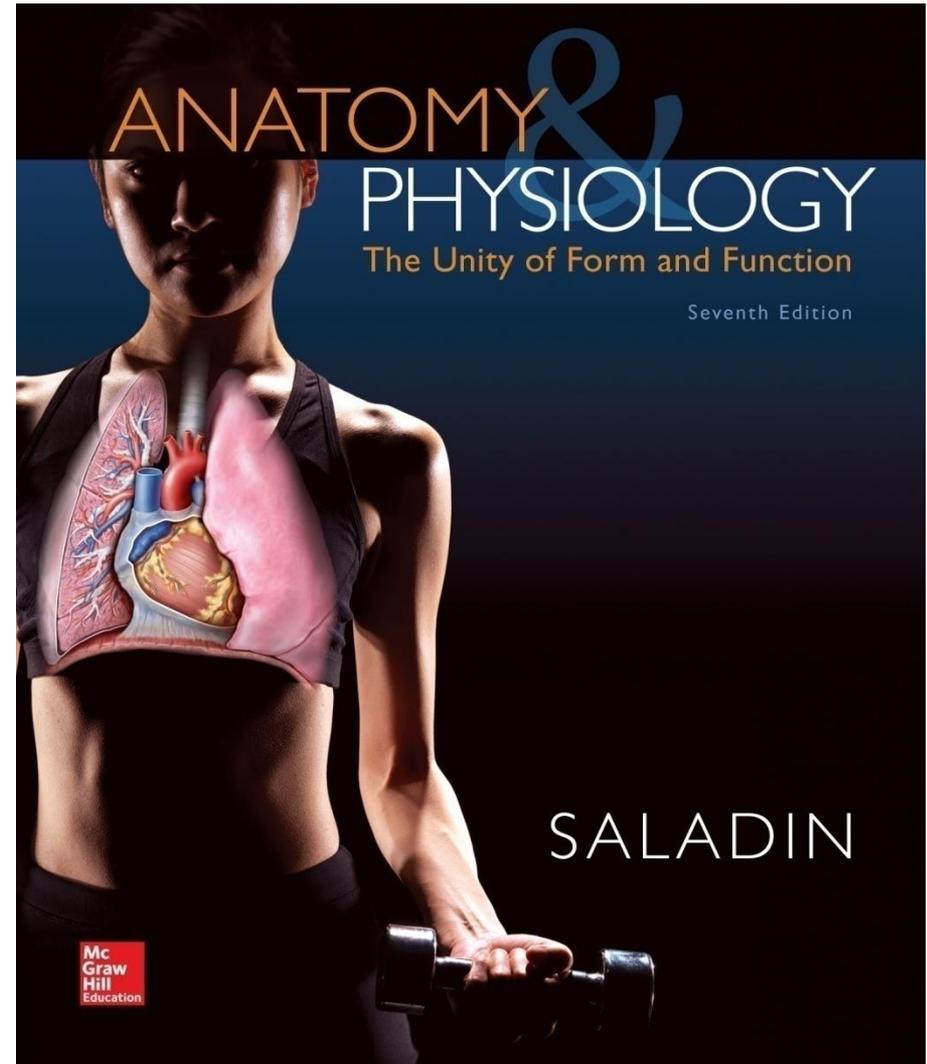


Chapter 16

Lecture Outline

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



Introduction

- **Sensory input is vital to the integrity of personality and intellectual function**
 - Sensory deprivation can cause hallucinations
- **Some information communicated by sense organs never comes to our conscious attention**
 - Blood pressure, body temperature, and muscle tension
 - These sense organs initiate somatic and visceral reflexes that are indispensable to homeostasis and to our survival

Properties and Types of Sensory Receptors

- **Expected Learning Outcomes**
 - Define *receptor* and *sense organ*.
 - List the four kinds of information obtained from sensory receptors, and describe how the nervous system encodes each type.
 - Outline three ways of classifying receptors.

Properties and Types of Sensory Receptors

- **Sensory receptor**—a structure specialized to detect a stimulus
 - Some receptors are bare nerve endings
 - Others are true **sense organs**: nerve tissue surrounded by other tissues that enhance response to a certain type of stimulus
 - Accessory tissues may include added epithelium, muscle, or connective tissue

General Properties of Receptors

- **Transduction**—the conversion of one form of energy to another
 - Fundamental purpose of any sensory receptor is conversion of stimulus energy (light, heat, touch, sound, etc.) into nerve signals
 - Transducers can also be non biological devices (e.g., a lightbulb)
- **Receptor potential**—small local electrical change on a receptor cell brought about by a stimulus
 - Results in release of neurotransmitter or a volley of action potentials that generates nerve signals to the CNS

General Properties of Receptors

- **Sensation**—a subjective awareness of the stimulus
 - Most sensory signals delivered to the CNS produce no conscious sensation
 - Filtered out in the brainstem, thus preventing information overload
 - Some signals do not require conscious awareness like pH and body temperature

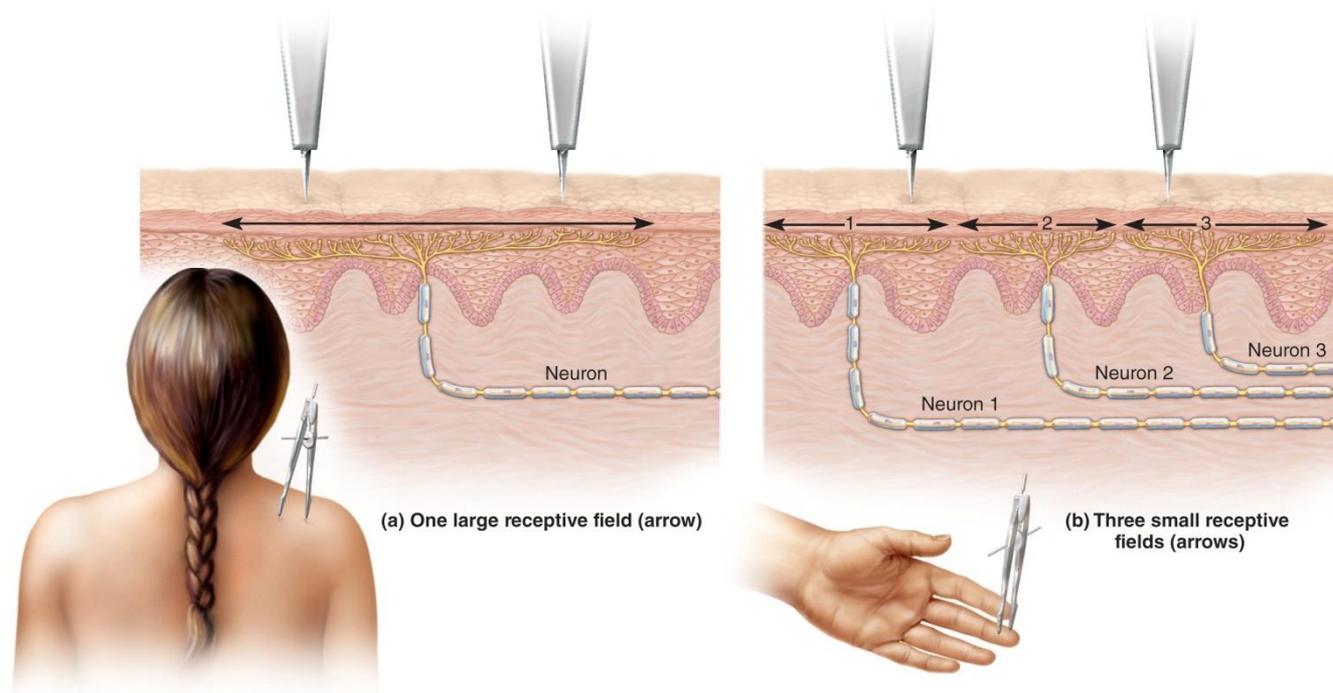
General Properties of Receptors

- **Sensory receptors transmit four kinds of information:** modality, location, intensity, duration
- **Modality**—type of stimulus or sensation it produces
 - Vision, hearing, taste
 - **Labeled line code:** all action potentials are identical. Each nerve pathway from sensory cells to the brain is labeled to identify its origin, and the brain uses these labels to interpret what modality the signal represents

General Properties of Receptors

- **Location**—encoded by which nerve fibers are firing
 - **Receptive field:** area within which a sensory neuron detects stimuli
 - Receptive fields vary in size
 - Neurons in fingertips have small, receptive fields allowing for fine two-point touch discrimination

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General Properties of Receptors

Location (continued)

