

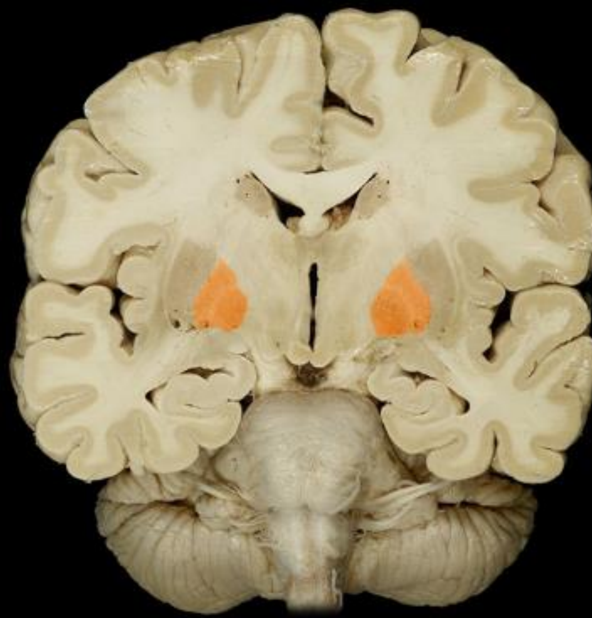
Basal Nuclei

Basal Nuclei



Caudate nucleus

Putamen

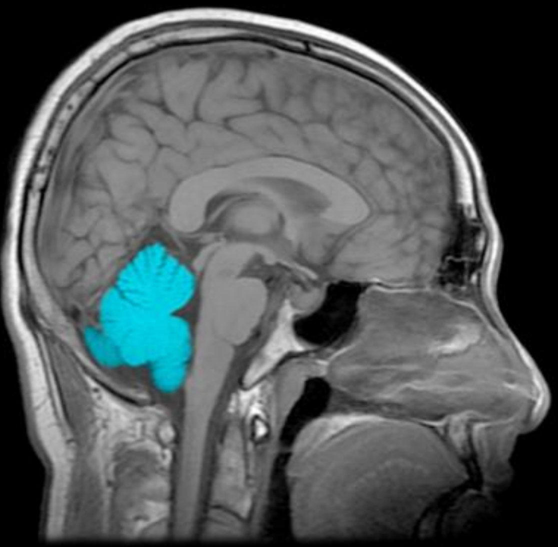


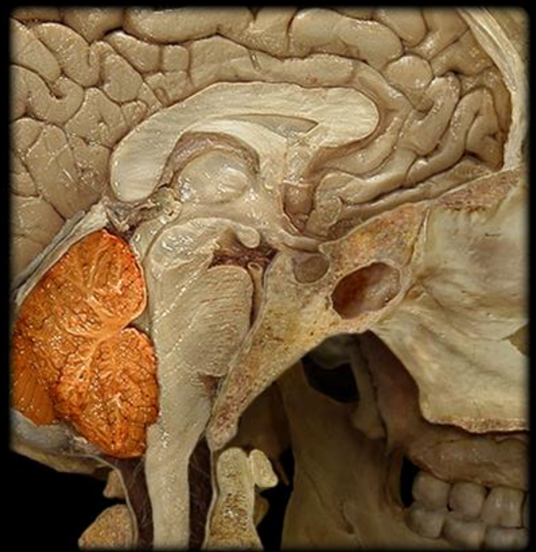
Globus pallidus

Cerebellum

- Helps maintain muscle tone in postural muscles, helps control balance during movement, and coordinate eye movements

