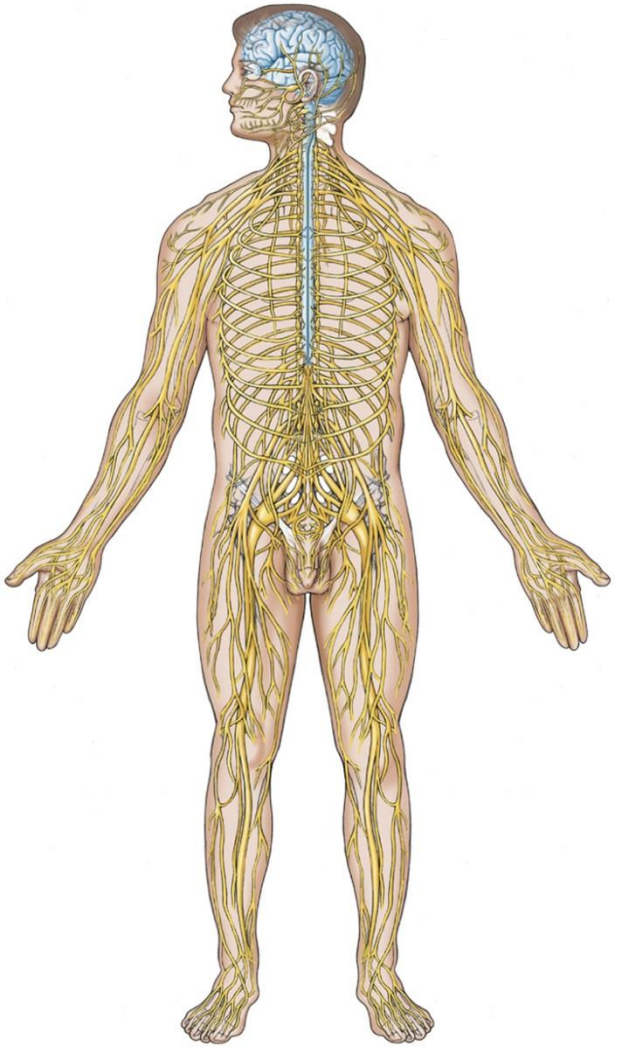
ECE 370
Introduction to Biomedical Engineering

The Senses

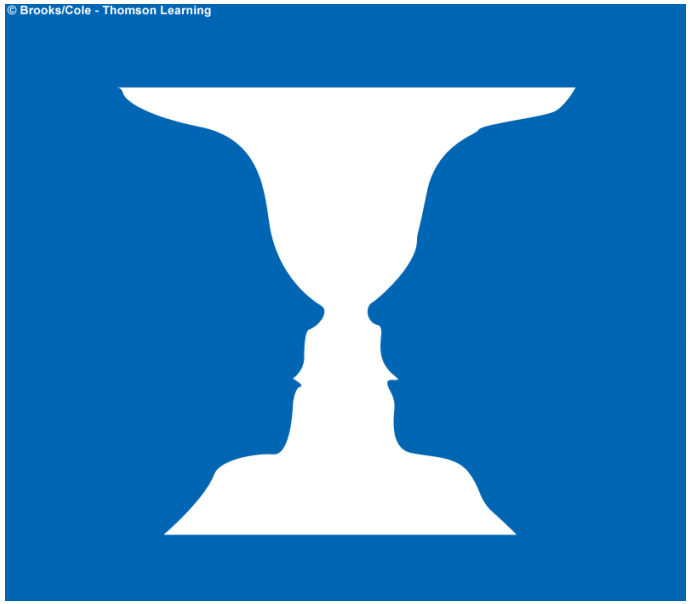
The Peripheral Nervous System

- **Peripheral Nervous System**
  - Afferent Division
    - Sends information from the PNS to the CNS
  - Efferent Division
    - Send information from the CNS to the PNS
- **Afferent Division**
  - Visceral afferents (subconscious input)
    - Pressure, O2, temperature, etc.
  - Sensory afferents (conscious input)
    - Somatic sensation
      - Somesthetic sensation from skin
      - Proprioception from muscle joints, skin and inner ear
    - Special senses
      - Vision, hearing, taste and smell
- **Efferent Division**
  - Autonomic Nervous System
    - Cardiac muscle, smooth muscle, most exocrine glands, some endocrine glands, adipose tissue
  - Somatic Nervous system
    - Skeletal muscle



Sensation and Perception

- **Sensation ≠ Perception**
- **Perception**
  - Our understanding (conscious interpretation) of the physical world
  - An interpretation of the senses
  - Different from what is out there because
    - Our receptors detect limited number of existing energy forms
    - The information does not reach our brain unaltered.
      - Some features are accentuated and some are suppressed
    - The brain interprets the information and often distorts it
      - “completes the picture” or “feels in the gaps” to extract conclusions.
    - Interpretation is affected by cultural, social and personal experiences stored in our memory

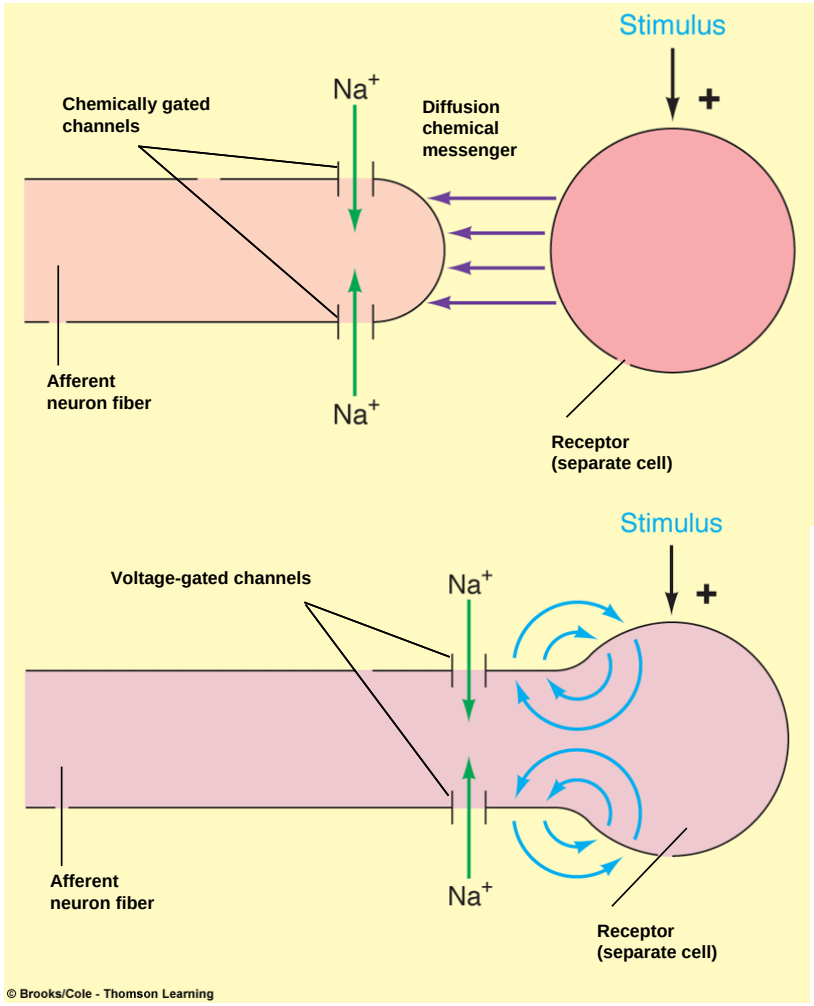


Receptor Physiology

- **Receptors**
  - Convert forms of energy into electrical signals (action potentials)
    - Process is called transduction
- **Types of receptors**
  - Photoreceptors
    - Responsive to visible wavelengths of light
  - Mechanoreceptors
    - Sensitive to mechanical energy
  - Thermoreceptors
    - Sensitive to heat and cold
  - Osmoreceptors
    - Detect changes in concentration of solutes in body fluids and resultant changes in osmotic activity
  - Chemoreceptors
    - Sensitive to specific chemicals
    - Include receptors for smell and taste and receptors that detect O2 and CO2 concentrations in blood and chemical content of digestive tract
  - Nociceptors
    - Pain receptors that are sensitive to tissue damage or distortion of tissue

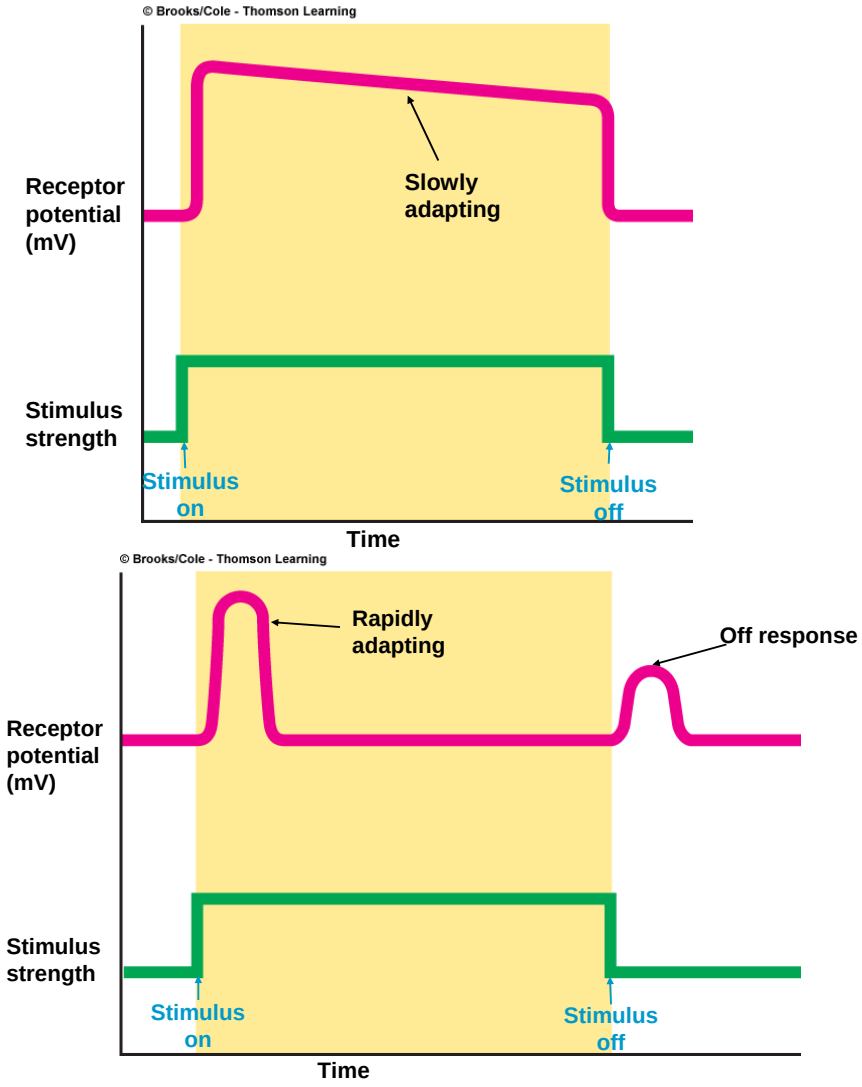
Receptor Physiology

- **Receptors may be**
  - Separate cell closely associated with peripheral ending of a neuron
    - Graded potential → synapse
  - Specialized ending of an afferent neuron
    - Action potentials



Receptor Physiology

- **May adapt slowly or rapidly to sustained stimulation**
- **Types of receptors according to their speed of adaptation**
  - Tonic receptors
    - Do not adapt at all or adapt slowly
    - Muscle stretch receptors, joint proprioceptors → continuously receive information regarding posture and balance
  - Phasic receptors
    - Rapidly adapting receptors
    - Tactile receptors in skin → the reason you don't "feel" your clothes or watch

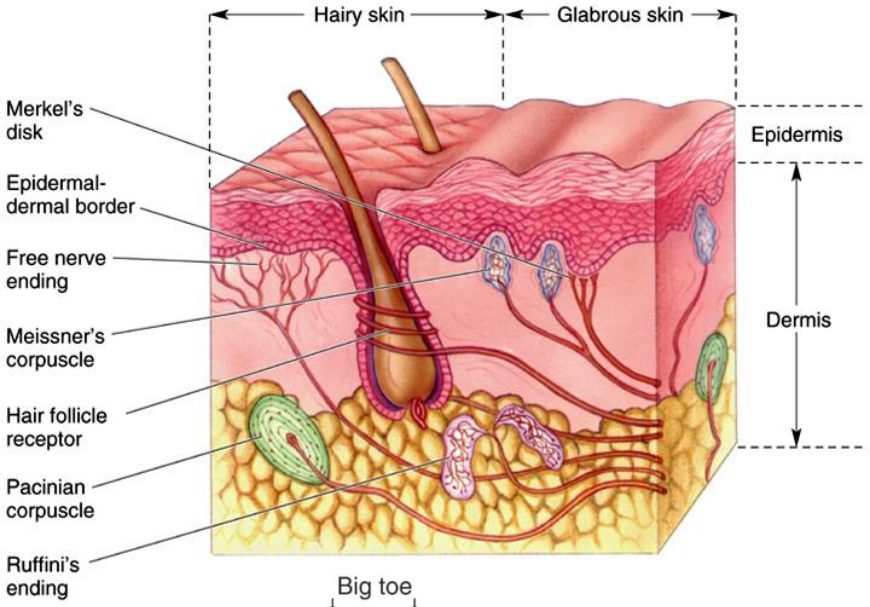


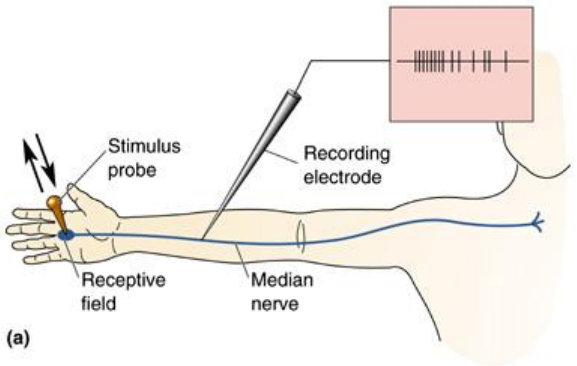
Somatic Sensation

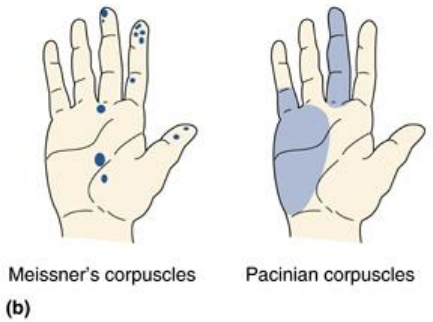
- **Enables body to feel, ache, chill**
- **Responsible for feeling of touch, pain and temperature**
- **Somatic sensory system: Different from other systems**
  - Receptors are distributed throughout
  - Respond to different kinds of stimuli