- **Sensory projection:** brain identifies site of stimulation
- **Projection pathways:** pathways followed by sensory signals to their ultimate destinations in the CNS
- **Intensity**—encoded in three ways
 - Brain can distinguish stimulus intensity by:
 - Which fibers are sending signals
 - How many fibers are doing so
 - How fast these fibers are firing

General Properties of Receptors

- **Duration**—how long the stimulus lasts
 - Changes in firing frequency over time
 - **Sensory adaptation**: if a stimulus is prolonged, firing of the neuron gets slower over time
 - **Phasic receptors**—adapt rapidly: generate a burst of action potentials when first stimulated, then quickly reduce or stop signaling even though the stimulus continues
 - Smell, hair movement, and cutaneous pressure
 - **Tonic receptors**—adapt slowly: generate nerve signals more steadily throughout presence of stimulus
 - **Proprioceptors**—body position, muscle tension, and joint motion

Classification of Receptors

- **By modality**
 - Thermoreceptors, photoreceptors, nociceptors, chemoreceptors, and mechanoreceptors
- **By origin of stimuli**
 - Exteroceptors: detect external stimuli
 - Interoceptors: detect internal stimuli
 - Proprioceptors: sense body position and movements
- **By distribution**
 - General (somesthetic) senses: widely distributed
 - Special senses: limited to head
 - Vision, hearing, equilibrium, taste, and smell

The General Senses

- **Expected Learning Outcomes**

- List several types of somatosensory receptors.
- Describe the projection pathways for the general senses.
- Explain the mechanisms of pain and the spinal blocking of pain signals.

The General Senses

- **Receptors for the general senses are relatively simple in structure and physiology**
- **Consist of one or a few sensory nerve fibers and a sparse amount of connective tissue**

Unencapsulated Nerve Endings

- **Unencapsulated nerve endings lack connective tissue wrappings**

- **Free nerve endings**

- For pain and temperature
- Skin and mucous membrane

- **Tactile discs**

- For light touch and texture
- Associated with Merkel cells at base of epidermis

- **Hair receptors**

- Coil around a hair follicle
- Monitor movement of hair

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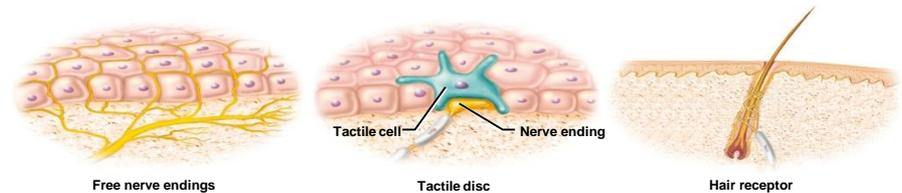


Figure 16.2 (top)

Encapsulated Nerve Endings

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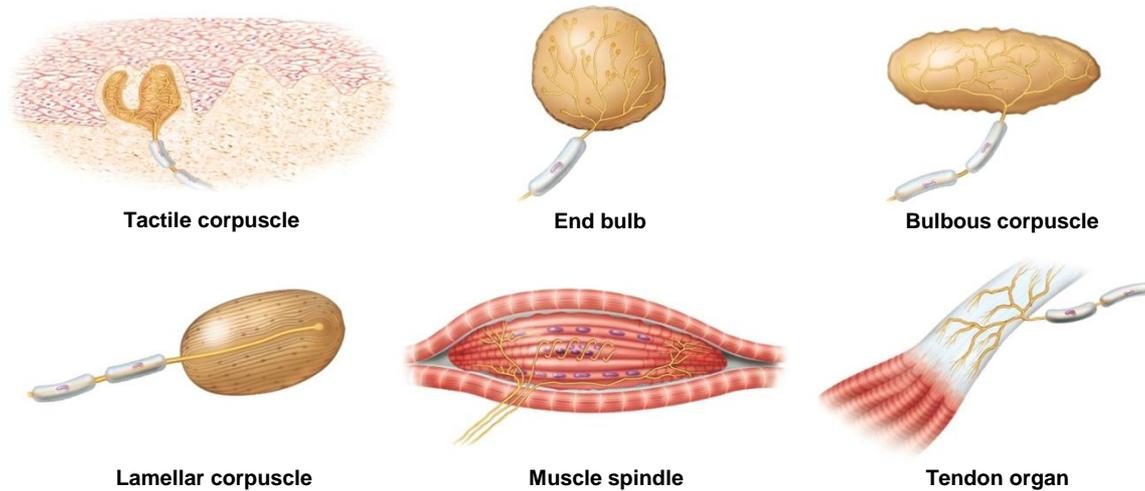


Figure 16.2 (middle/bottom)

- **Encapsulated nerve endings are wrapped by glial cells or connective tissue**
- **Wrapping enhances sensitivity or selectivity of response**

Encapsulated Nerve Endings

- **Tactile (Meissner) corpuscles**
 - Light touch and texture
 - Dermal papillae of hairless skin
- **Krause end bulbs**
 - Tactile; in mucous membranes
- **Lamellar (pacinian) corpuscles**—phasic
 - Deep pressure, stretch, tickle, and vibration
 - Periosteum of bone, and deep dermis of skin
- **Bulbous (Ruffini) corpuscles**—tonic
 - Heavy touch, pressure, joint movements, and skin stretching

Somatosensory Projection Pathways

- From receptor to final destination in the brain, most somesthetic signals travel by way of **three neurons**
- **First-order neuron**
 - From body, enters posterior horn of spinal cord via spinal nerves
 - From head, enters pons or medulla via cranial nerve
 - Touch, pressure, and proprioception fibers are large, fast, myelinated axons
 - Heat and cold fibers are small and unmyelinated
- **Second-order neuron**
 - Decussate to opposite side in spinal cord, medulla, or pons
 - End in **thalamus**, except for proprioception, which ends in cerebellum
- **Third-order neuron**
 - Thalamus to primary somesthetic cortex of cerebrum

Pain

- **Pain**—discomfort caused by tissue injury or noxious stimulation, and typically leading to evasive action
 - Important since it helps protect us
 - Lost in diabetes mellitus—**diabetic neuropathy**
- **Nociceptors**—two types providing different pain sensations
 - **Fast pain** travels myelinated fibers at 12 to 30 m/s
 - Sharp, localized, stabbing pain perceived with injury
 - **Slow pain** travels unmyelinated fibers at 0.5 to 2 m/s
 - Longer-lasting, dull, diffuse feeling

Pain

- **Somatic pain**—from skin, muscles, and joints
- **Visceral pain**—from the viscera
 - Stretch, chemical irritants, or ischemia of viscera (poorly localized)
- **Injured tissues release chemicals that stimulate pain fibers**
 - **Bradykinin**: most potent pain stimulus known
 - Makes us aware of injury and activates cascade of reactions that promote healing
 - Histamine, prostaglandin, and serotonin also stimulate nociceptors

Projection Pathways for Pain

- **Two main pain pathways to brain, and multiple subroutes**
- **Pain signals from head**
 - **First-order neurons** travel in cranial nerves V, VII, IX, and X and end in the medulla
 - **Second-order neurons** start in medulla and ascend to thalamus
 - **Third-order neurons** from thalamus, reach postcentral gyrus of cerebrum

Projection Pathways for Pain

- Pain signals from **neck down**
 - Travel by way of three ascending tracts
 - **Spinothalamic tract**—most significant pain pathway
 - Carries most somatic pain signals
 - **Spinoreticular tract**—carries pain signals to reticular formation
 - Activate visceral, emotional, and behavioral reactions to pain
 - **Gracile fasciculus**—carries signals to the thalamus for visceral pain