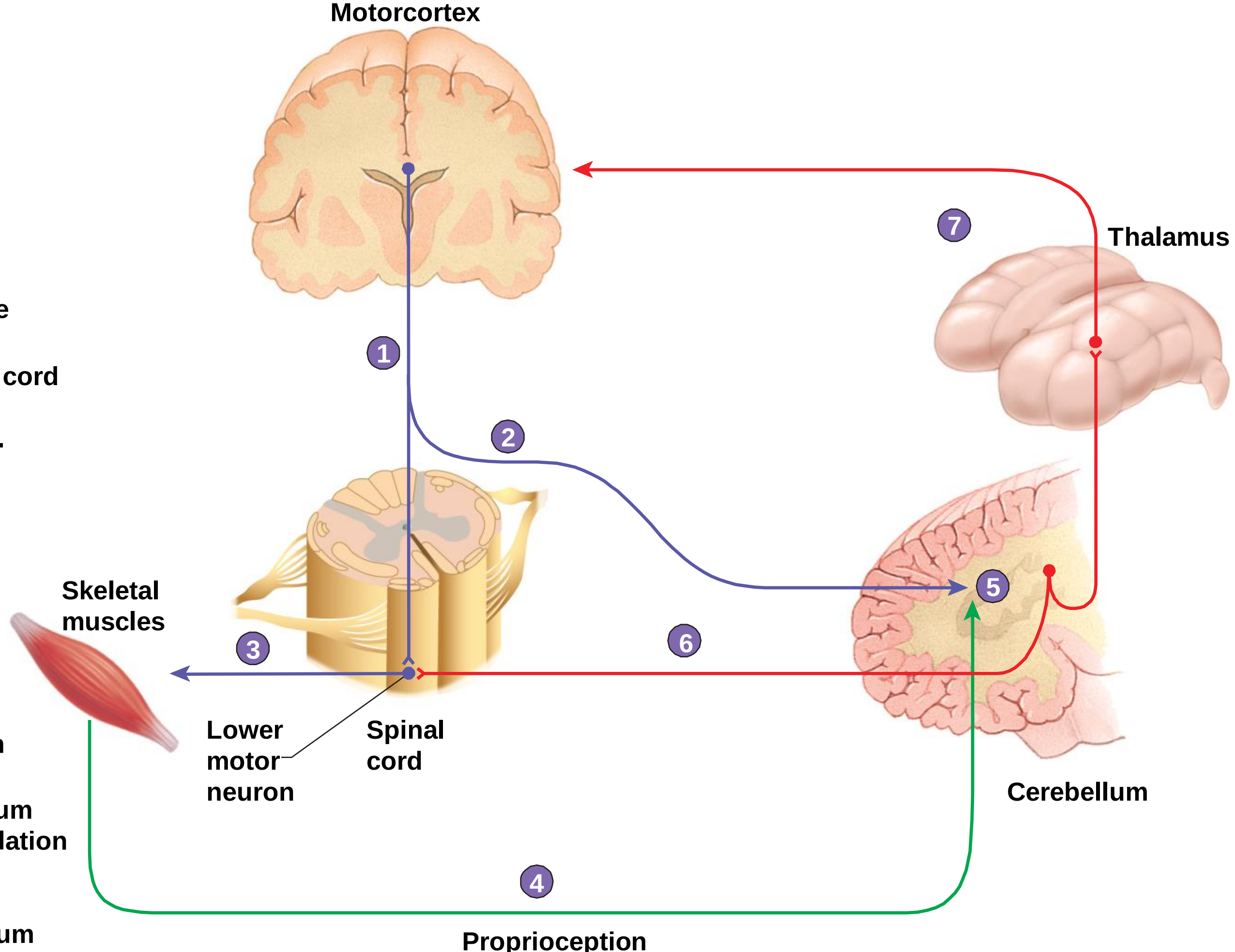
Cerebellum





Cerebellar Comparator Function

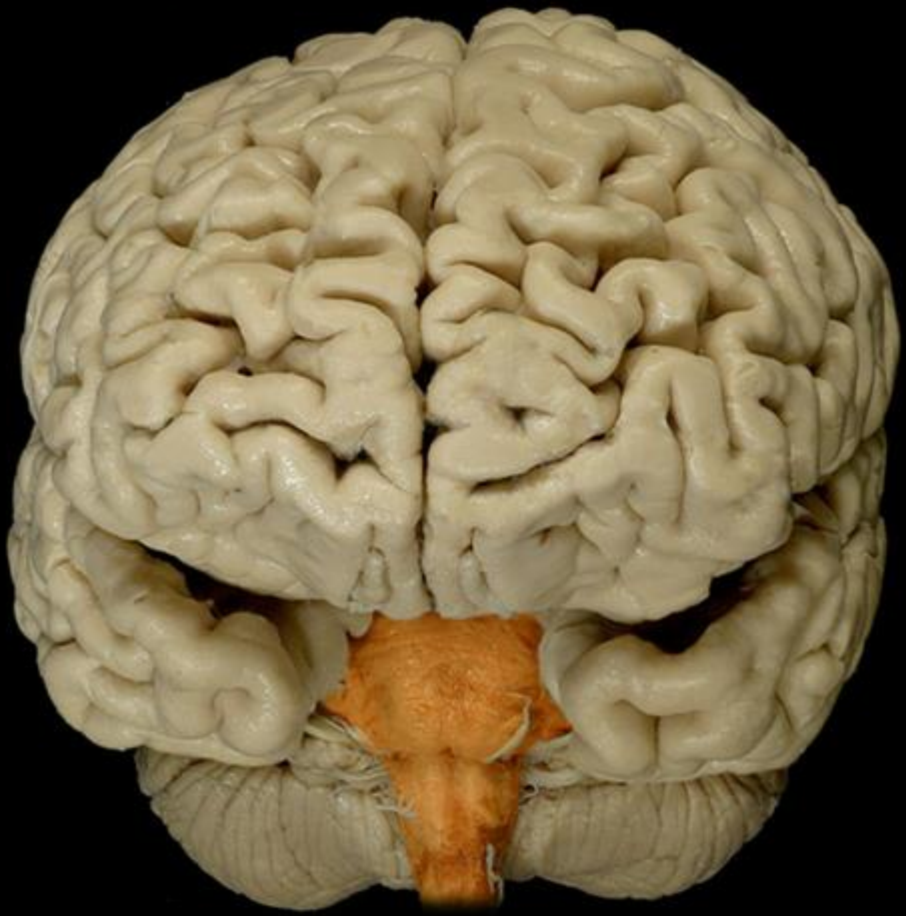
1. The motor cortex sends action Potentials to lower motor neurons In the spinal cord.
2. Action potentials from the motor Cortex inform the cerebellum of the Intended movement.
3. Lower motor neurons in the spinal cord Send action potentials to skeletal muscles, causing them to contract.
4. Proprioceptive signals from the Skeletal muscles and joints to the Cerebellum convey information Concerning the status of the Muscles and the structure being Moved during contraction.
5. The cerebellum compares the information from the motor cortex with the proprioceptive information from the skeletal muscle joints
6. Action potentials from the cerebellum to the spinal cord modify the stimulation from the motor cortex to the lower motor neurons