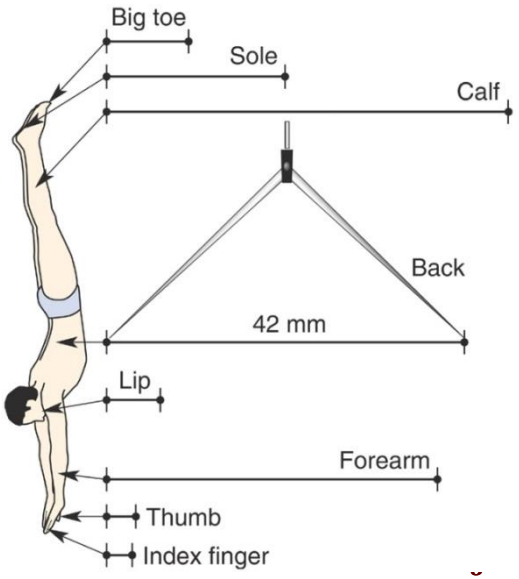
Touch

- **Receptors**
  - Embedded in the skin
    - Most somatosensory receptors are mechanoreceptors
  - Sensitivity:
    - Varies for different parts of the body
    - Min: 0.006 mm high x 0.04 mm wide
      - E.g. fingertips
    - Max: several centimeter
      - E.g. back
  - Hair
    - Sensitive to movement (Exquisitely sensitive in some animals)



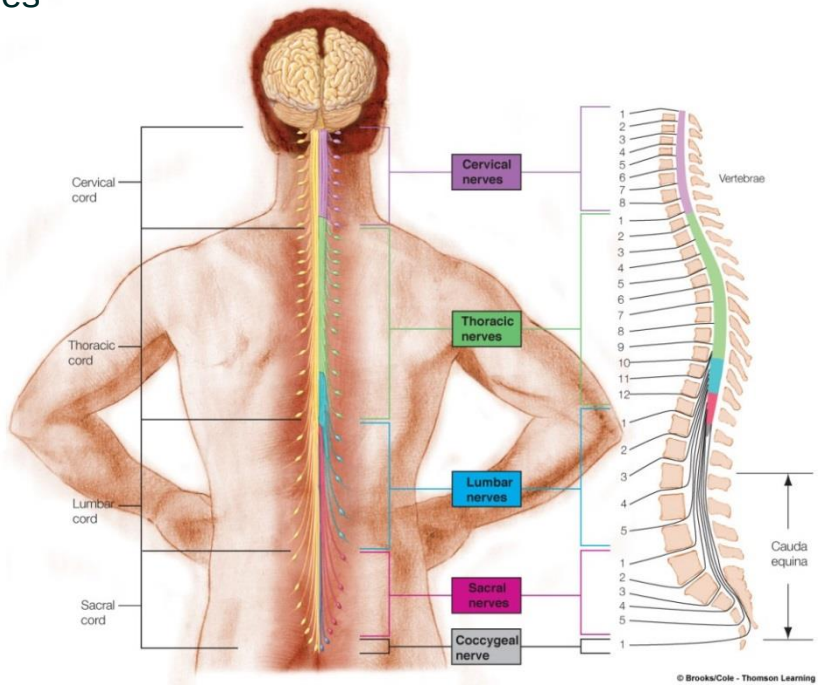


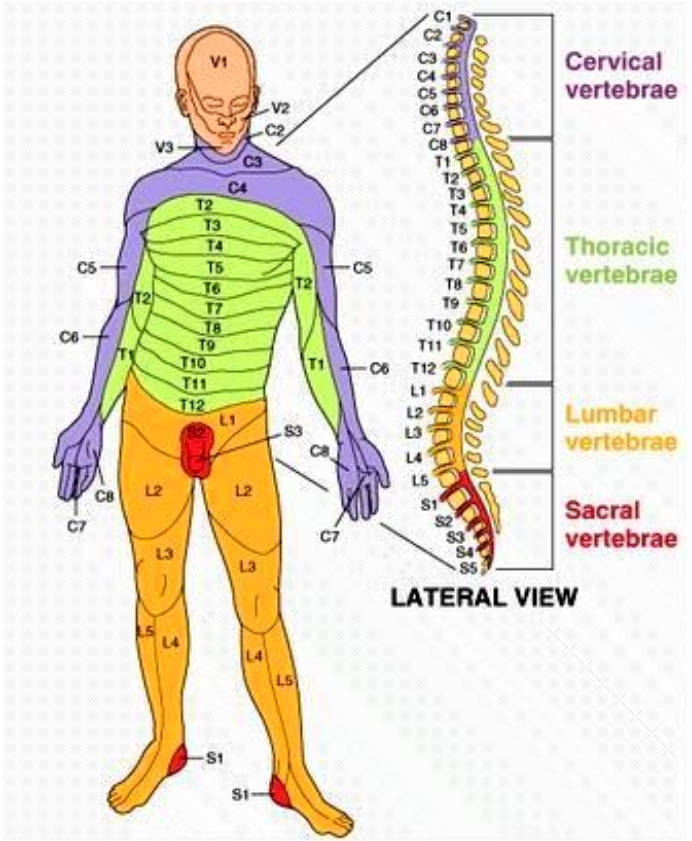




Touch

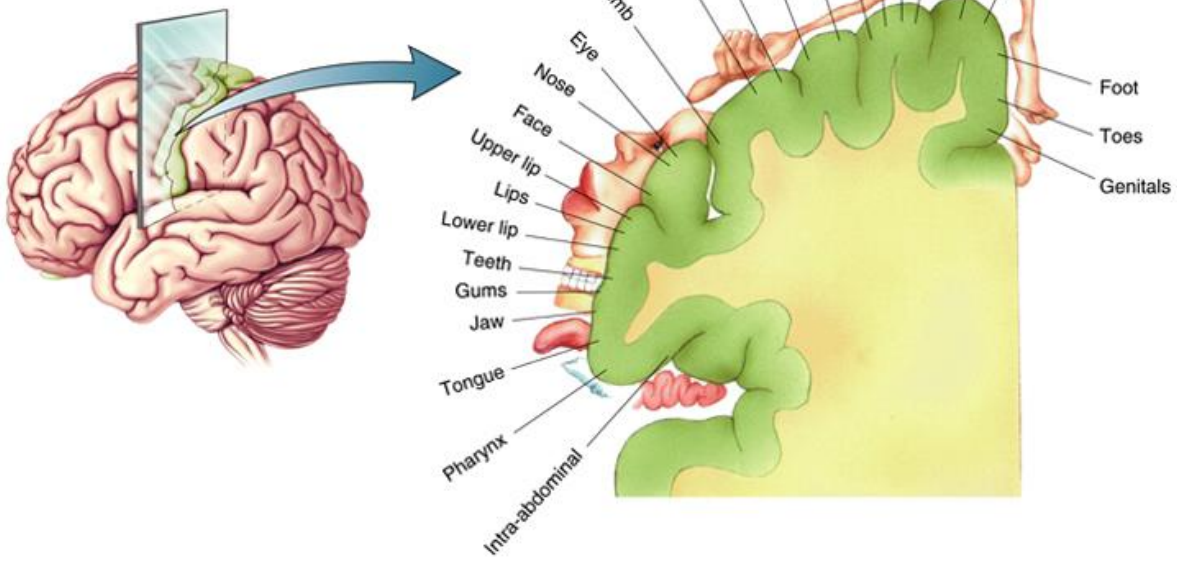
- **Spinal nerves**
  - 31 pairs of spinal nerves emerge from spinal cord through spaces formed between arches of adjacent vertebrae
  - Named for region of vertebral column from which they emerge
    - 8 pairs cervical (neck) nerves
    - 12 pairs thoracic (chest) nerves
    - 5 pairs lumbar (abdominal) nerves
    - 5 pairs sacral (pelvic) nerves
    - 1 pair coccygeal (tailbone) nerves
- **Dermatomes- 1-to-1 correspondence with segments**
  - Shingles

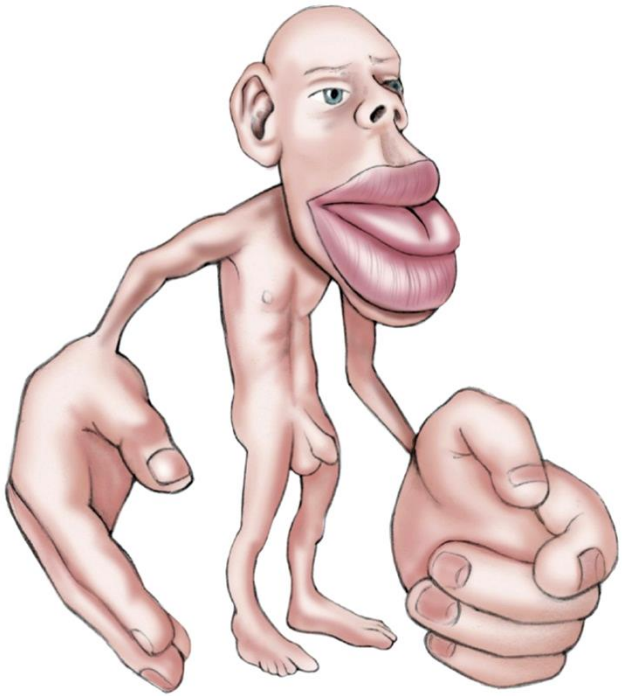




Touch

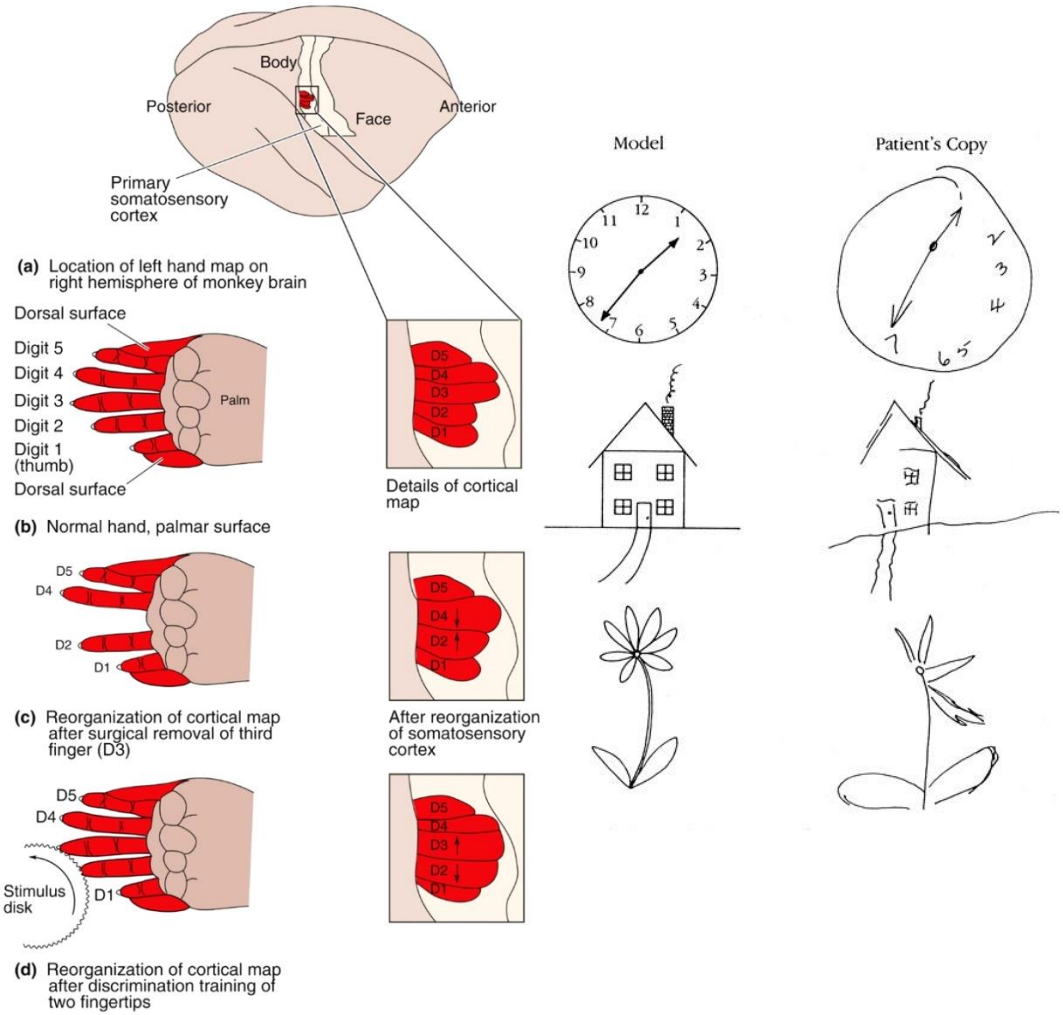
- **Somatosensory Cortex**
  - Cortical Somatotopy
    - Homunculus
    - Importance of mouth
      - Tactile sensations: Important





Touch

- **Somatosensory Cortex**
  - Cortical Map Plasticity
  - Remove or overstimulate
    - Dynamic reorganization of cortical maps
    - Adjust depending on the amount of sensory experience
- **Sensory Association Cortex**
  - The Posterior Parietal Cortex
  - Integration of all sensory information (somatic sensation, visual stimuli, etc)
  - Keeps a map of the body and the world
    - Useful in movement planning
  - Deficits
    - Agnosia
    - Astereoagnosia
    - Neglect syndrome



Pain

- **Pain**
  - Primarily a protective mechanism meant
    - Bring a conscious awareness that tissue damage is occurring or is about to occur
  - Storage of painful experiences in memory
    - Avoid potentially harmful events in future
    - Motivated behavioral responses and emotional reactions
  - Subjective perception can be influenced by other past or present experiences.
    - Are you afraid of your dentist?