Projection Pathways for Pain

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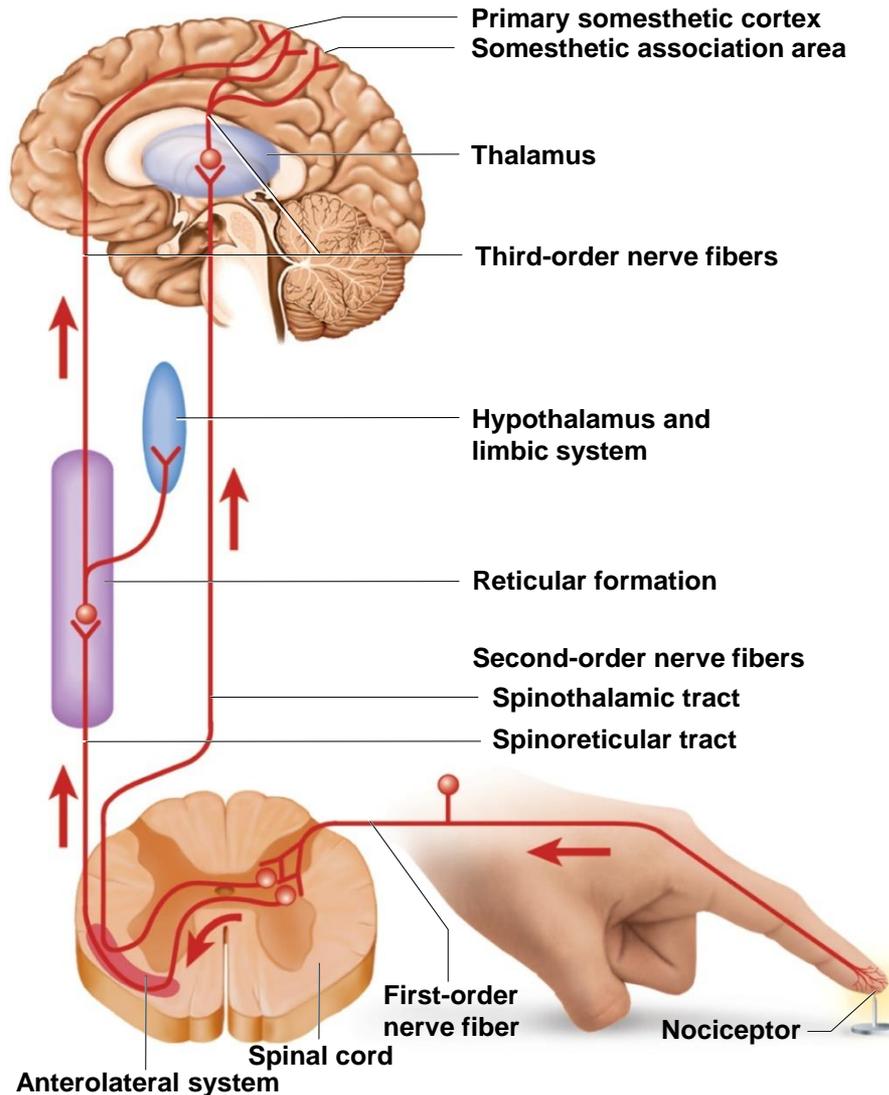


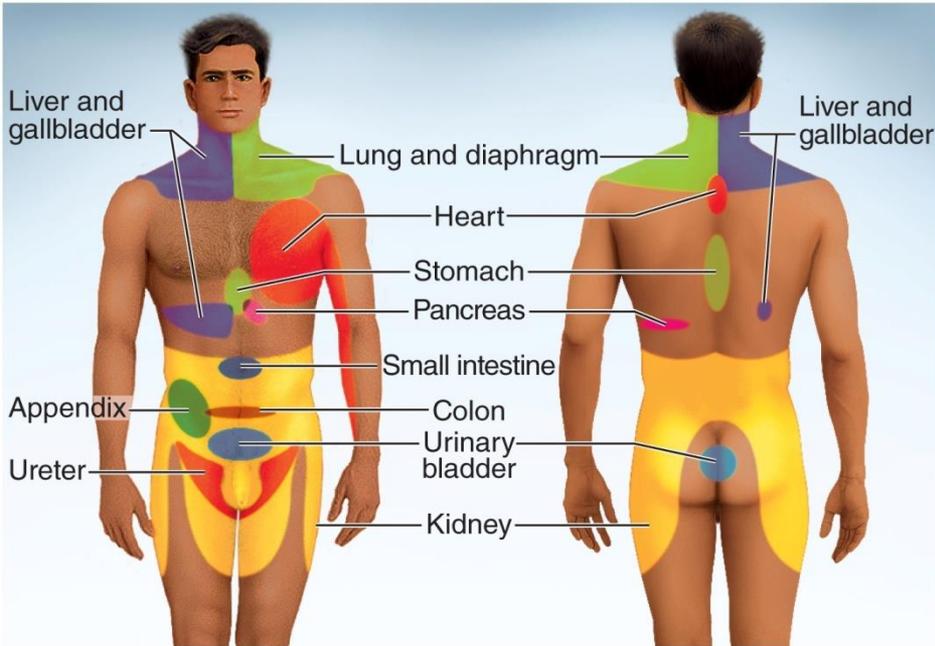
Figure 16.3

Projection Pathways for Pain

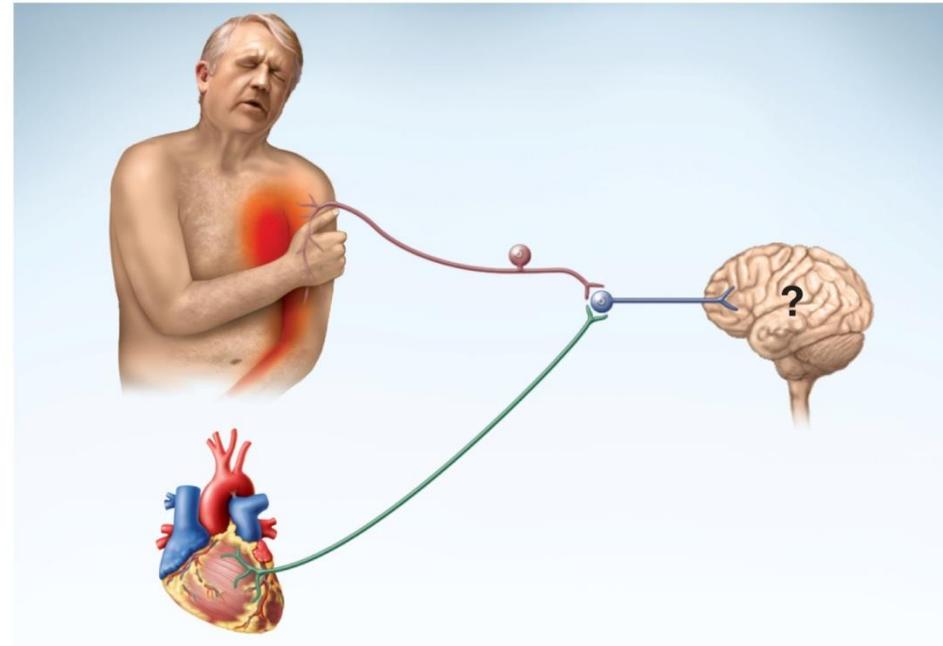
- **Referred pain**—pain in viscera often mistakenly thought to come from the skin or other superficial site
 - Results from convergence of neural pathways in CNS
 - Brain “assumes” visceral pain is coming from skin
 - Brain cannot distinguish source
 - Heart pain felt in shoulder or arm because both send pain input to spinal cord segments T1 to T5

Referred Pain

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(a)



(b)

Figure 16.4

CNS Modulation of Pain

- **Analgesic (pain-relieving)** mechanisms of CNS just beginning to be understood
- **Endogenous opioids:** internally produced opium-like substances
 - **Enkephalins:** two analgesic oligopeptides with 200 times the potency of morphine
 - **Endorphins** and **dynorphins**—larger analgesic neuropeptides discovered later
- **Secreted by the CNS, pituitary gland, digestive tract, and other organs**
- **Act as neuromodulators that block pain and give pleasure**

CNS Modulation of Pain

- **Spinal gating**—stops pain signals at posterior horn of spinal cord
 - Analgesic fibers arise in brainstem, descend in reticulospinal tract and block pain signals in spinal cord
- **Review of normal pain pathway**
 - **Nociceptor** stimulates second-order nerve fiber with **Substance P** neurotransmitter
 - Second-order fiber sends signal up **spinothalamic tract** to thalamus
 - **Thalamus** relays signal to cerebral cortex where awareness of pain occurs