7. Action potentials from the cerebellum are sent to the motor cortex to modify its motor activity.

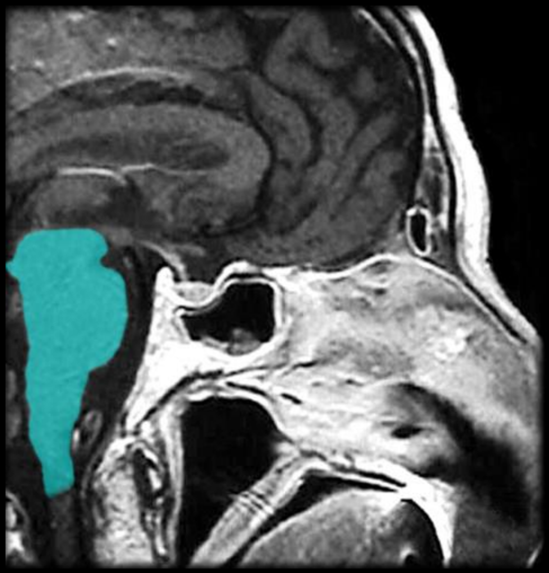


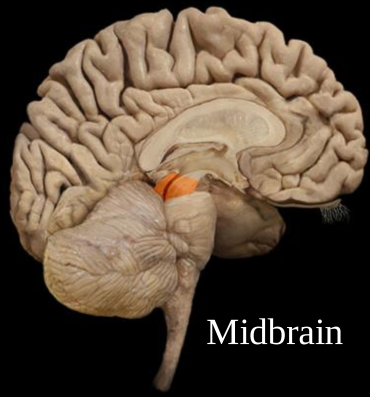
14.3 Brainstem Functions

- All ascending and descending pathways pass through the brainstem
- Nuclei of cranial nerves II-XII located here
- Many reflexes important to survival located here: heart rate, blood pressure, respiration, sleep, swallowing, vomiting, coughing, and sneezing
- Reticular activating system (RAS)- controls sleep/wake cycle
- RAS receives input from cranial nerves II (optic), VIII (vestibulocochlear), ascending tactile sensory pathways and descending neurons from the cerebral cortex. Wakefulness is maintained by information coming in from the eyes, ears, and because of information coming in from the cerebral cortex. Most alarm clocks function using sound to awaken the sleeping person.