Pain

- **Three categories of nociceptors**
  - Mechanical nociceptors
    - Respond to mechanical damage such as cutting, crushing, or pinching
  - Thermal nociceptors
    - Respond to temperature extremes
  - Polymodal nociceptors
    - Respond equally to all kinds of damaging stimuli
- **Nociceptors do not adapt to sustained or repetitive stimulation**

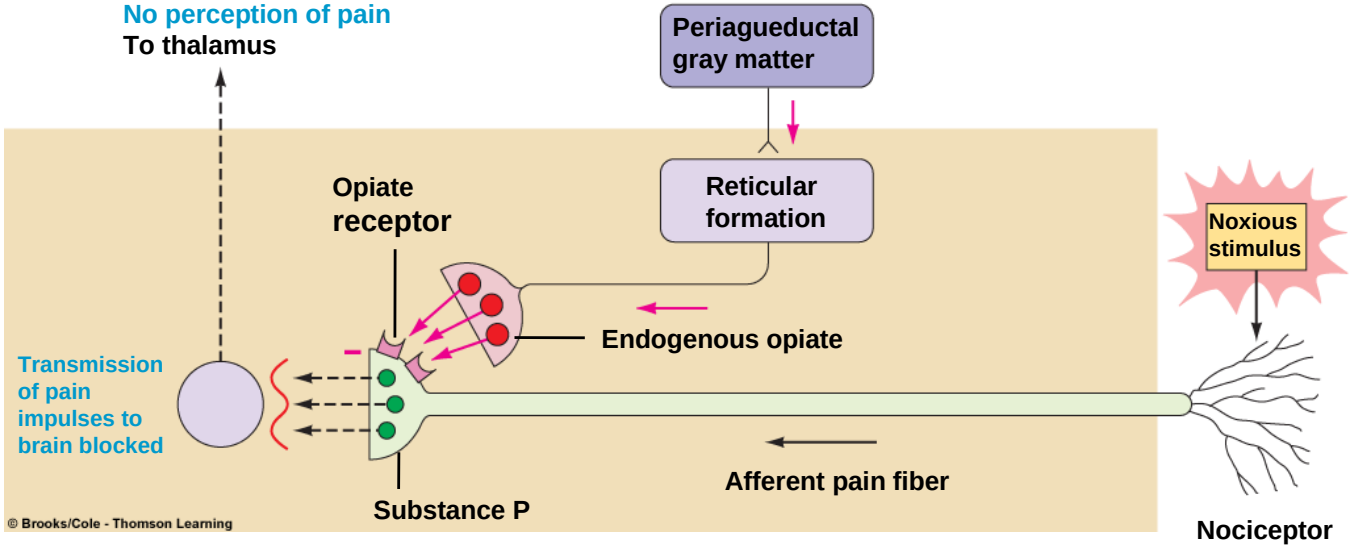
Pain

- **Characteristics of pain**

Fast Pain	Slow Pain
Occurs on stimulation of mechanical and thermal nociceptors	Occurs on stimulation of polymodal nociceptors
Carried by small, myelinated A-delta fibers	Carried by small, unmyelinated C fibers
Produces sharp, prickling sensation	Produces dull, aching, burning sensation
Easily localized	Poorly localized
Occurs first	Occurs second, persists for longer time, more unpleasant
	Provoked and sustained by release of bradykinin

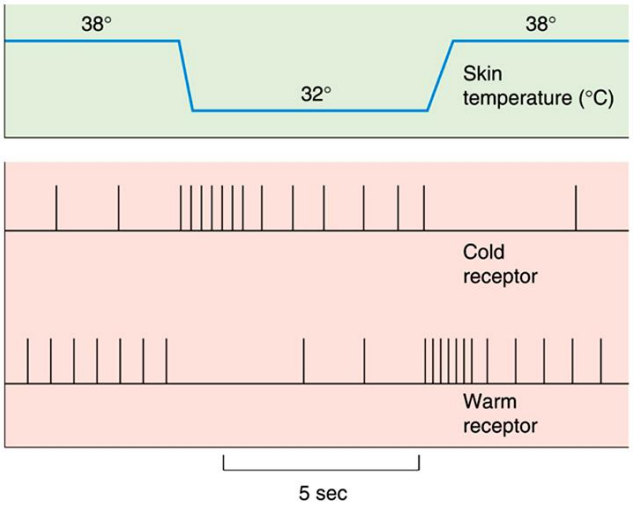
Pain

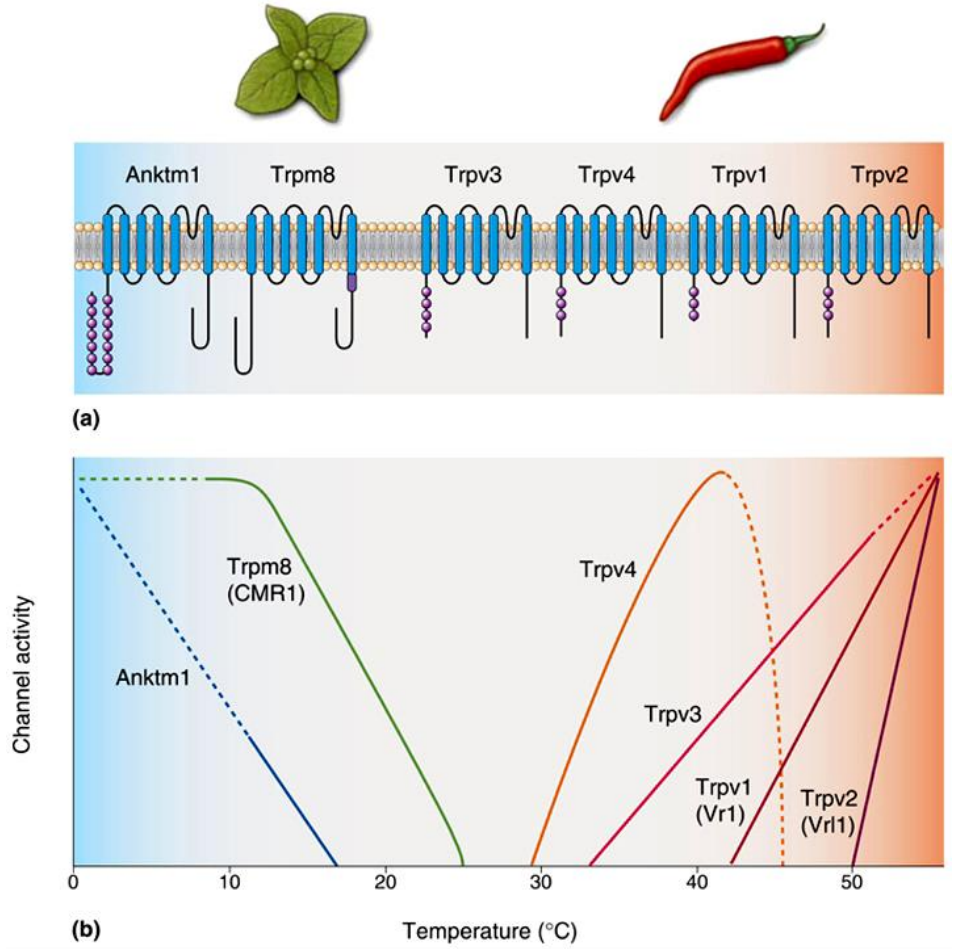
- **Brain has built in analgesic system**
  - Suppress release of pain neurotransmitter (Substance P)
    - Presence of opiate receptors
      - Endogenous opiates (morphine like substances) – endorphins, enkephalins, dynorphin
  - Factors which modulate pain
    - Exercise (“runner’s high”)
    - Stress (survival mechanism)
    - Acupuncture



Temperature

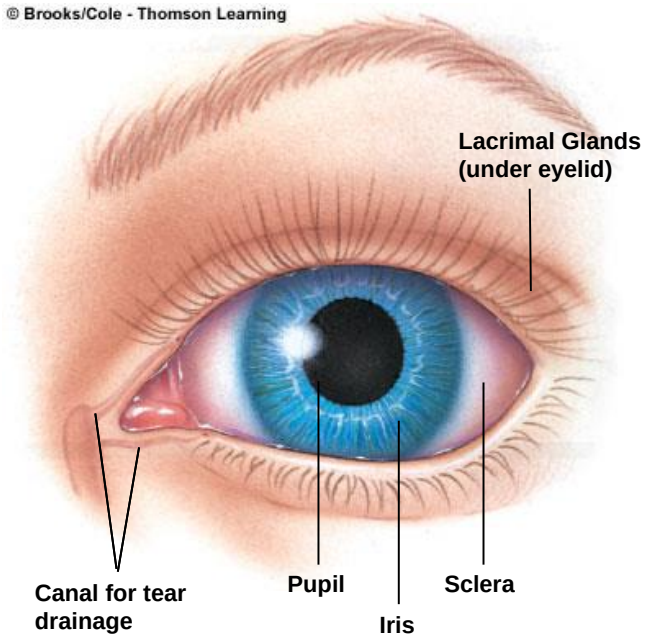
- **Thermoreceptors**
  - "Hot" and "cold" receptors
  - Varying sensitivities
  - Perceive changes as small as 0.01 ^{o}C
  - Adaptation

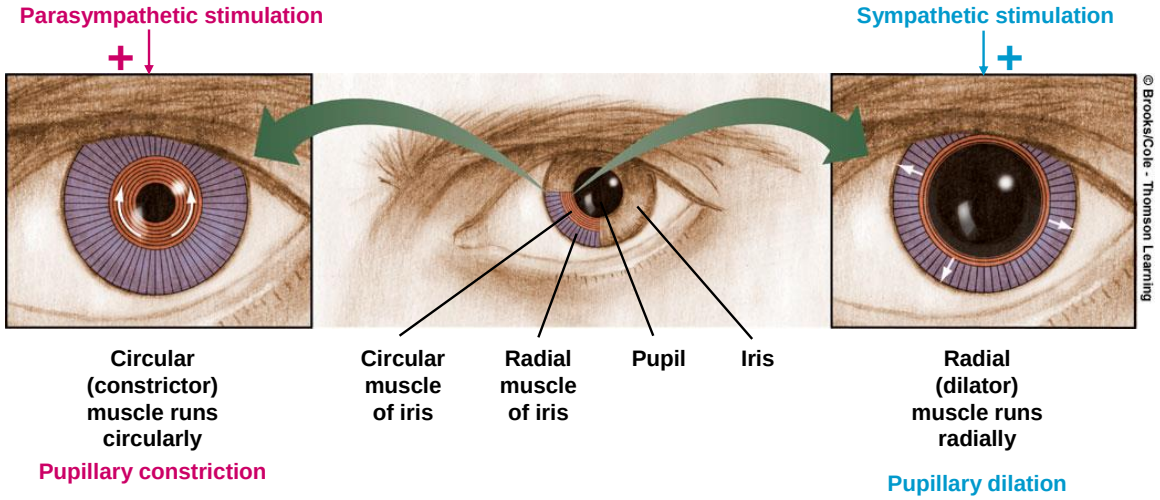




Vision

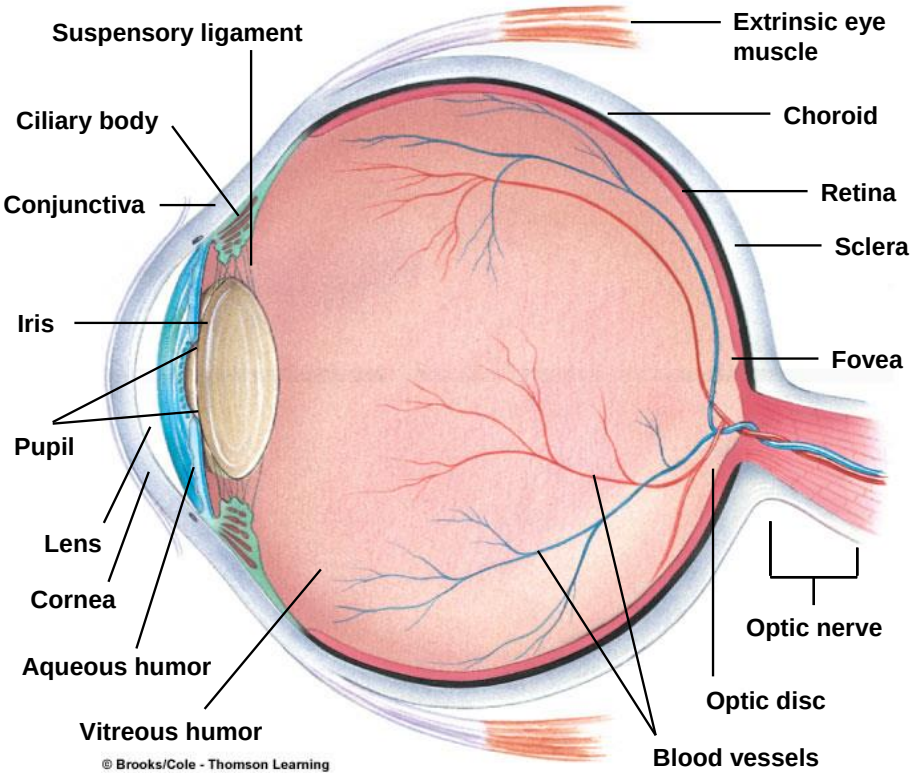
- **Eye**
  - Sensory organ for vision
  - Pupil
    - Round opening through which light enters the eye
  - Iris
    - Controls amount of light entering eye
    - Pigment in iris is responsible for eye color
      - Unique for each individual
      - Basis for latest identification technology





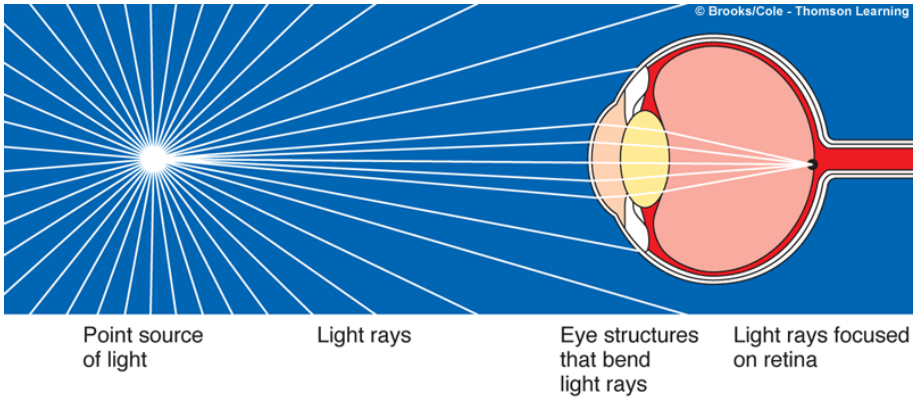
Vision

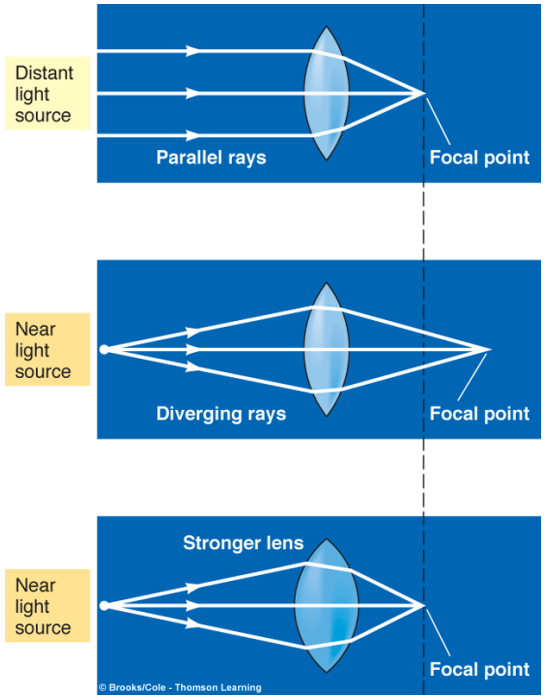
- **Eye**
  - Spherical, fluid-filled structure enclosed by three tissue layers
  - Sclera/cornea
    - Sclera – tough outer layer of connective tissue; forms visible white part of the eye
    - Cornea – anterior, transparent outer layer through which light rays pass into interior of eye
  - Choroid
    - Middle layer underneath sclera which contains blood vessels that nourish retina
    - Includes the iris
  - Retina
    - Innermost layer
    - Contains the photoreceptors