CNS Modulation of Pain

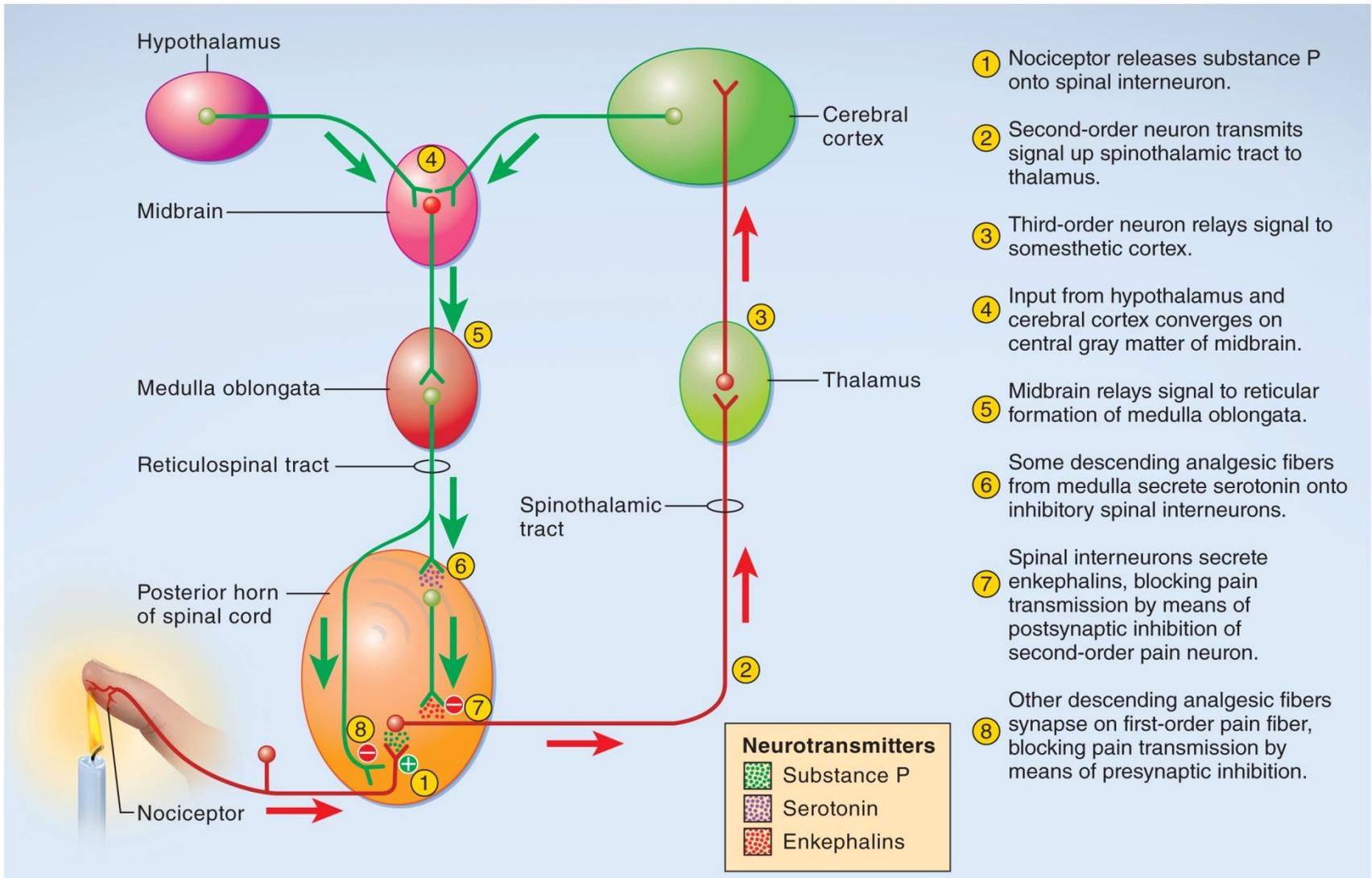
- **Pathway for pain blocking (modulation)**
 - Signals from hypothalamus and cerebral cortex feed into central gray matter of midbrain
 - Allows both autonomic and conscious influences on pain perception
 - Midbrain relays signals to certain nuclei in the reticular formation of the medulla oblongata
 - Medulla issues descending, serotonin-secreting analgesic fibers to the spinal cord via the reticulospinal tract
 - The fibers terminate in the posterior horn at all levels of the spinal cord

CNS Modulation of Pain

- **Pathway for pain blocking (modulation) (cont.)**
 - In posterior horn, descending analgesic fibers synapse on short spinal interneurons
 - The interneurons secrete enkephalins and inhibit the second-order neuron (postsynaptically)
 - Some fibers from the medulla also exert presynaptic inhibition by synapsing on the axons of nociceptors and blocking the release of substance P

CNS Modulation of Pain

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- 1 Nociceptor releases substance P onto spinal interneuron.
- 2 Second-order neuron transmits signal up spinothalamic tract to thalamus.
- 3 Third-order neuron relays signal to somesthetic cortex.
- 4 Input from hypothalamus and cerebral cortex converges on central gray matter of midbrain.
- 5 Midbrain relays signal to reticular formation of medulla oblongata.
- 6 Some descending analgesic fibers from medulla secrete serotonin onto inhibitory spinal interneurons.
- 7 Spinal interneurons secrete enkephalins, blocking pain transmission by means of postsynaptic inhibition of second-order pain neuron.
- 8 Other descending analgesic fibers synapse on first-order pain fiber, blocking pain transmission by means of presynaptic inhibition.

Figure 16.5

CNS Modulation of Pain

- **Another pathway of spinal gating**—rubbing or massaging injury
 - Pain-inhibiting neurons of the posterior horn receive input from mechanoreceptors in the skin and deeper tissues
- **Rubbing stimulates mechanoreceptors, which stimulates spinal interneurons to secrete enkephalins that inhibit second-order pain neurons**

The Chemical Senses

- **Expected Learning Outcomes**
 - Explain how taste and smell receptors are stimulated.
 - Describe the receptors and projection pathways for these two senses.

Taste

- **Gustation (taste)**—sensation that begins with action of chemical stimulants (**tastants**) on taste buds
 - 4,000 taste buds found mainly on tongue
 - Some found (especially in children) inside cheeks, and on soft palate, pharynx, and epiglottis
- **Lingual papillae**--bumps
 - **Filiform:** no taste buds
 - Help sense food texture
 - **Foliate:** weakly developed
 - Taste buds degenerate by age 3
 - **Fungiform:** a few taste buds
 - At tips and sides of tongue
 - **Vallate (circumvallate)**
 - At rear of tongue in a “V”
 - Contains up to one-half of all taste buds

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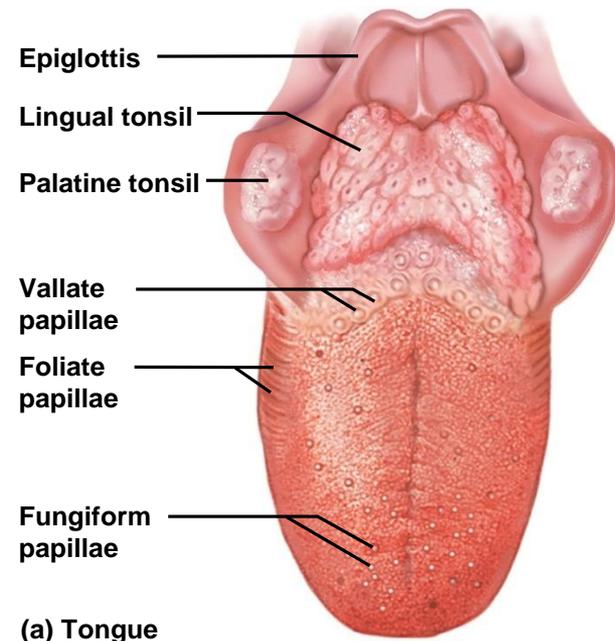
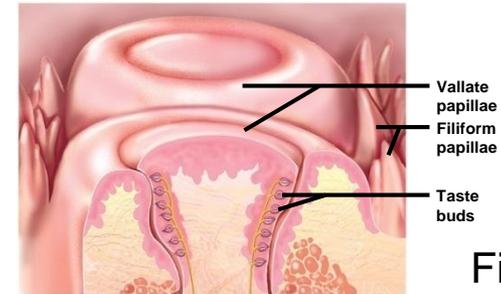


Figure 16.6a

Taste

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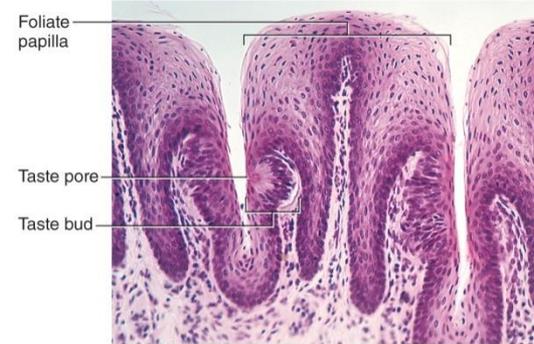
- All taste buds look alike
- Lemon-shaped groups of 40 to 60 taste cells, supporting cells, and basal cells
- Taste cells
 - Have tuft of apical microvilli (**taste hairs**) that serve as receptor surface for taste molecules
 - **Taste pores:** pit into which the taste hairs project
 - Taste hairs are **epithelial cells**, not neurons
 - Synapse with and release neurotransmitters onto sensory neurons at their base