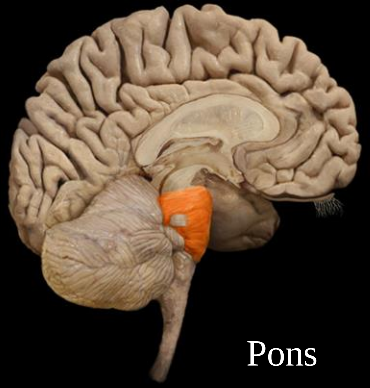
Brainstem



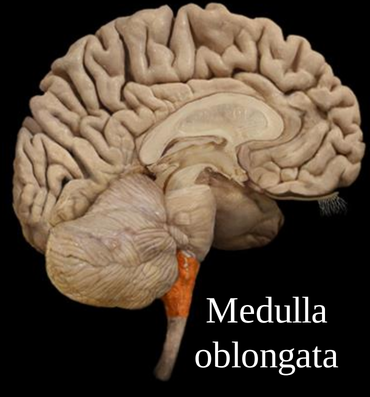




Midbrain

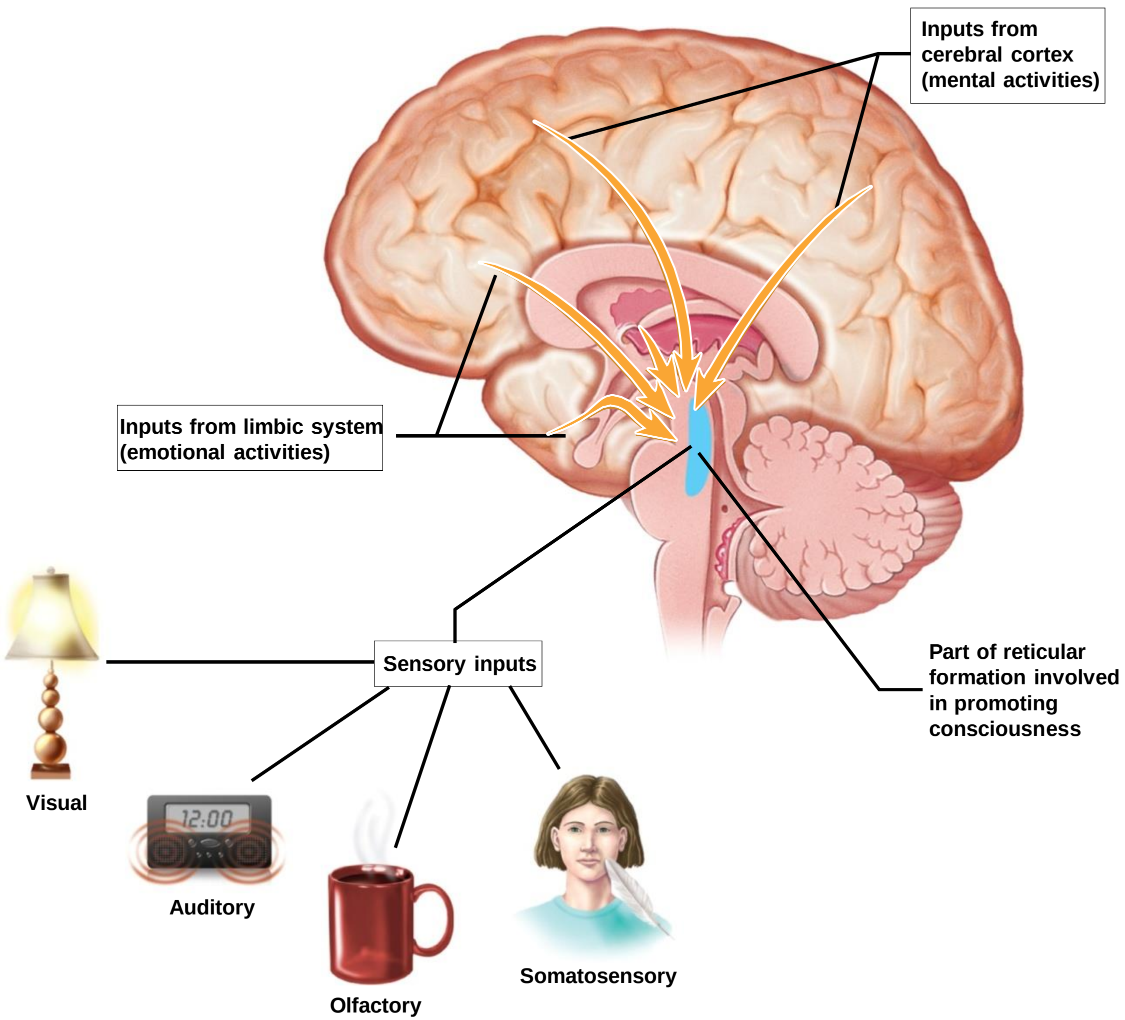


Pons



Medulla
oblongata

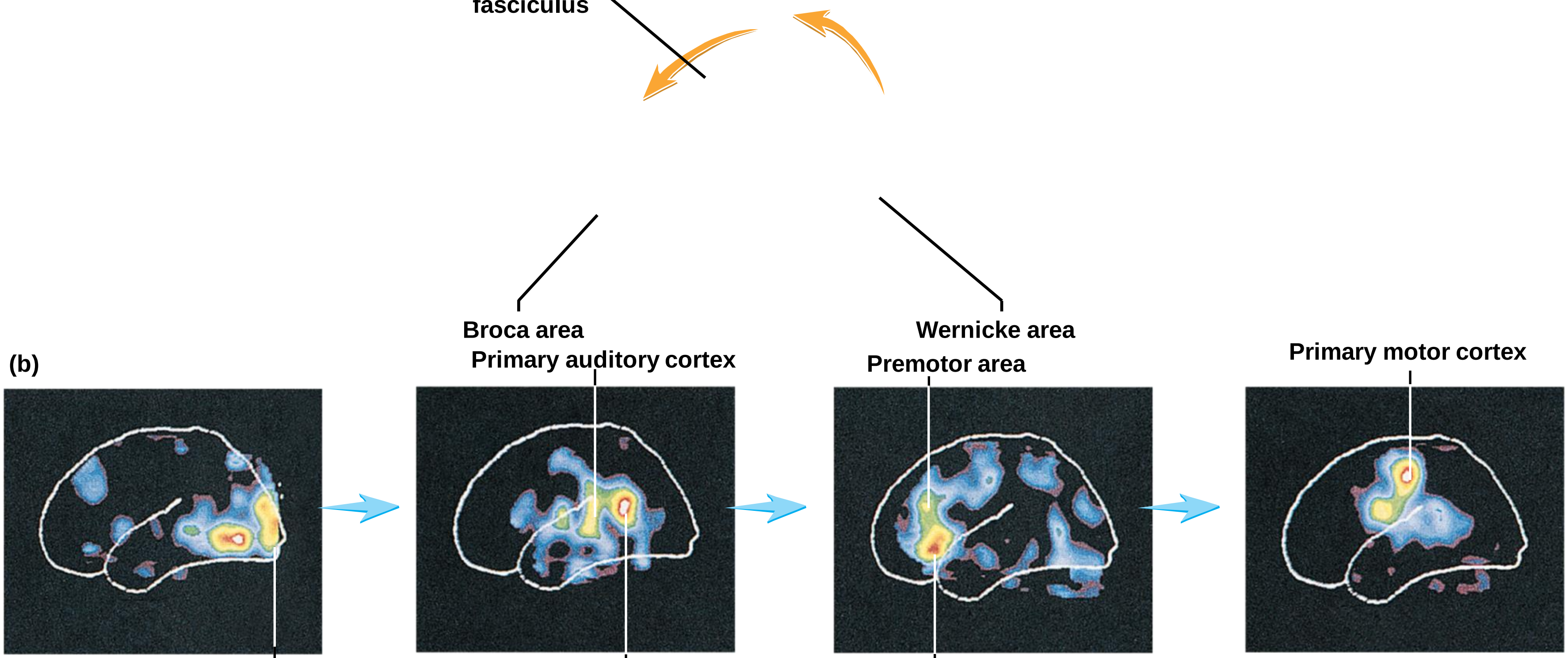
Reticular Activating System



14.4 Other Brain Functions

- Speech - Area normally in left cerebral cortex
  - **Wernicke's area**: sensory speech- understanding what is heard and thinking of what one will say.
  - **Broca's area**: motor speech- sending messages to the appropriate muscles to actually make the sounds.
  - Sound is heard first in the 1^{o} association area, then information travels to Wernicke's area. Neuronal connections between Wernicke's area and Broca's area.
  - **Aphasia**: absent or defective speech or language comprehension. Caused by lesion somewhere in the auditory/speech pathway.