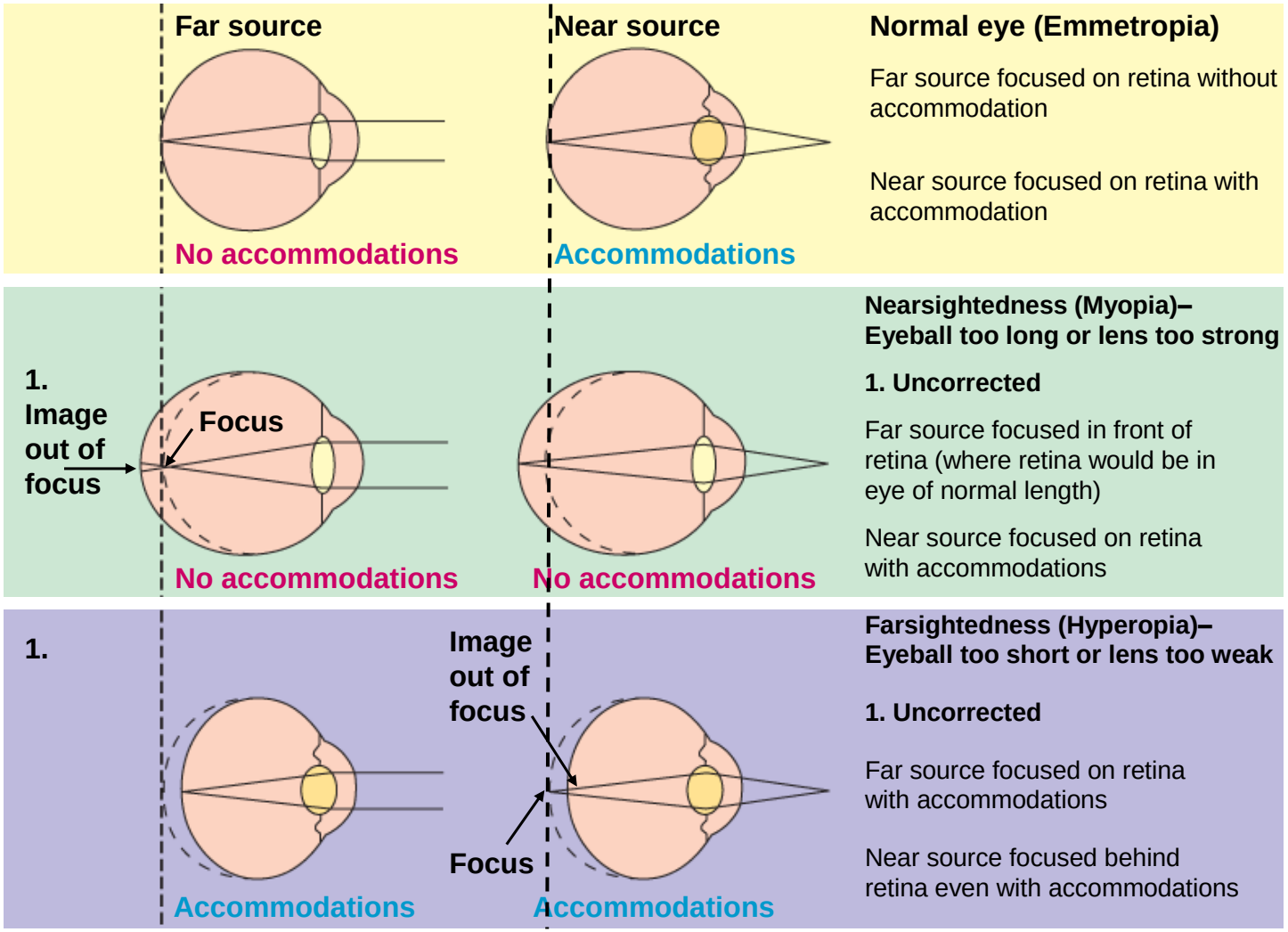
Vision

- **Convex structures of eye produce convergence of diverging light rays that reach eye**
- **Two structures most important in eye's refractive ability are**
  - Cornea
    - Contributes most extensively to eye's total refractive ability
    - Refractive ability remains constant because curvature never changes
  - Lens
    - Refractive ability can be adjusted by changing curvature as needed for near or far vision (accommodation)
    - Age-related reduction in accommodation ability - presbyopia



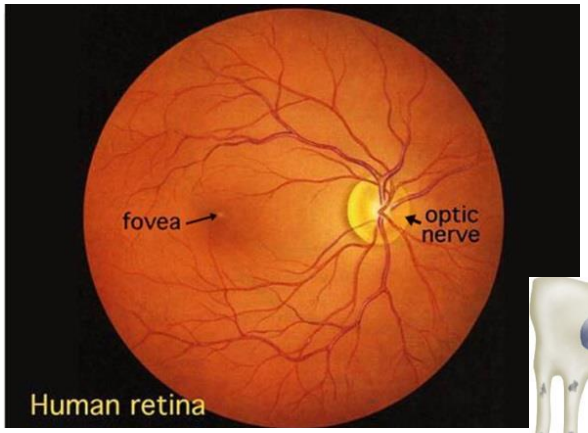


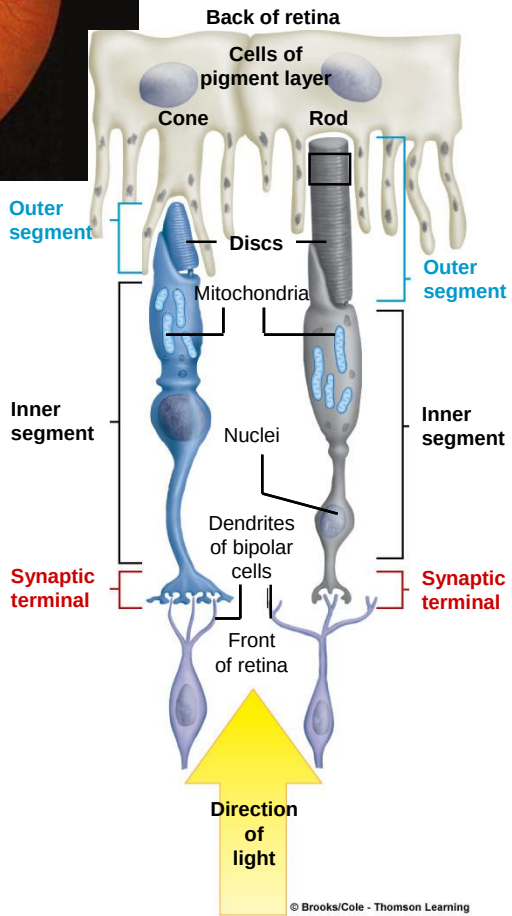
Vision


Far source
Near source
Normal eye (Emmetropia)
Far source focused on retina without accommodation
Near source focused on retina with accommodation
No accommodations
Accommodations
1. Image out of focus
Focus
Nearsightedness (Myopia)– Eyeball too long or lens too strong
1. Uncorrected
Far source focused in front of retina (where retina would be in eye of normal length)
Near source focused on retina with accommodations
No accommodations
No accommodations
1.
Image out of focus
Farsightedness (Hyperopia)– Eyeball too short or lens too weak
1. Uncorrected
Far source focused on retina with accommodations
Near source focused behind retina even with accommodations
Focus
Accommodations
Accommodations

Vision

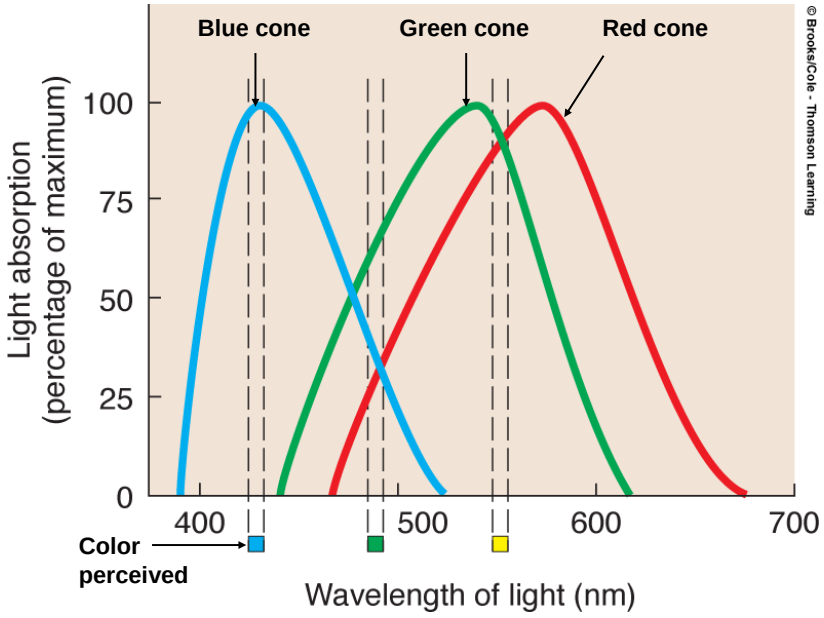
- **Retina**
  - Several layers of cells
  - Receptor containing portion is actually an extension of the CNS
- **Photoreceptors**
  - Rod and cone cells
  - Photopigments on their membranes
    - Rod → one type
      - one pigment, high sensitivity
    - Cones → three different types
      - Red, green, blue sensing pigments, lower sensitivity
  - Undergo chemical alterations when activated by light
    - Change the receptor potential
    - Induce action potentials

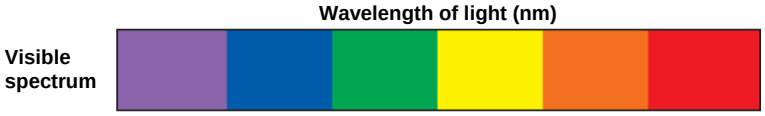




Vision

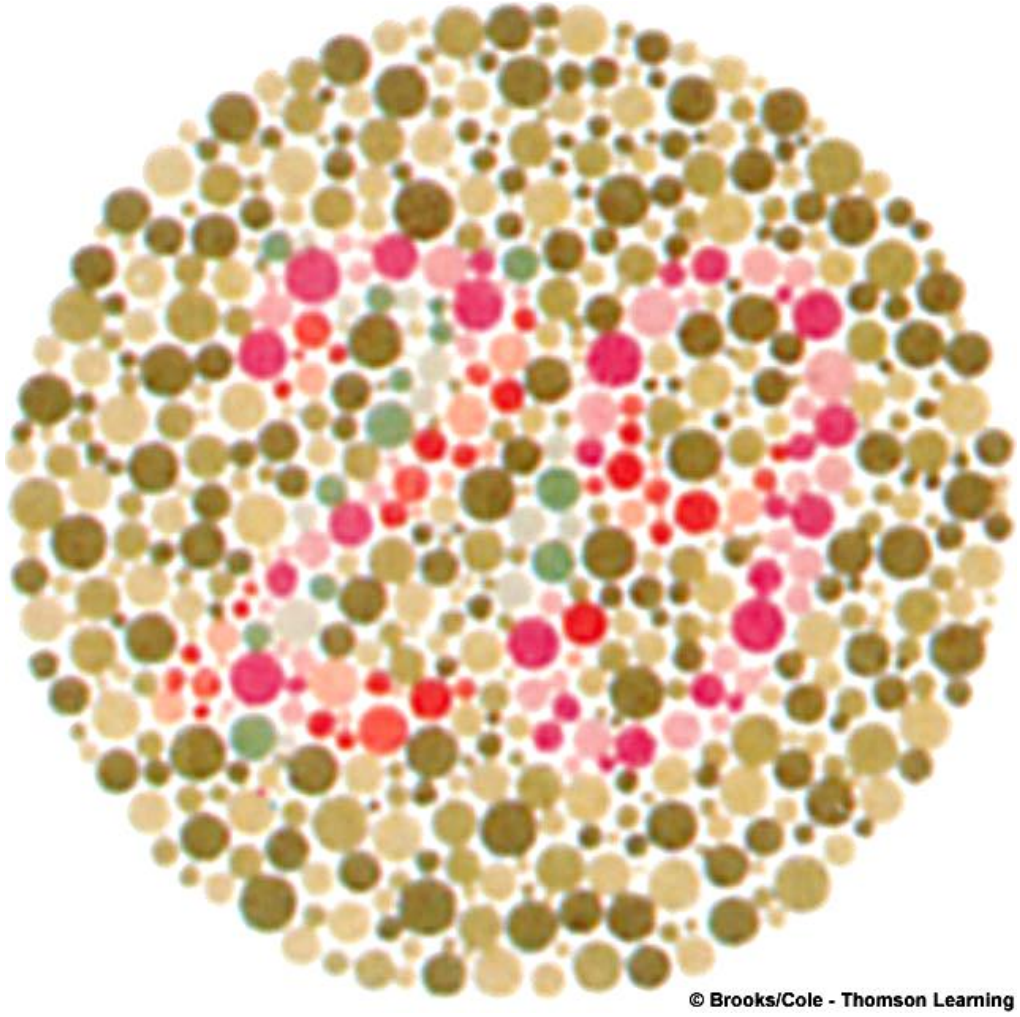
- **Color Vision**
  - Perception of color
  - Depends on the ratio of stimulation of three different cones
    - Different absorption of cone pigments
  - Coded and transmitter by different pathways
  - Processed in color vision center of primary visual cortex
  - Color blindness
    - Defective cone
    - Colors become combinations of two cones
    - Most common = red-green color blindness





Color perceived	Percent of maximum stimulation		
	Red cones	Green cones	Blue cones
	0	0	100
	31	67	36
	83	83	0

Vision



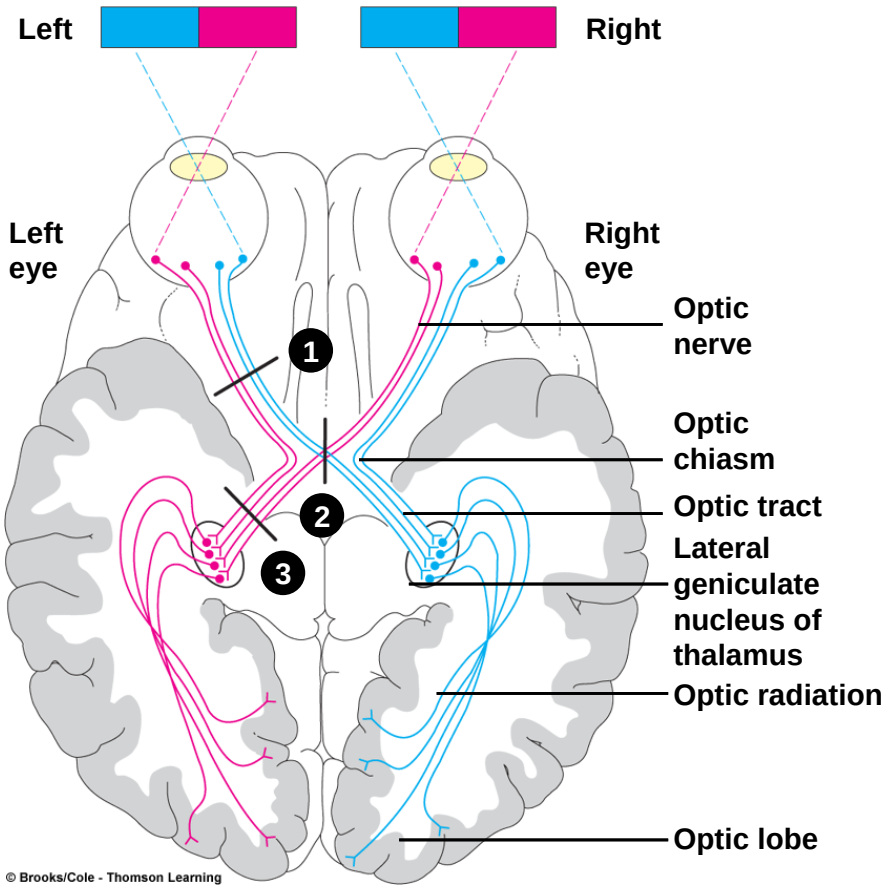
Vision

- **Properties of Rod and Cone Vision**

Rods	Cones
100 million per retina	3 million per retina
Vision in shades of gray	Color vision
High sensitivity to light	Low sensitivity to light
High sensitivity to motion	Low sensitivity to motion
Low acuity (many combined together)	High acuity (few combined together)
Night vision (from high sensitivity and more convergence)	Day vision (lack sensitivity and convergence)
More numerous in periphery (less detail but motion peripherally)	Concentrated in fovea (best vision centrally)