(b) Vallate papillae

Figure 16.6b

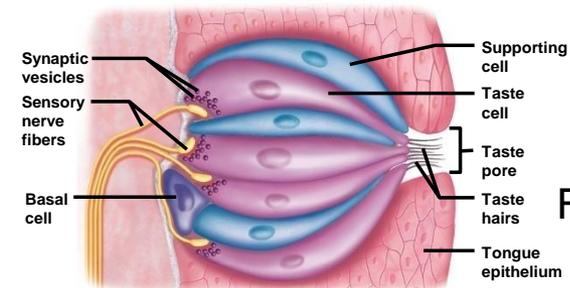
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(c) Foliate papillae

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Figure 16.6c



(d) Taste bud

Figure 16.6d

Taste

- **Basal cells**
 - Stem cells that replace taste cells every 7 to 10 days
- **Supporting cells**
 - Resemble taste cells without taste hairs, synaptic vesicles, or sensory role

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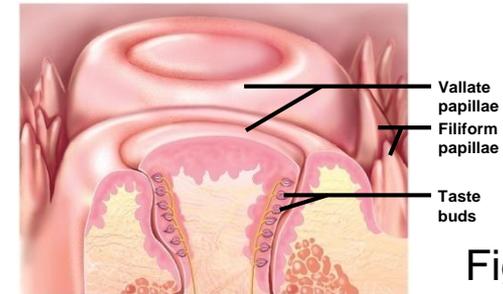


Figure 16.6b

(b) Vallate papillae

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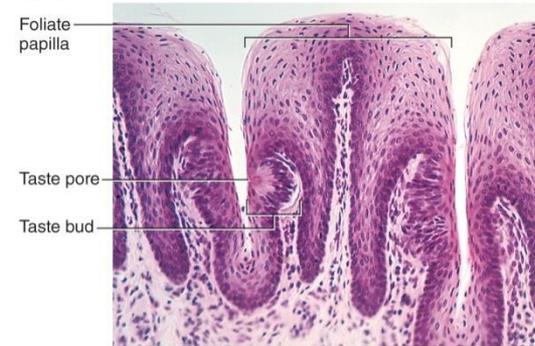


Figure 16.6c

(c) Foliate papillae

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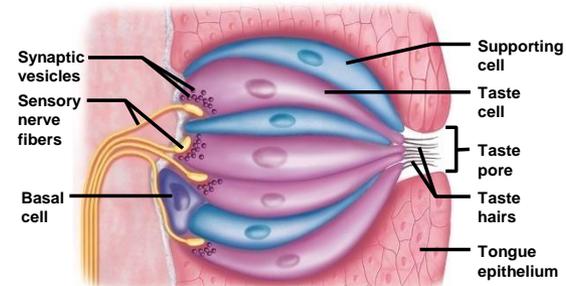


Figure 16.6d

(d) Taste bud

Taste

- **To be tasted, molecules must dissolve in saliva and flood the taste pore**
- **Five primary sensations**
 - **Salty:** produced by metal ions (sodium and potassium)
 - **Sweet:** associated with carbohydrates and other foods of high caloric value
 - **Sour:** acids such as in citrus fruits
 - **Bitter:** associated with spoiled foods and alkaloids such as nicotine, caffeine, quinine, and morphine
 - **Umami:** “meaty” taste of amino acids in chicken or beef broth

Taste

- **Taste is influenced by food texture, aroma, temperature, and appearance**
 - **Mouthfeel:** detected by branches of lingual nerve in papillae
- **Hot pepper stimulates free nerve endings (pain), not taste buds**
- **Regional differences in taste sensations on tongue**
 - Tip is most sensitive to sweet, edges to salt and sour, and rear to bitter

Taste

- **Two mechanisms of action**
 - **Activate second-messenger systems**
 - Sugars, alkaloids, and glutamate bind to receptors which activates G proteins and second-messenger systems within the cell
 - **Depolarize cells directly**
 - Sodium and acids penetrate cells and depolarize them directly
- **Either mechanism results in release of neurotransmitters that stimulate dendrites at base of taste cells**

Taste

- **Facial nerve** collects sensory information from taste buds over anterior two-thirds of tongue
- **Glossopharyngeal nerve** from posterior one-third of tongue
- **Vagus nerve** from taste buds of palate, pharynx, and epiglottis

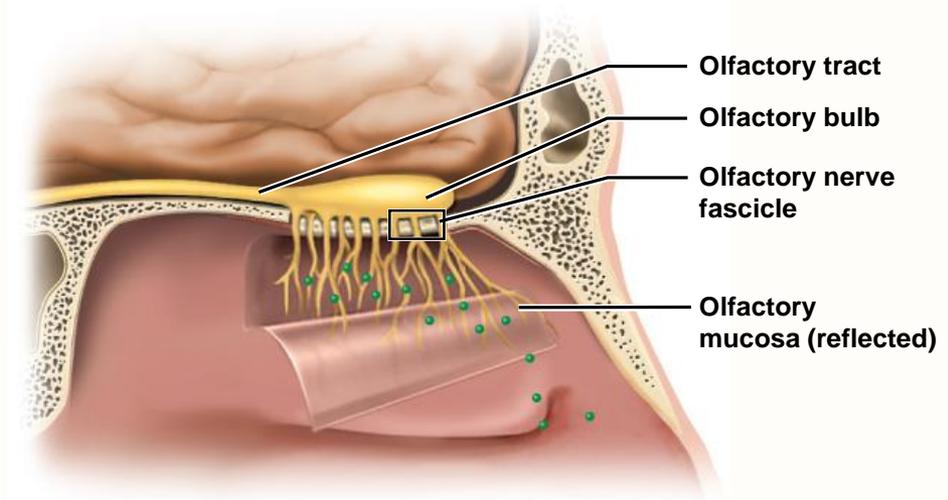
Taste

- All fibers reach **solitary nucleus** in medulla oblongata
- **From there, signals sent to two destinations**
 - **Hypothalamus** and **amygdala** control autonomic reflexes: salivation, gagging, and vomiting
 - **Thalamus** relays signals to **postcentral gyrus of cerebrum** for conscious sense of taste
 - Sent on to **orbitofrontal cortex** to be integrated with signals from nose and eyes; form impression of flavor and palatability of food

Smell

- **Olfaction**—sense of smell
 - Response to **odorants** (chemicals)
- **Olfactory mucosa**
 - Contains 10 to 20 million **olfactory cells (neurons)**, epithelial supporting cells, and basal stem cells
 - Mucosa of superior concha, nasal septum, and roof of nasal cavity covering about 5 cm²
 - On average 2,000 to 4,000 odors distinguished

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(a)

Figure 16.7a

Smell

- **Olfactory cells (continued)**
 - Basal end of each cell becomes the axon
 - Axons collect into small fascicles and leave cranial cavity through the **cribriform foramina in the ethmoid bone**
 - Fascicles are collectively regarded as **cranial nerve I**

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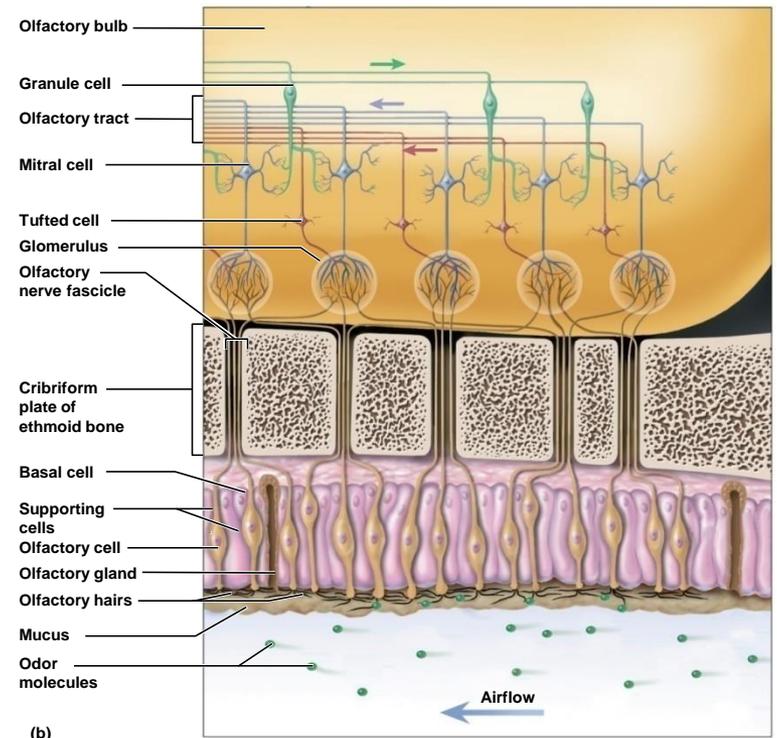