Pet Scan of Cerebral Activity



1. The word is seen in the visual cortex.

2. Information concerning the word is understood in Wernicke area.

3. Information from Wernicke area is transferred to Broca area.

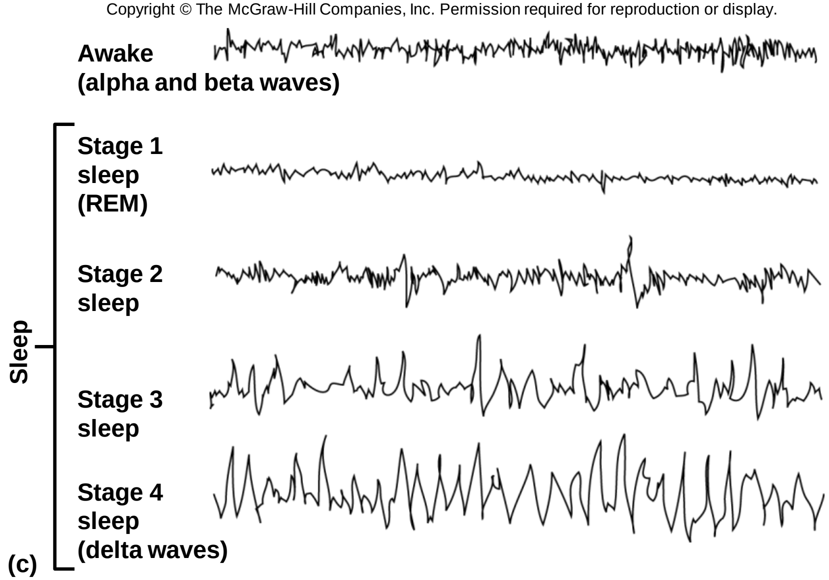
4. Information is transferred from Broca ar ea to the primary motor cortex.

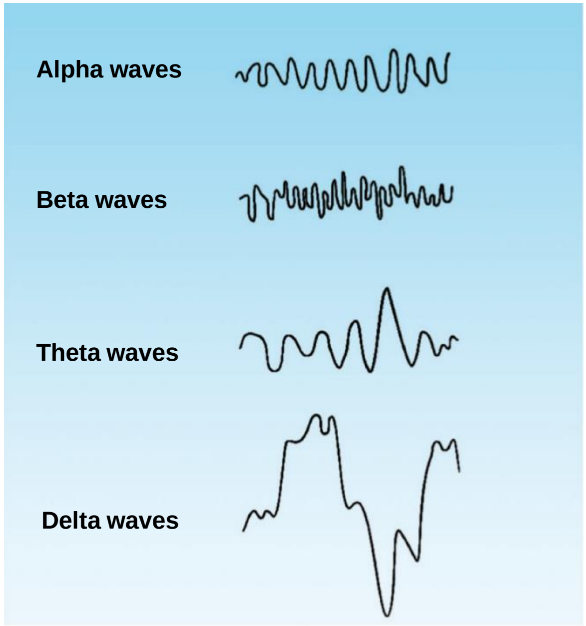
Right and Left Cerebral Cortex

- Right: controls muscular activity in and receives sensory information from left side of body
- Left: controls muscular activity in and receives sensory information from right side of body
- Sensory information of both hemispheres shared through commissures: corpus callosum
- Language, and possibly other functions like artistic activities, not shared equally
  - Left: mathematics and speech
  - Right: three-dimensional or spatial perception, recognition of faces, musical ability