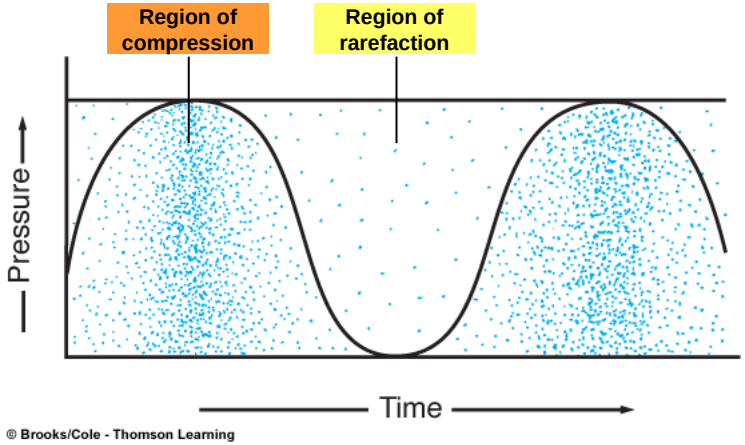
Vision

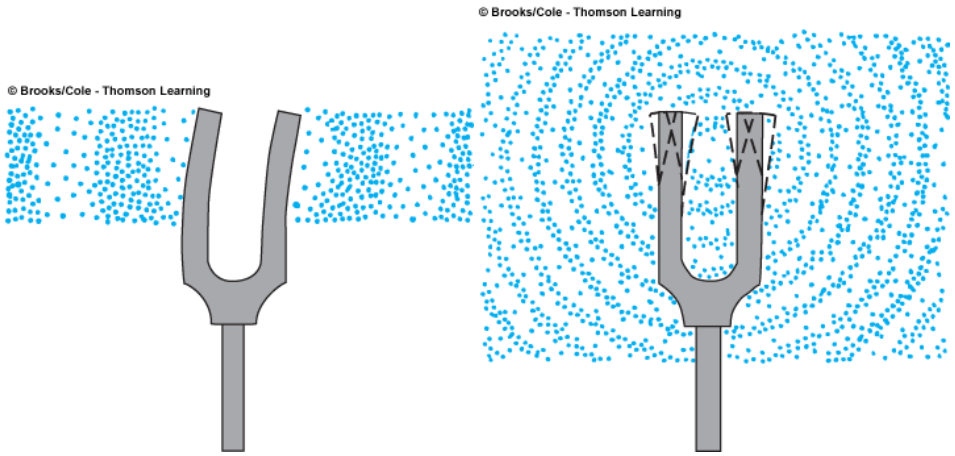
- **Visual field**
  - Area which can be seen without moving the head) → overlap between eyes
- **Information arrives altered at the primary visual cortex**
  - Upside down and backward because of the lens
  - Initial processing and combinations in the retina
- **The left and right halves of the brain receive information from the left and right halves of the visual field**
- **Depth Perception**
  - Visual field of two eyes slightly different
  - Depth perception with one eye
    - Other cues (such as size, location, experience)
- **>30% of cortex participates in visual information processing**
  - "What" and "where" pathways



Hearing

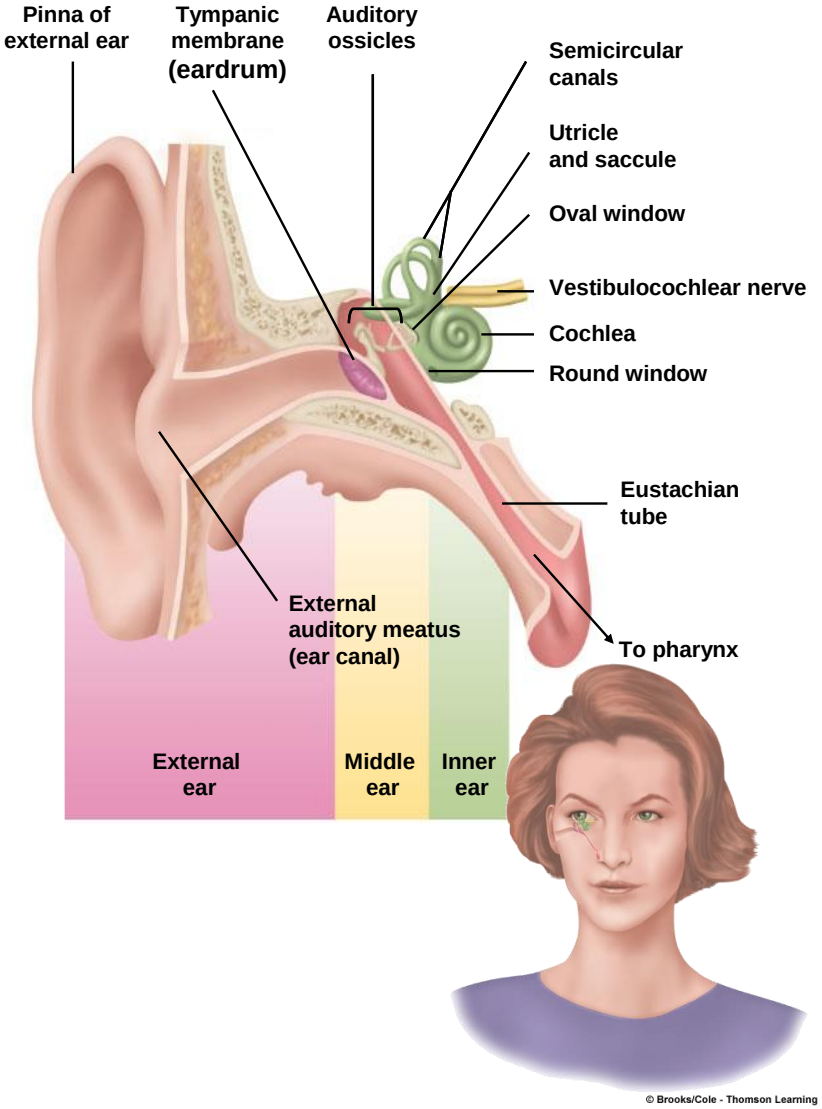
- **Hearing**
  - Neural perception of sound energy
  - Involves two aspects
    - Identification of the sounds (“what”)
    - Localization of the sounds (“where”)
  - Sound waves
    - Traveling vibrations of air
    - Consist of alternate regions of compression and rarefaction of air molecules





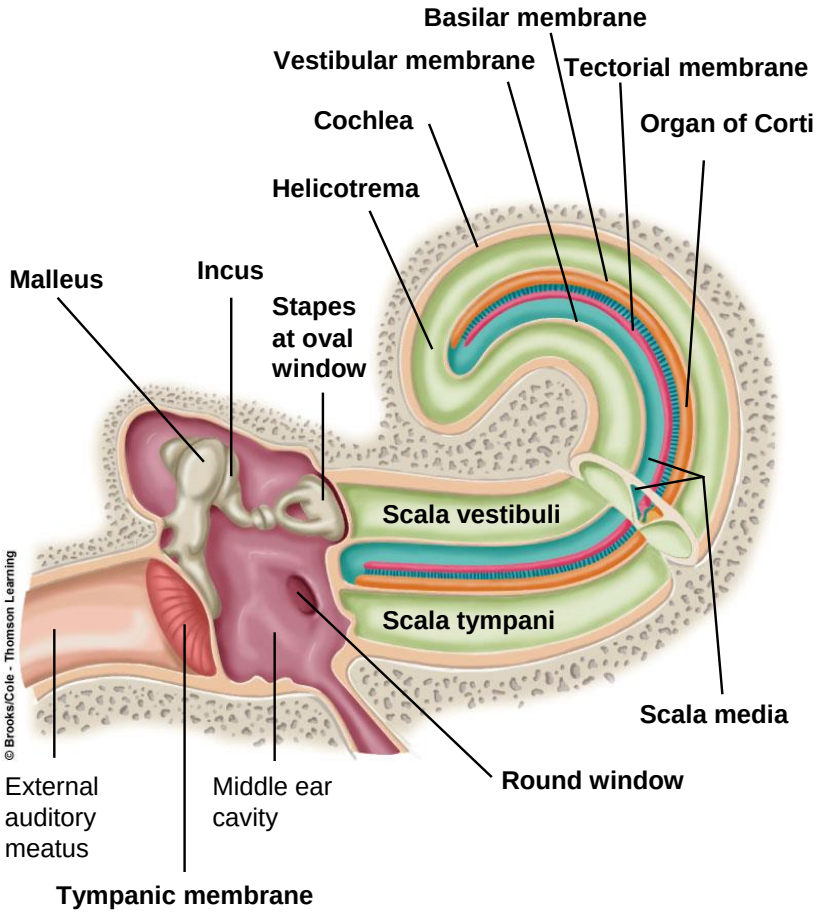
Hearing

- **Ear**
  - Consists of three parts
  - External ear
    - Consists of pinna, external auditory meatus, and tympanum
    - Transmits airborne sound waves
    - Concentrates sound energy
  - Middle ear
    - Transmits airborne sound waves to fluid-filled inner ear
    - Amplifies sound energy
  - Inner ear
    - Houses two different sensory systems
      - Cochlea (For conversion of sound waves into nerve impulses → hearing)
      - Vestibular apparatus (For sense of equilibrium)



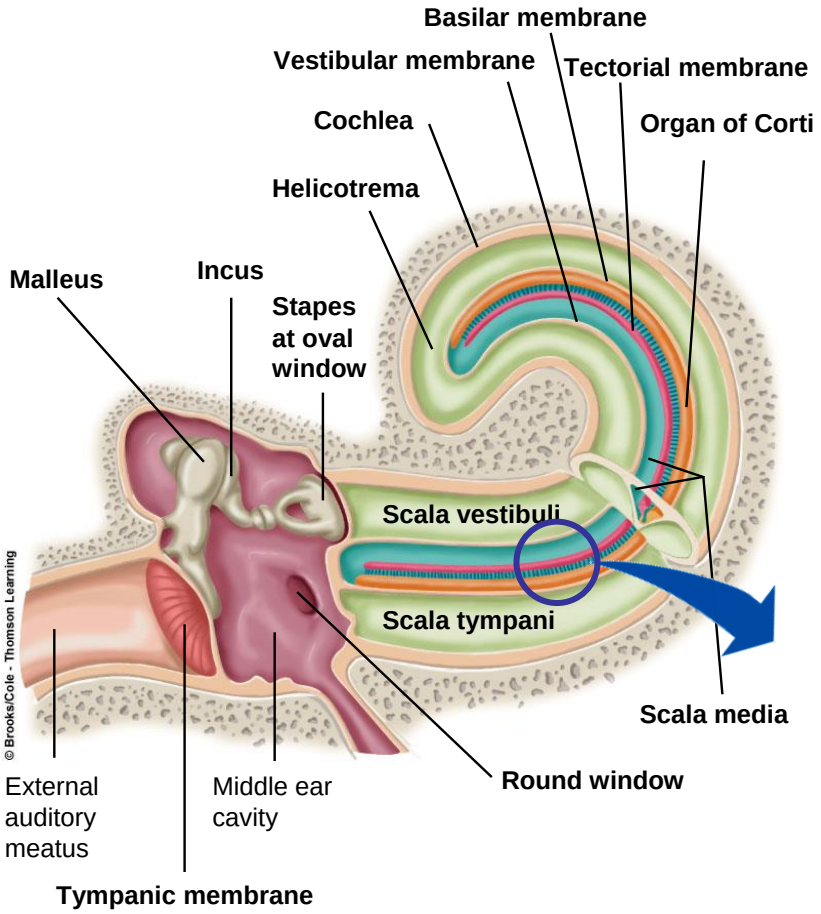
Hearing

- **Sound Wave Transmission**
  - Tympanic membrane
    - Vibrates when struck by sound waves
  - Middle ear
    - Transfers vibrations through ossicles (malleus, incus, stapes) to oval window (entrance into fluid-filled cochlea)
    - Amplify the pressure 20x
      - Large surface of the tympanic membrane transferred to the smaller oval window
      - Lever action of the osscicles
    - Small muscles change the stifness of the tympanic membrane
      - Protection mechanism
      - Slow action (40 msec) → protects only from prolonged sounds