Figure 16.7b

Smell

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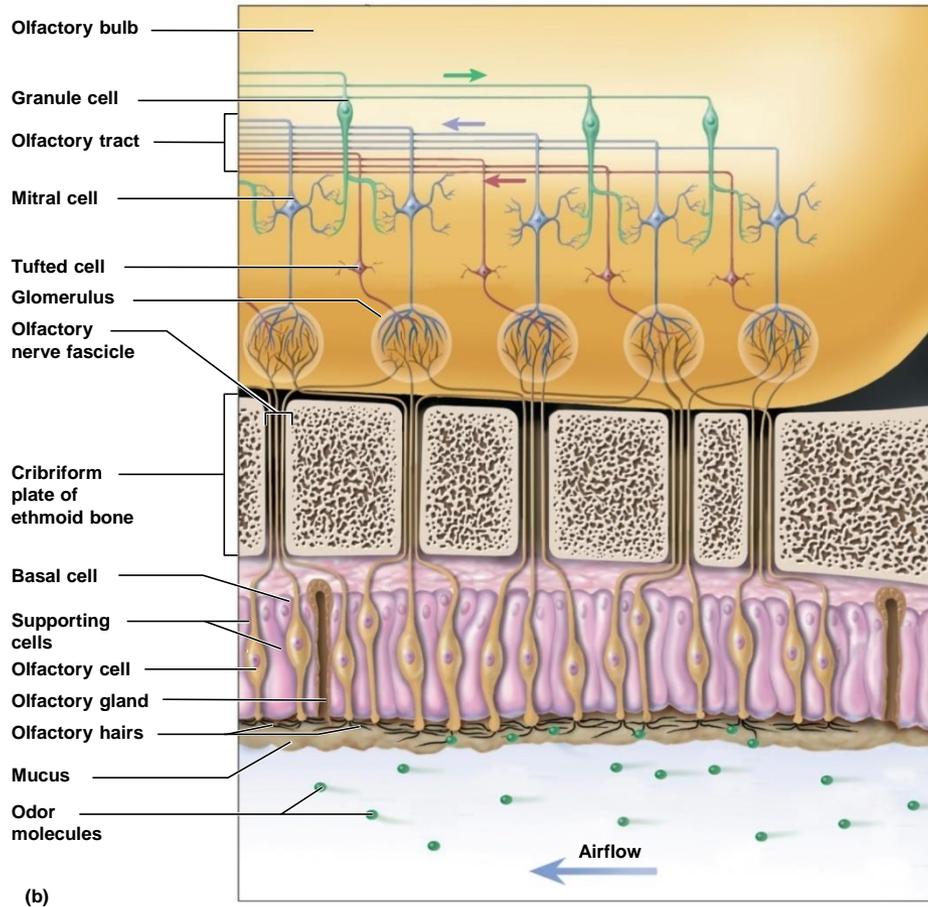


Figure 16.7b

- **Only neurons in the body directly exposed to the external environment**
 - Have a lifespan of only 60 days
 - Basal cells continually divide and differentiate into new olfactory cells
- **Supporting cells**
- **Basal cells**
 - Divide and differentiate to replace olfactory cells

Smell

- **Humans have a poorer sense of smell than most other mammals**
 - Still, more sensitive than our sense of taste
 - Women more sensitive to odors than men; especially to certain odors at time they are ovulating
 - Humans have only about 350 kinds of olfactory receptors
- **Odorant molecules** bind to membrane receptor on olfactory hair
 - Hydrophilic odorants diffuse through mucus
 - Hydrophobic ones transported by odorant-binding protein in mucus

Smell

- **Odorant activates G protein and cAMP system in olfactory cell**
- **Opens ion channels for Na⁺ or Ca²⁺**
 - Depolarizes membrane and creates receptor potential
- **Triggers action potential that travels to brain**
- **Olfactory receptors adapt quickly**
 - Due to synaptic inhibition in olfactory bulbs
- **Some odorants act on nociceptors of trigeminal nerve**
 - Ammonia, menthol, chlorine, and capsaicin of hot peppers

Human Pheromones

- **Human body odors may affect sexual behavior**
- **A person's sweat and vaginal secretions affect other people's sexual physiology**
 - Dormitory effect
- **Presence of men seems to influence female ovulation**
- **Ovulating women's vaginal secretions contain pheromones called copulines, that have been shown to raise men's testosterone level**

Smell

- **Olfactory projection pathways:**
 - Olfactory cells synapse in **olfactory bulb** on dendrites of mitral and tufted cells
 - Dendrites meet in spherical clusters called **glomeruli**
 - Each glomerulus dedicated to a single odor
 - Tufted and mitral cell axons form **olfactory tracts**
 - Reach **primary olfactory cortex** in the inferior surface of the temporal lobe
 - **Secondary destinations:** hippocampus, amygdala, hypothalamus, insula, and orbitofrontal cortex
 - Identify odors, integrate with taste, evoke memories, emotions, and visceral reactions
 - Fibers reach back to olfactory bulbs where **granule cells** inhibit the mitral and tufted cells
 - Odors change under different conditions
 - Food smells more appetizing when hungry

Olfactory Projection Pathways

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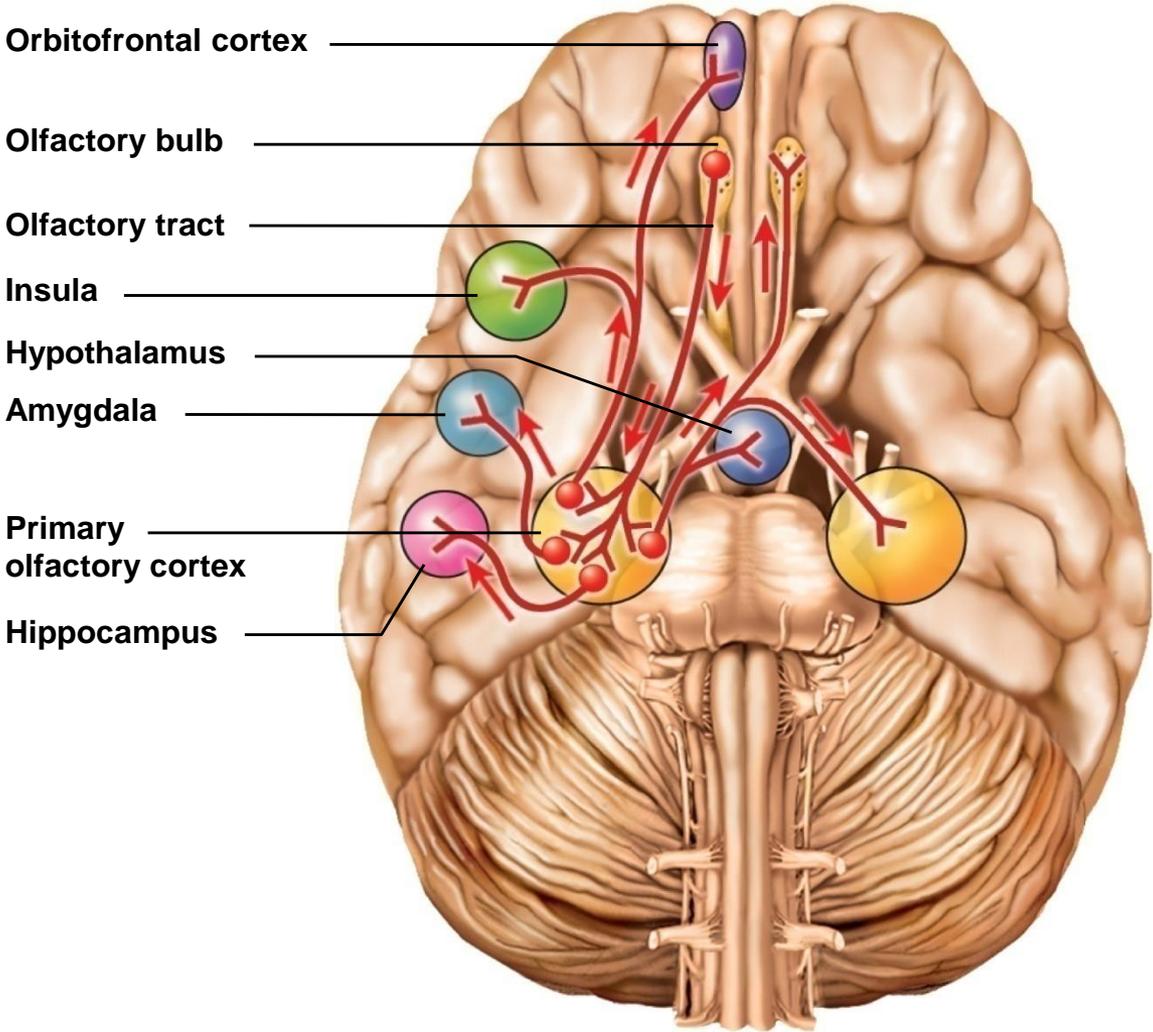


Figure 16.8

Hearing and Equilibrium

- **Expected Learning Outcomes**

- Identify the properties of sound waves that account for pitch and loudness.
- Describe the gross and microscopic anatomy of the ear.
- Explain how the ear converts vibrations to nerve signals and discriminates between sounds of different intensity and pitch.
- Explain how the vestibular apparatus enables the brain to interpret the body's position and movements.
- Describe the pathways taken by auditory and vestibular signals to the brain.