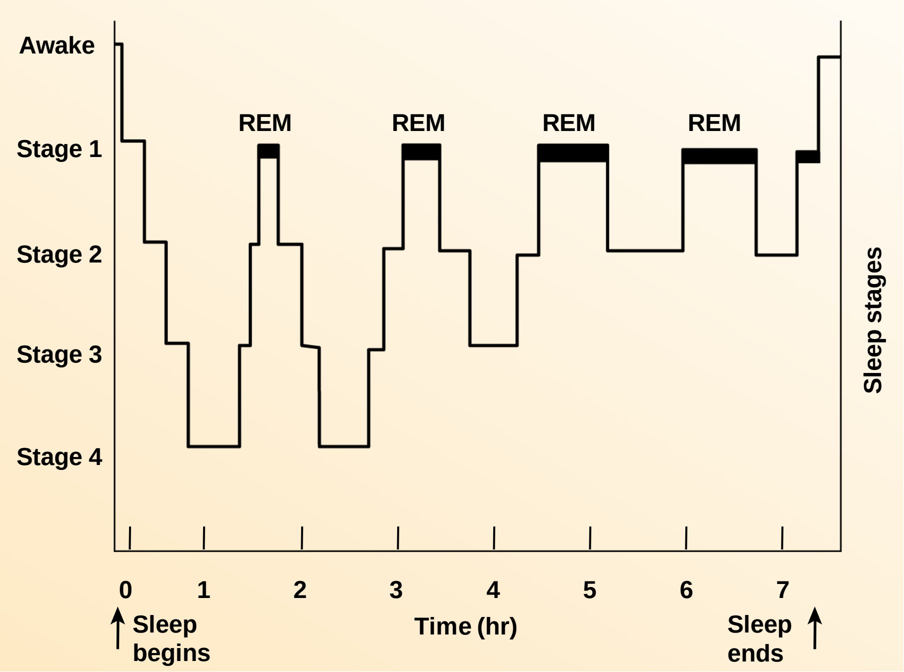
Brain Waves and Sleep

- **Electroencephalogram** (EEG): record of brain's electrical activity. Summation of all of the action potentials occurring at a particular moment sensed by electrodes placed on the scalp.
- Brain wave patterns
  - **Alpha**: Resting state with eyes closed
  - **Beta**: During intense mental activity
  - **Theta**: Occur in children but also in adults experiencing frustration or brain disorders
  - **Delta**: Occur in deep sleep, infancy, and severe brain disorders
- Sleep: note pattern of nREM and REM sleep.




Alpha waves
Beta waves
Theta waves
Delta waves

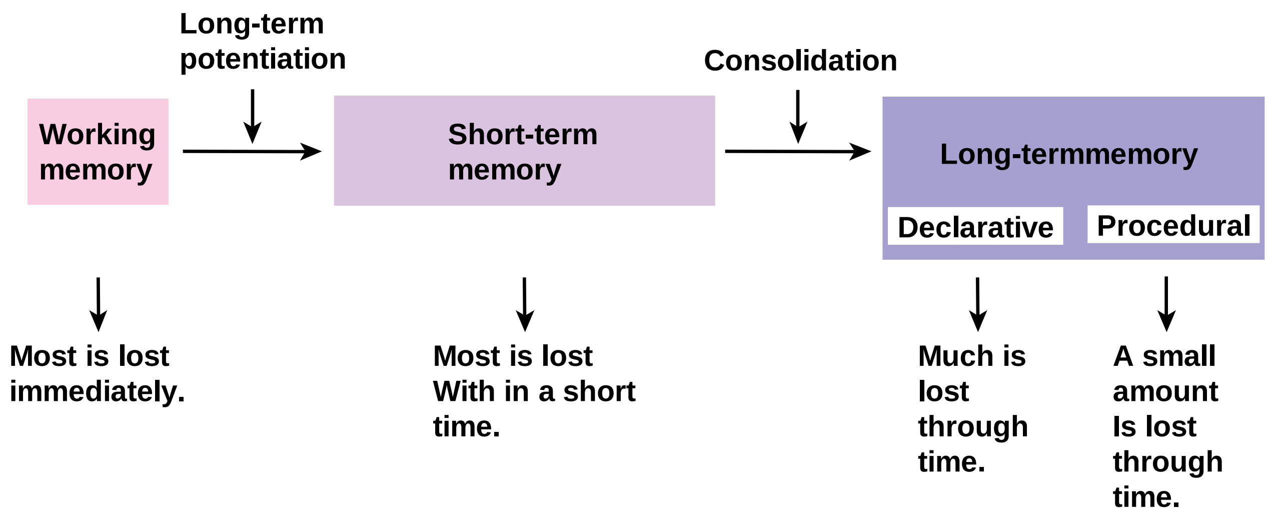
(b)


Awake
Stage 1
Stage 2
Stage 3
Stage 4
REM
REM
REM
REM
Sleep stages
0
1
2
3
4
5
6
7
Sleep begins
Time (hr)
Sleep ends

(d)