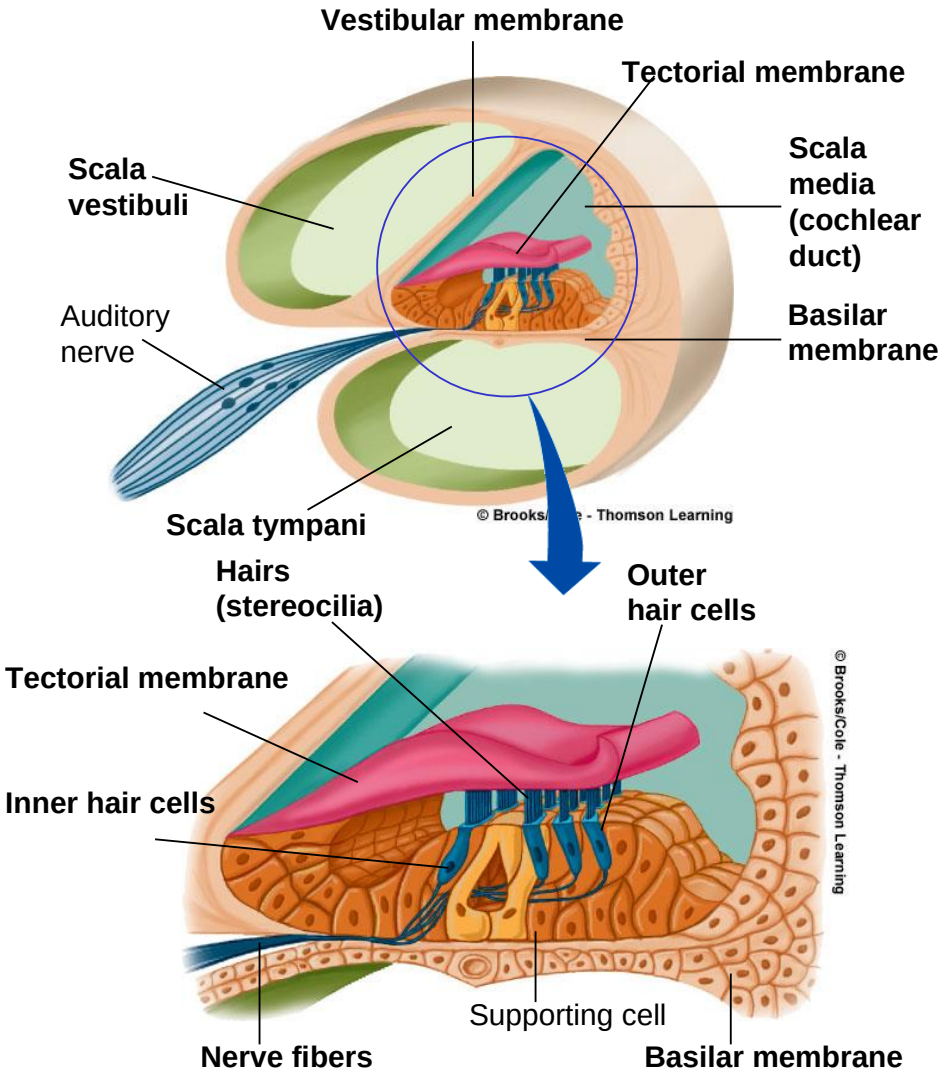
Hearing

- **Sound Wave Transmission**
  - Inner ear
    - Sound dissipates in cochlea
    - Waves in cochlear fluid (endolymph) set basilar membrane in motion
    - Sound converted to electrical signals by the Organ of Corti



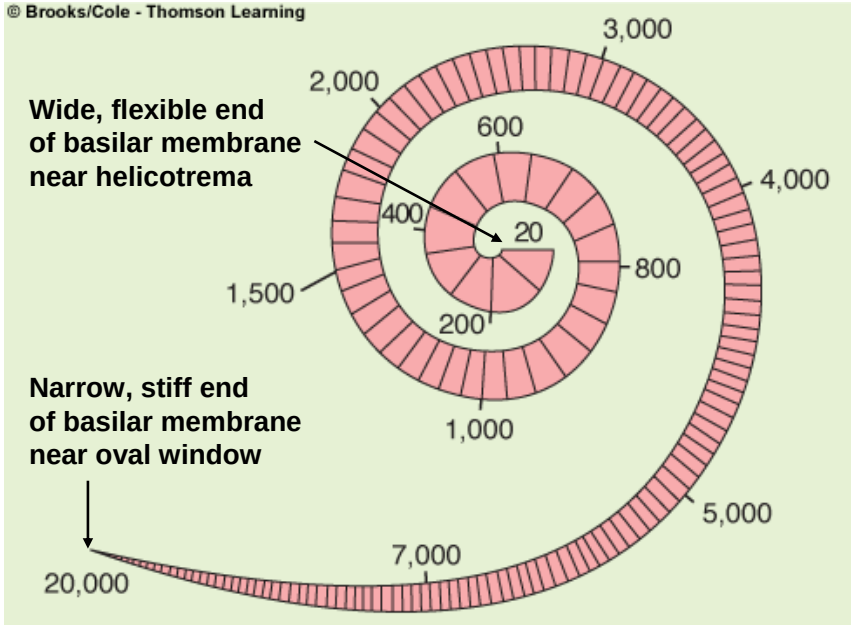
Hearing

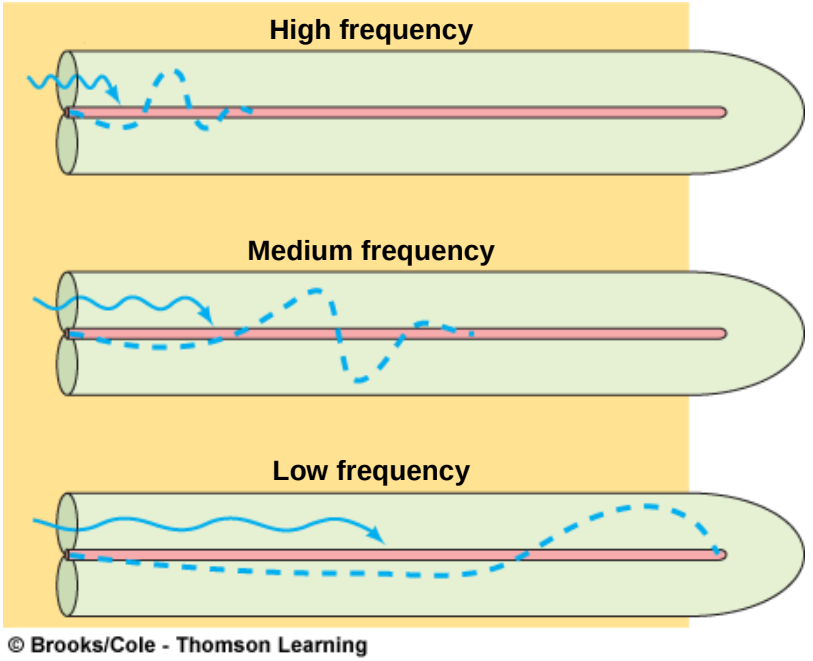
- **Sound Transduction**
  - Organ of Corti
    - Hair cells with ~ 100 sterocilia each
    - Hair cells are tilted as basilar membrane oscillates
    - Mechanically gated channels open and close → graded potentials
    - Synapse → Action potentials in auditory nerve cells
- **Cortical Pathway**
  - Thalamus
  - Brain stem → reflexes
  - Primary auditory cortex (temporal lobe) → processing and perception



Hearing

- **Frequency Discrimination**
  - Spectral analysis!
  - Basilar membrane does not have uniform mechanical properties
    - Narrow and stiff to wide and flexible
  - Different regions vibrate maximally at different frequencies
  - Frequency (or frequencies) are discriminated by the location along the basilar membrane of hair cells firing





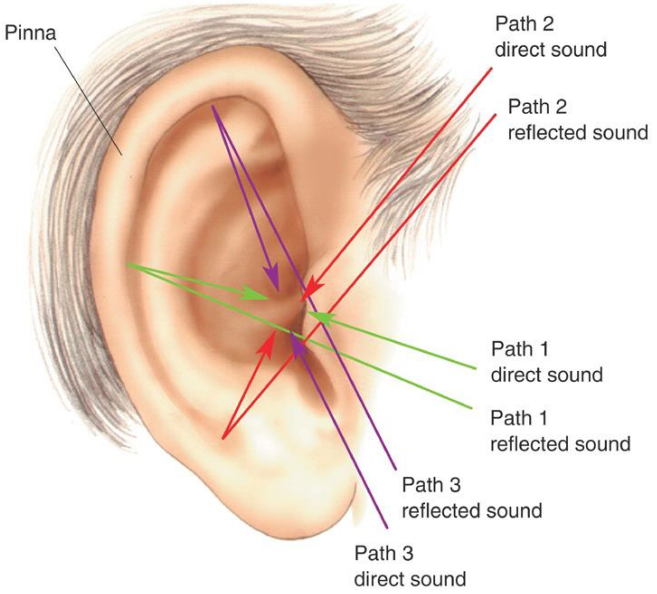
Hearing

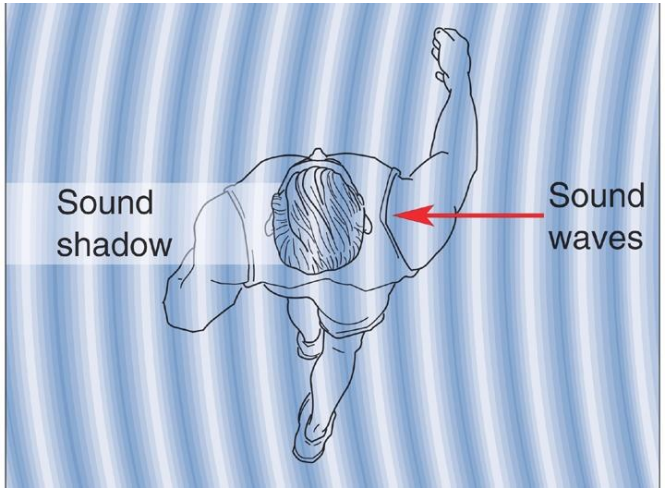
- **Loudness discrimination**
  - Exquisitely sensitive organ (motion less than a molecule of Hydrogen) → easily damaged
  - Wide range (every 10 dB means 10-fold increase in intensity)
  - Higher intensity causes larger basilar membrane movement
    - Stronger graded potential of hair cells
    - Faster rate of action potentials from auditory nerve cells and more nerves firing
  - Anything > 100 dB can cause permanent damage

Sound	Loudness in decibels (dB)	Comparison to faintest audible sound (hearing threshold)
Rustle of leaves	10 dB	10 x louder
Ticking of watch	20 dB	100 x
Hush of Library	30 dB	1000 x
Normal conversation	60 dB	1 million x
Food Blender	90 dB	1 billion x
Loud rock concert	120 dB	1 trillion x
Takeoff of jet plane	150 dB	1 quadrillion x

Hearing

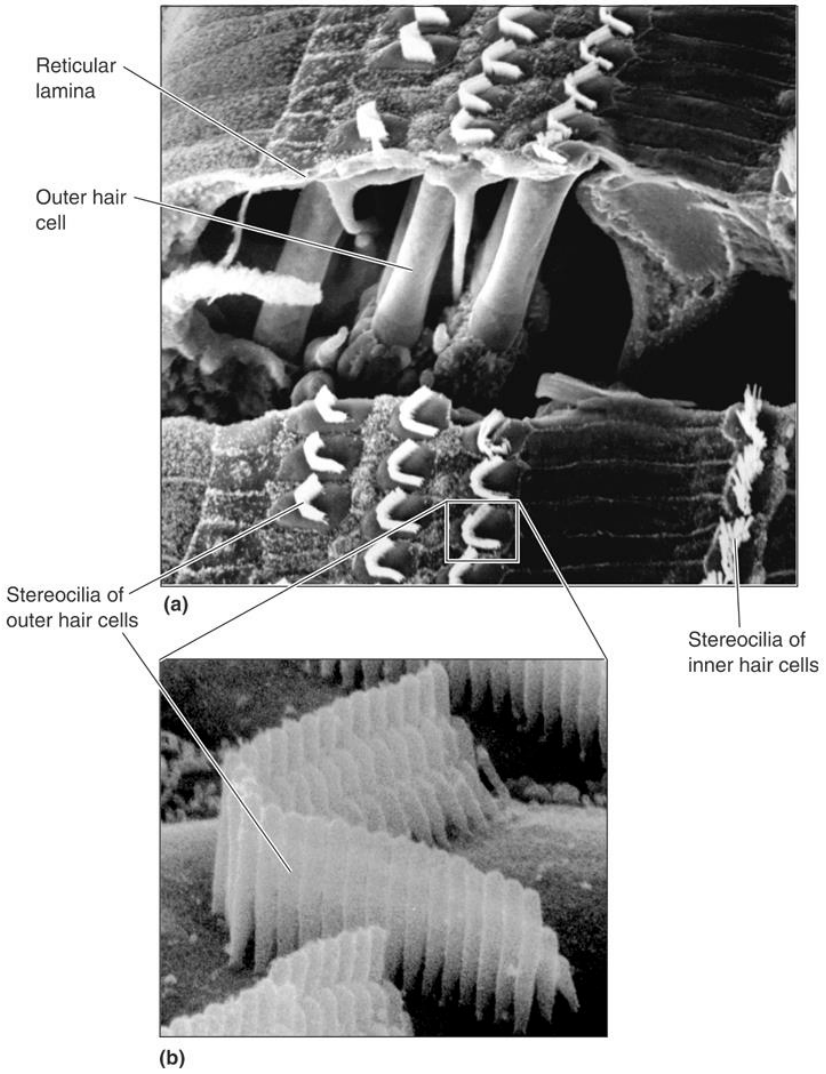
- **Localization**
  - Up-Down localization (elevation)
    - External ear (Pinna) shape changes sound timbre and intensity slightly according to elevation
  - Left-right localization (azimuth)
    - Sound arriving to proximal ear arrives
      - Slightly earlier (~ 0.5 msec)
      - Slightly stronger
    - Brain uses the electrical activity changes of these two cues to localize the direction





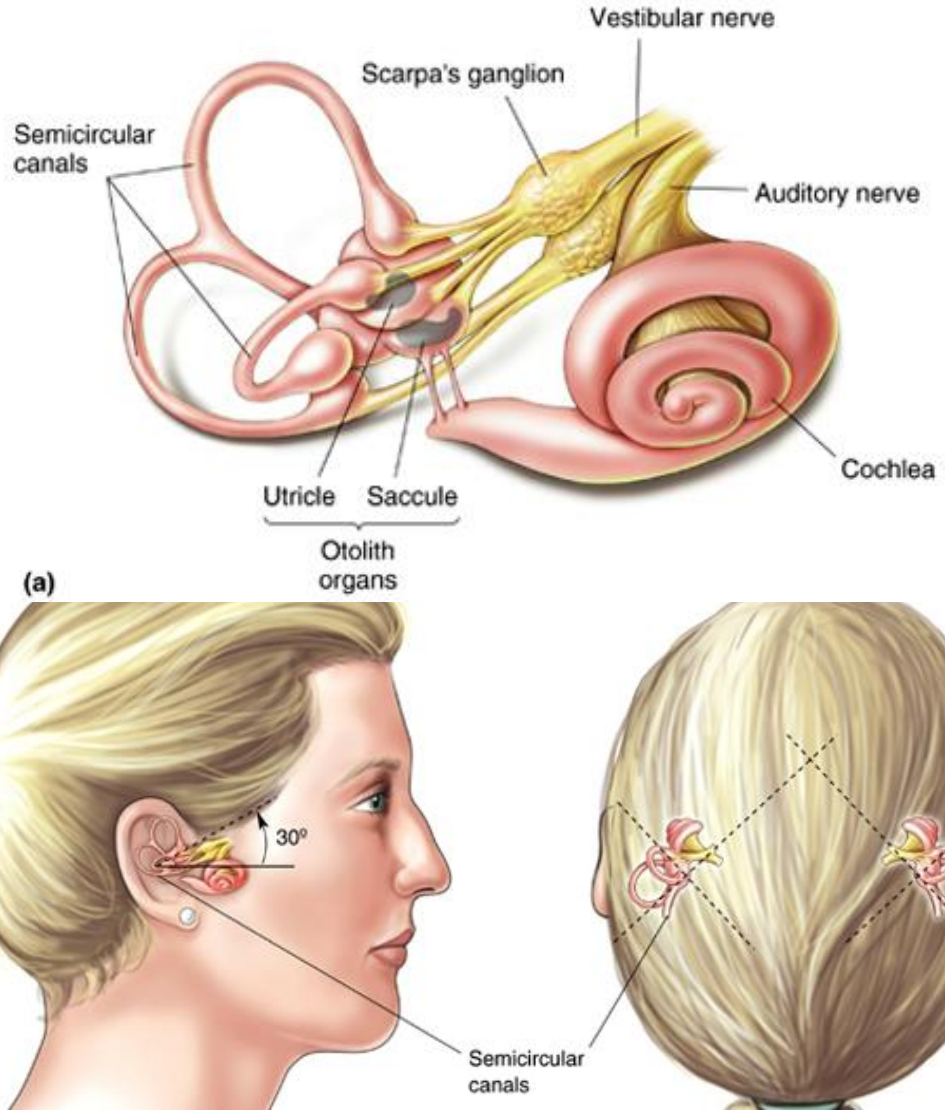
Hearing

- **Deafness**
  - Conductive
    - Sound waves not adequately conducted through external and middle portions of ear
    - Blockage, rupture of ear drum, middle ear infection, iddle ear adhesions
    - Hearing aids might help
  - Senosineural
    - Sound waves conducted but not translated into electrical signals
    - Neural presbycusis, certain antibiotics, poisoning
    - Cochlear implants might help
      - Electrical devices stimulating the auditory nerve directly