Hearing and Equilibrium

- **Hearing**—a response to vibrating air molecules
- **Equilibrium**—the sense of motion, body orientation, and balance
- Both senses reside in the **inner ear**, a maze of fluid-filled passages and sensory cells
- **Fluid is set in motion and the sensory cells convert this motion into an informative pattern of action potentials**

The Nature of Sound

- **Sound**—any audible vibration of molecules
 - A vibrating object (e.g., tuning fork) pushes on air molecules
 - These, in turn, push on other air molecules
 - Air molecules hitting eardrum cause it to vibrate

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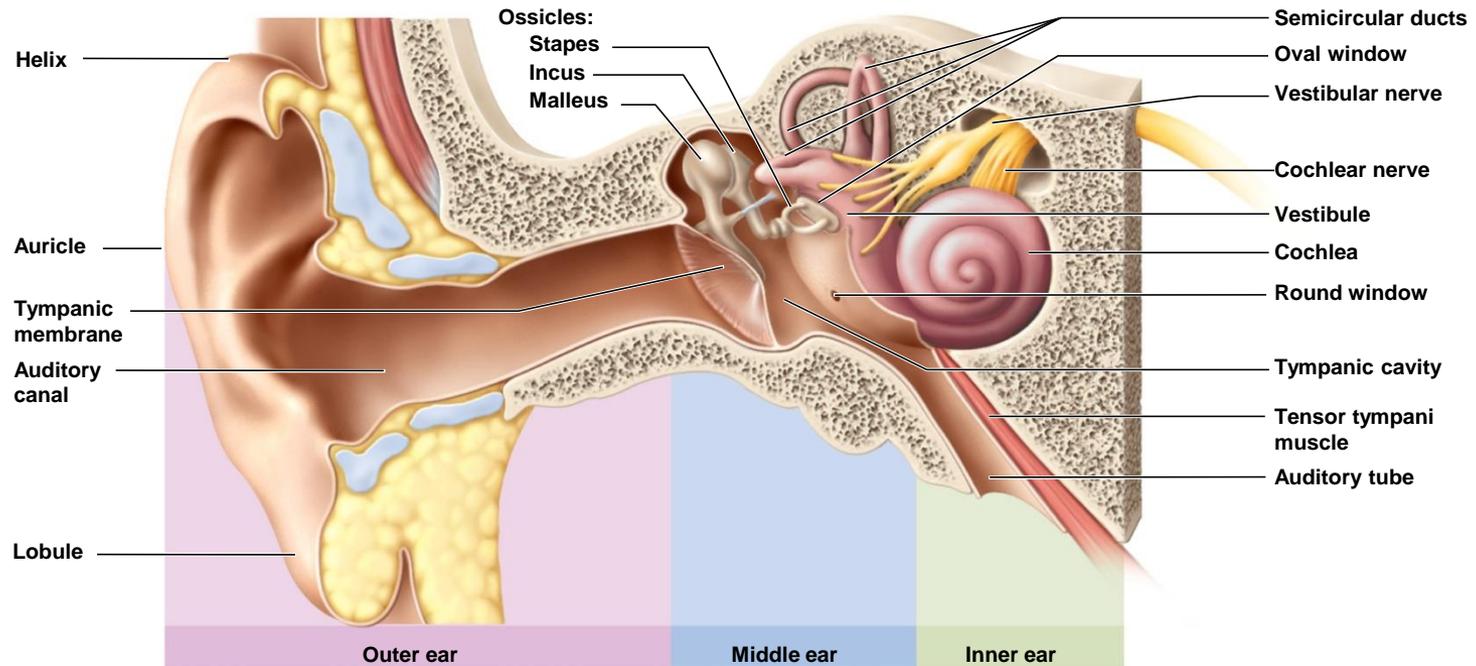


Figure 16.11

Pitch

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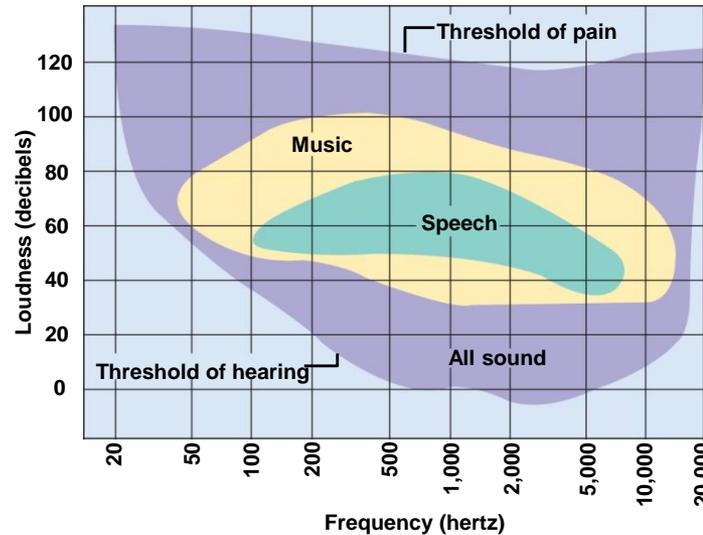


Figure 16.9

- **Pitch**—our sense of whether a sound is “high” or “low”
 - Determined by vibration **frequency: hertz (Hz)** or cycles/second
 - Human hearing range is 20 to 20,000 Hz
 - **Infrasonic** frequencies below 20 Hz
 - **Ultrasonic** frequencies above 20,000 Hz
 - Speech is 1,500 to 5,000 Hz, where hearing is most sensitive
 - Most hearing loss with age is in range of 250 to 2,050 Hz

Loudness

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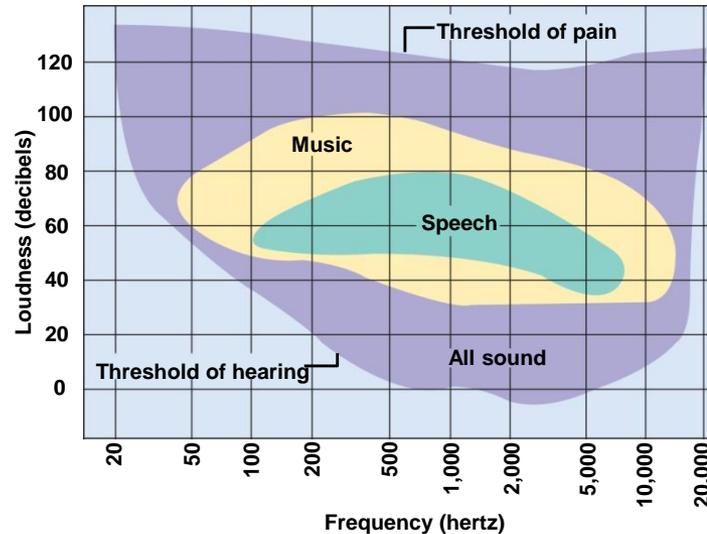


Figure 16.9

- **Loudness**—the perception of sound energy, intensity, or amplitude of the vibration
 - Expressed in **decibels (dB)**
 - Prolonged exposure to sounds > 90 dB can cause damage

Anatomy of the Ear

- **Ear** has three sections: **outer, middle, and inner ear**
 - First two are concerned only with the transmission of sound to the inner ear
 - Inner ear: vibrations converted to nerve signals