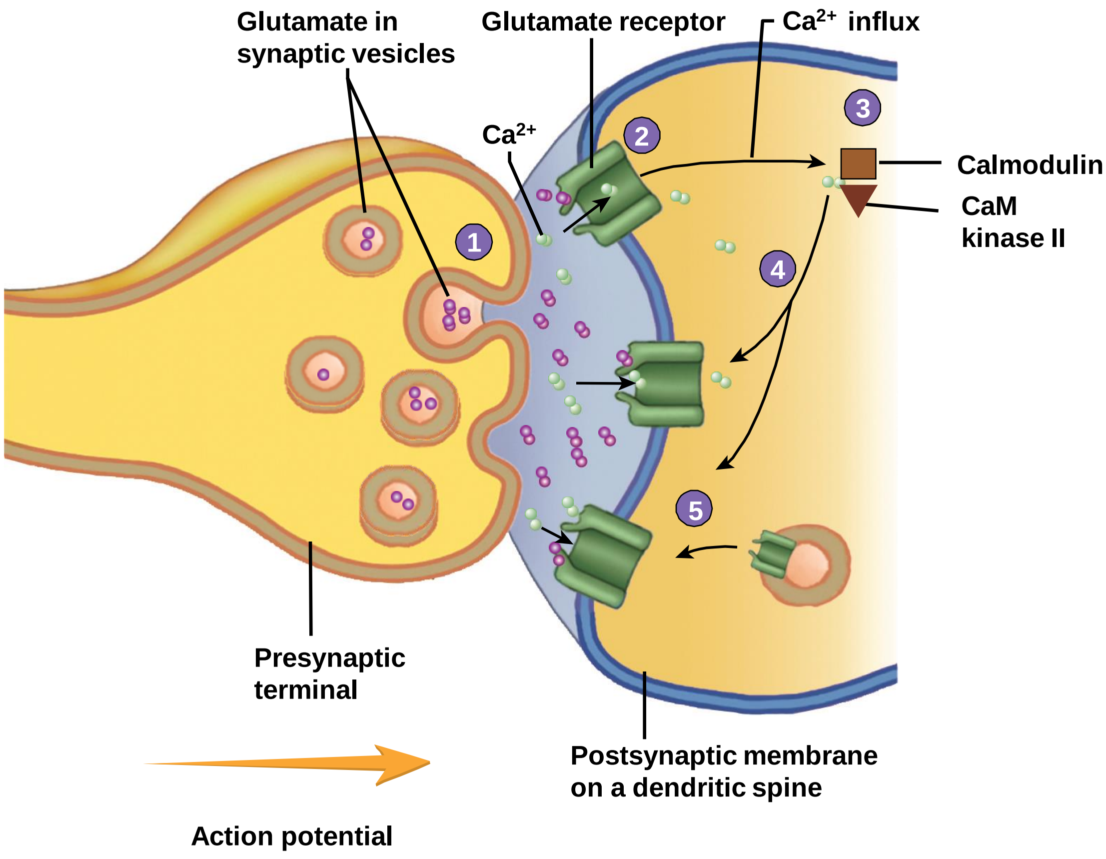
Memory

- **Sensory**: very short-term retention of sensory input
- **Short-term**: information retained for few seconds to minutes
- **Long-term**: declarative or explicit
  - Retention of facts
  - Accessed by hippocampus (actual memory) and amygdaloid nucleus (emotional)
- **Procedural** (implicit; reflexive) memory: development of skills such as riding a bicycle



Long-Term Potentiation

1. **The amount of glutamate released by the presynaptic neuron increases.**
2. **Glutamate binds its receptors and causes ligand-gated ion channels to open. Calcium enters the cell.**
3. **The Ca^{2+} that enter the cell associate with the intracellular molecule calmodulin.**
4. **Ca^{2+} -calmodulin activates calmodulin-dependent protein kinase II (CaM kinase II), which activates the glutamate receptors.**
5. **CaM kinase II also causes translocation of more glutam ate receptors to the cell surface to increase the number of receptors on the postsynaptic membrane.**



Formation of Long-Term Memory

- End result is changes in the cytoskeleton of the postsynaptic neuron. Memory becomes more or less permanent.
- **Memory engram** (memory trace): series of neurons and their pattern of activity. Involved in long-term retention of information, a thought, or an idea. Repetition and association of the new information with existing memories assist in transfer of info from short-term to long-term memory.

Limbic System

- Influences emotions, visceral responses to emotions, motivation, mood, sensations of pain and pleasure
- Basic survival instincts: acquisition of food and water; reproduction
- **Pheromones**: molecules released by one organism that have an effect on another organism; e.g., females release pheromones that affect menstrual cycle of other women
- Cingulate gyrus: satisfaction center

14.5 Effects of Aging on the Nervous System

- Gradual decline in sensory and motor function
- Reflexes slow
- Size and weight of brain decrease
- Decreased short-term memory in most people
- Long-term memory unaffected or improved
- Changes in sleep patterns