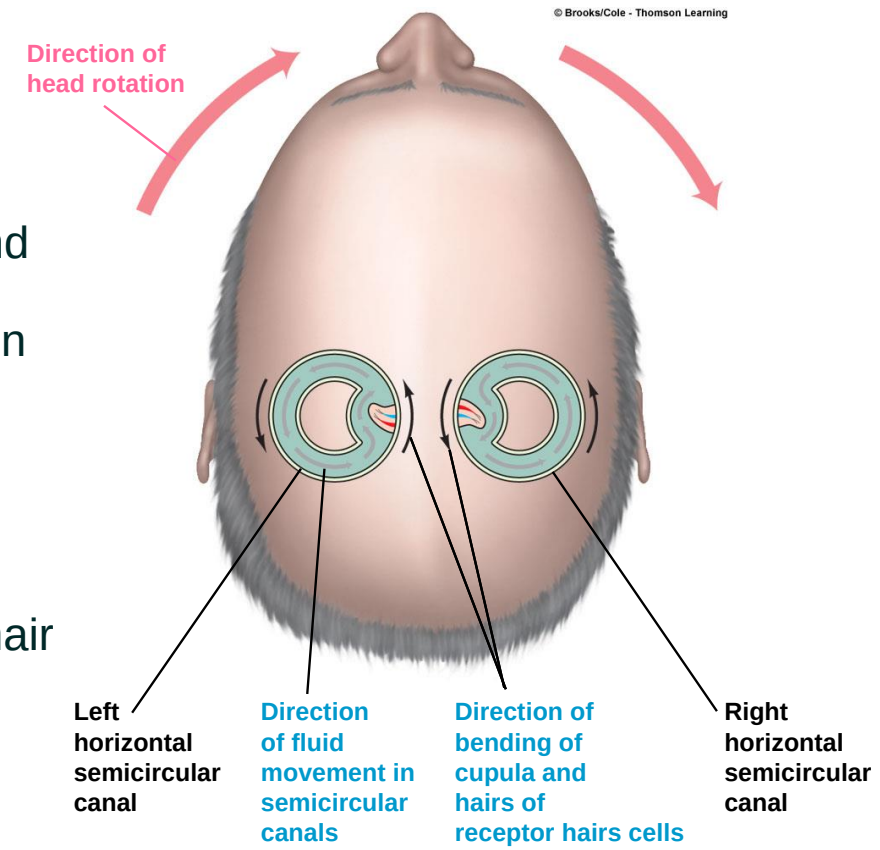
Equilibrium

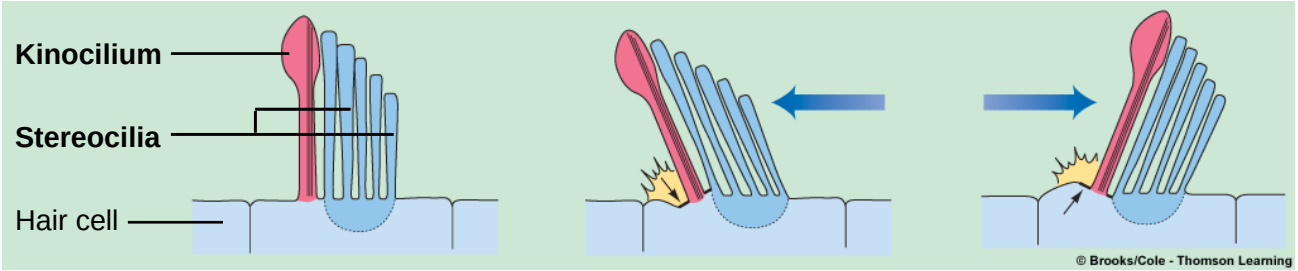
- **Detection of position and motion**
  - Posture and coordination
- **Vestibular apparatus**
  - Fluid filled tunnels In the inner ear
  - Semicircular canals
    - Three circular tunnels arranged on perpendicular planes
  - Otolith organs (Utricle and saccule)
    - Two bulges arranged in perpendicular directions



Equilibrium

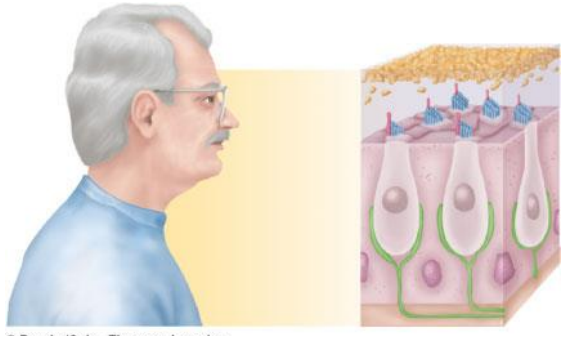
- **Semicircular canals**
  - Signal transduction
    - Head is rotated
    - Two of the canals are rotated around their axis in opposite directions
    - Fluid moves opposite to the direction of motion (inertia)
    - Cilia on hair cells bent and K+ channels open or close
    - The hair cells are depolarized or hyperpolarized
    - Neurotransmitter release from the hair cells is modified
    - Firing of the vestibular nerve is modified

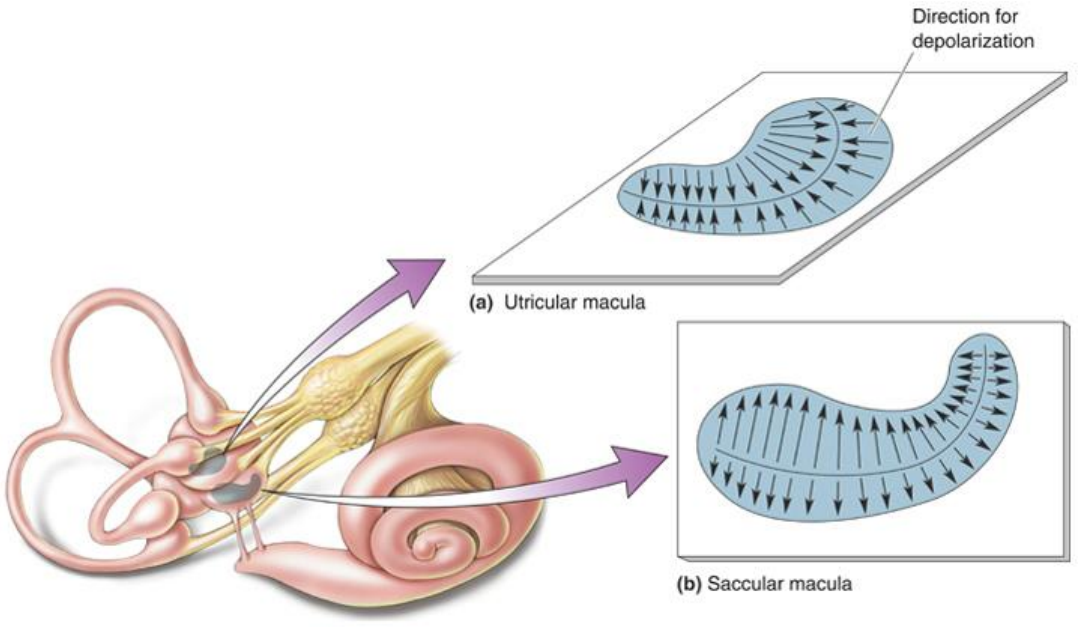




Equilibrium

- **Otolith Organs**
  - Detect changes in rate of linear movement in any direction
  - Arranged in perpendicular directions
  - Provide information important for determining head position in relation to gravity
  - Hair cells
    - As described before
    - In addition, calcium carbonate crystals (otoliths) are embedded in within the gelatinous layer
      - Increased inertia
      - Sensitivity to gravity





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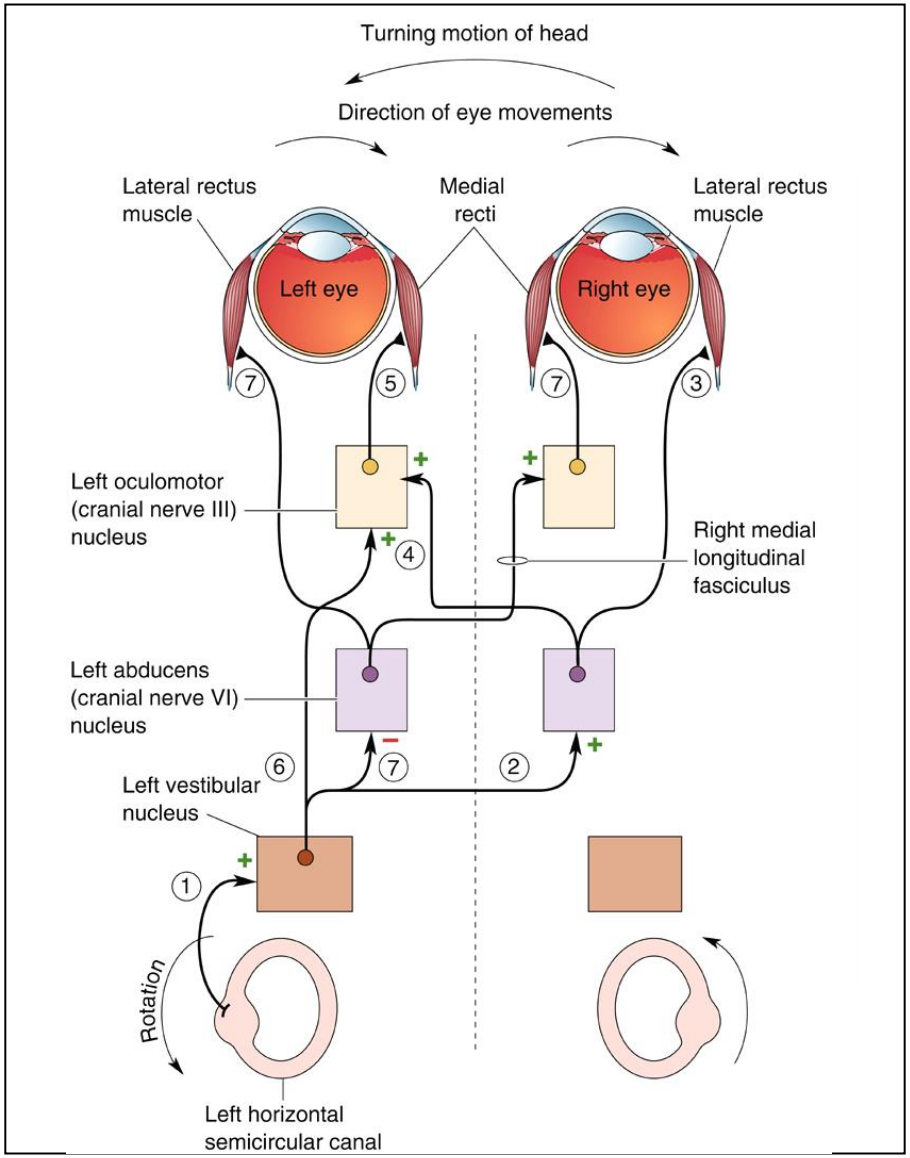
Equilibrium

- **Vestibular pathway**
  - Vestibular nuclei in brain stem
  - Motor neurons for controlling eye movement, perceiving motion and orientation
    - E.g. vestibuloocular reflex
  - Cerebellum for use in maintaining balance and posture,
- **The vestibular system detects acceleration**
  - Speed is calculated by integrating circuitry in the brain stem

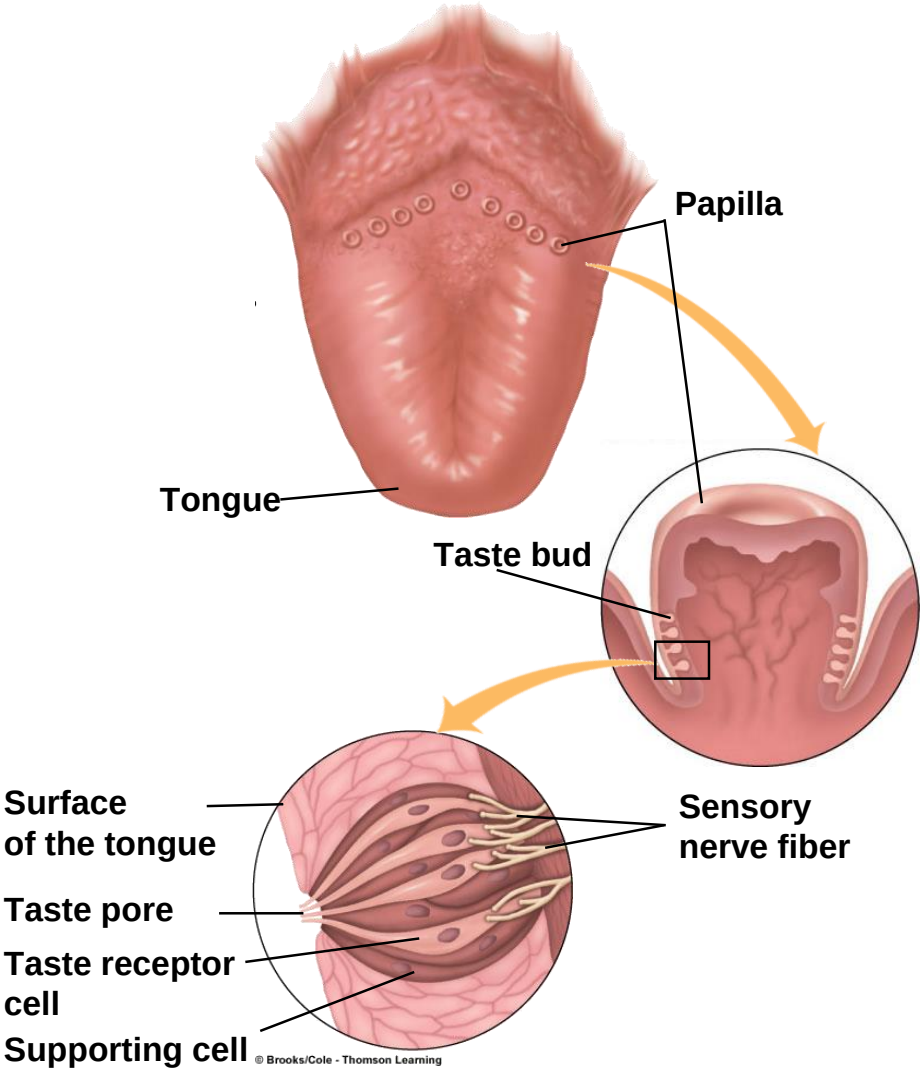


Taste and Smell

- **Taste (gustation) and smell (olfaction)**
  - Receptors are chemoreceptors
  - In association with food intake, influence flow of digestive juices and affect appetite
  - Stimulation of receptors induces pleasurable or objectionable sensations and signals presence of something to seek or to avoid
  - In lower animals also play a role in finding direction, seeking prey, avoiding predators and sexual attraction to a mate
  - Less developed and important in humans
    - Really? How much do you spend on perfumes and colognes

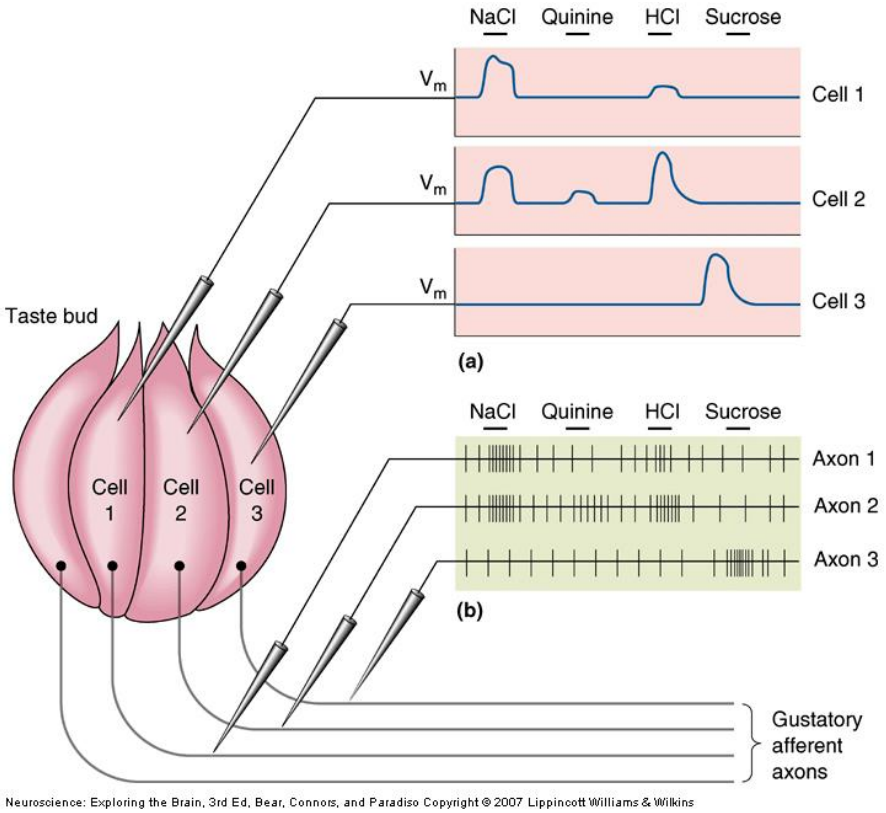
Taste (Gustation)

- **Chemoreceptors housed in taste buds**
- **Present in the oral cavity and throat**
- **Taste receptors have life span of about 10 days**
- **Taste bud consists of**
  - Taste pore
    - Opening through which fluids in mouth come into contact with surface of receptor cells
  - Taste receptor cells
    - Modified epithelial cells with surface folds called microvilli
    - Plasma membrane of microvilli contain receptor sites that bind selectively with chemical molecules



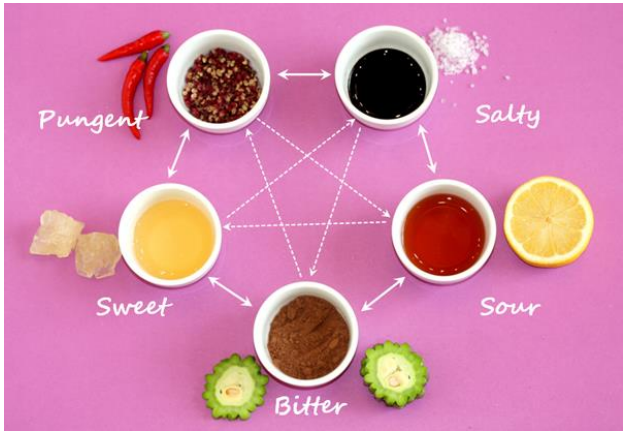
Taste (Gustation)

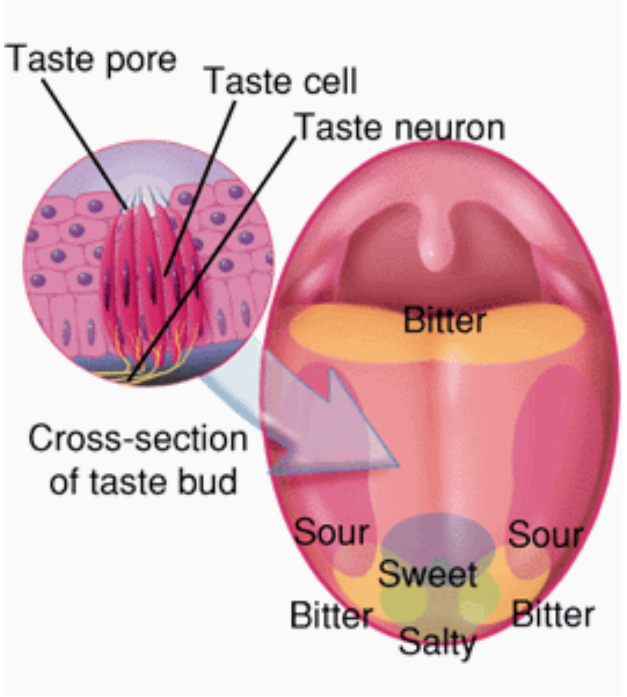
- **Signal transduction**
  - Binding of tastant (taste-provoking chemical) with receptor cell
  - Produce depolarizing receptor potential
  - Receptor potential releases neurotransmitter
  - Initiates action potentials within terminal endings of afferent nerve fibers with which receptor cell synapses
  - Signals conveyed via synaptic stops in brain stem and thalamus to cortical gustatory area



Taste (Gustation)

- **Five primary types of receptors accounting for the five primary tastes**
  - Salty
    - Stimulated by chemical salts, especially NaCl
  - Sour
    - Caused by acids which contain a free hydrogen ion, H+
  - Sweet
    - Evoked by configuration of glucose
  - Bitter
    - Brought about by more chemically diverse group of tastants
    - Examples – alkaloids, toxic plant derivatives, poisonous substances
  - Umami
    - Meaty or savory taste (MSG receptor!)



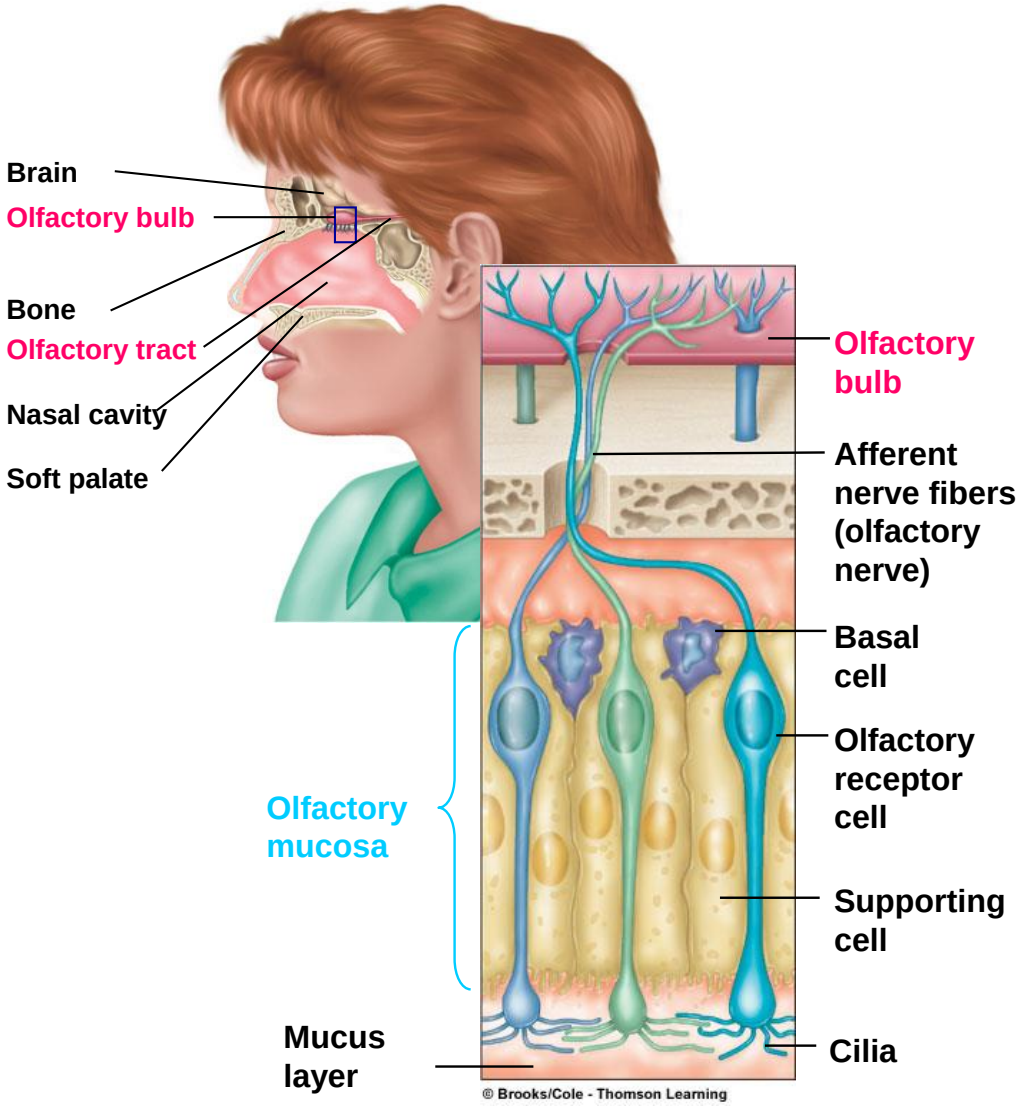


Taste (Gustation)

- **Taste Perception**
  - Influenced by information derived from other receptors, especially odor
  - Temperature and texture of food influence taste
  - Psychological experiences associated with past experiences with food influence taste
  - How cortex accomplishes perceptual processing of taste sensation is currently unknown

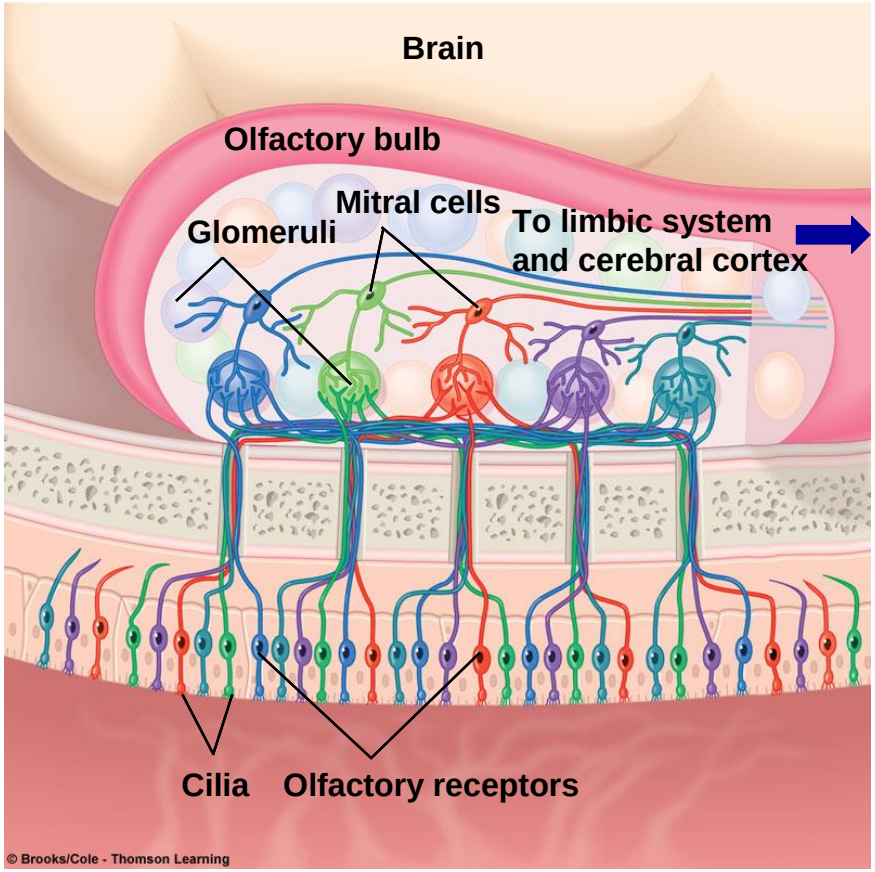
Smell (Olfaction)

- **Olfactory receptors in nose are specialized endings of renewable afferent neurons**
- **Olfactory mucosa**
  - 3cm2 of mucosa in ceiling of nasal cavity
- **Contains three cell types**
  - Olfactory receptor cell
    - Afferent neuron whose receptor portion is in olfactory mucosa in nose and afferent axon traverses into brain
    - Axons of olfactory receptor cells collectively form olfactory nerve
  - Supporting cells
    - Secrete mucus
  - Basal cells
    - Precursors of new olfactory receptor cells (replaced about every two months)



Smell (Olfaction)

- **Odorants**
  - Molecules that can be smelled
  - Act through second-messenger systems to open Na+ channels and trigger action potentials
  - To be smelled, substance must be
    - Sufficiently volatile that some of its molecules can enter nose in inspired air
    - Sufficiently water soluble that it can dissolve in mucus coating the olfactory mucosa
- **5 million olfactory receptors**
  - 1000 different types
- **Afferent signals are sorted according to scent component by glomeruli within olfactory bulb**
- **Two routes to the brain**
  - Subcortical (limbic system)
  - Through the thalamus to the cortex
- **The olfactory system adapts quickly and odorants are rapidly cleared (by odor-eating enzymes)**



Smell (Olfaction)

- **Vomeronasal Organ (VNO)**
  - Detects pheromones
    - Nonvolatile chemical signals passed subconsciously from one individual to another
  - Common in mammals but until recently was thought to nonexistent in humans
    - Governs emotional responses and sociosexual behaviors
  - Located about half an inch inside human nose next to vomer bone
  - Role in human behavior has not been validated
    - “Good chemistry” and “love at first sight”