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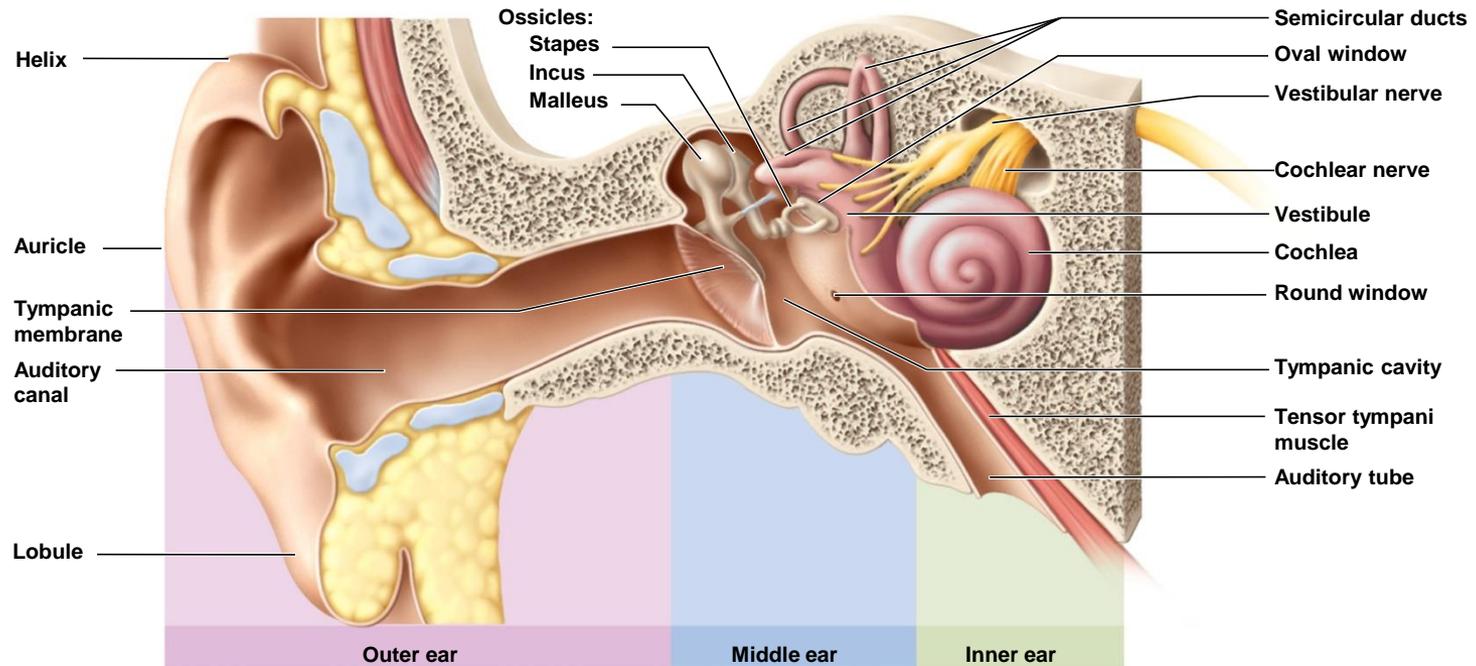
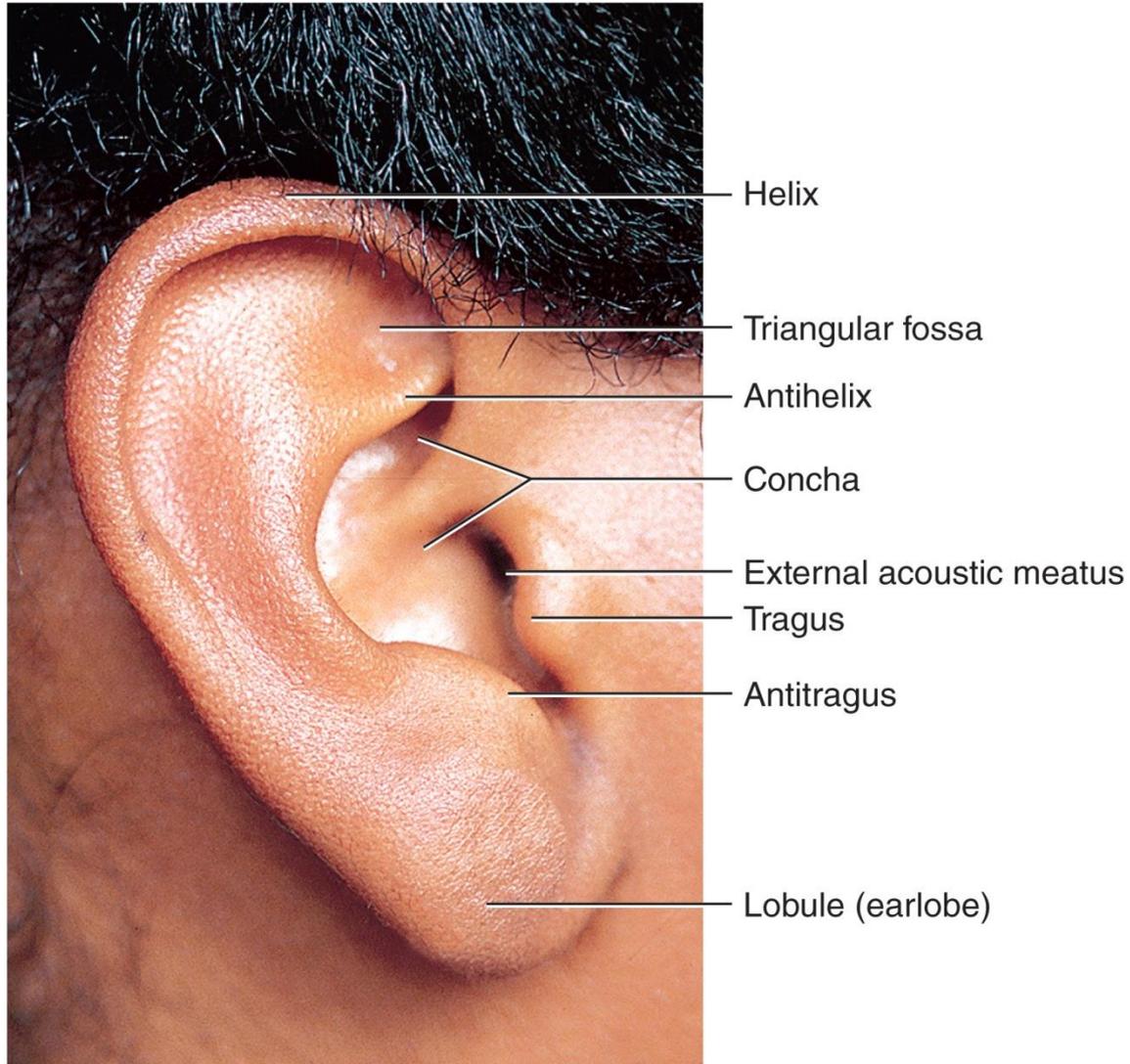


Figure 16.11

Outer Ear

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Outer Ear

- **Outer ear**—a funnel for conducting vibrations to the **tympanic membrane (eardrum)**
 - **Auricle (pinna)** directs sound down the auditory canal
 - Shaped and supported by elastic cartilage
 - **Auditory canal (external acoustic meatus):** passage leading through temporal bone to tympanic membrane
 - Slightly S-shaped tube that begins at the external opening and courses for about 3 cm
 - **Guard hairs** protect outer end of canal
 - **Cerumen (earwax)**—mixture of secretions of ceruminous and sebaceous glands and dead skin cells

Middle Ear

- **Middle ear**—located in the air-filled tympanic cavity in temporal bone
 - **Tympanic membrane (eardrum)** closes the inner end of the auditory canal (separates it from middle ear)
 - About 1 cm in diameter
 - Suspended in a ring-shaped groove in the temporal bone
 - Vibrates freely in response to sound
 - Innervated by sensory branches of vagus and trigeminal nerves
 - Highly sensitive to pain
 - **Tympanic cavity** is continuous with mastoid air cells
 - Space only 2 to 3 mm wide between outer and inner ears
 - Contains auditory ossicles

Middle Ear

- **Auditory (eustachian) tube** connects middle-ear to nasopharynx
 - Equalizes air pressure on both sides of tympanic membrane
 - Normally closed, but swallowing or yawning open it
 - Allows throat infections to spread to middle ear
- **Auditory ossicles**
 - **Malleus:** has long handle attached to inner surface of tympanic membrane
 - **Incus:** articulates with malleus and stapes
 - **Stapes:** shaped like a stirrup; footplate rests on oval window—where inner ear begins
- **Stapedius** and **tensor tympani muscles** attach to stapes and malleus

Middle Ear

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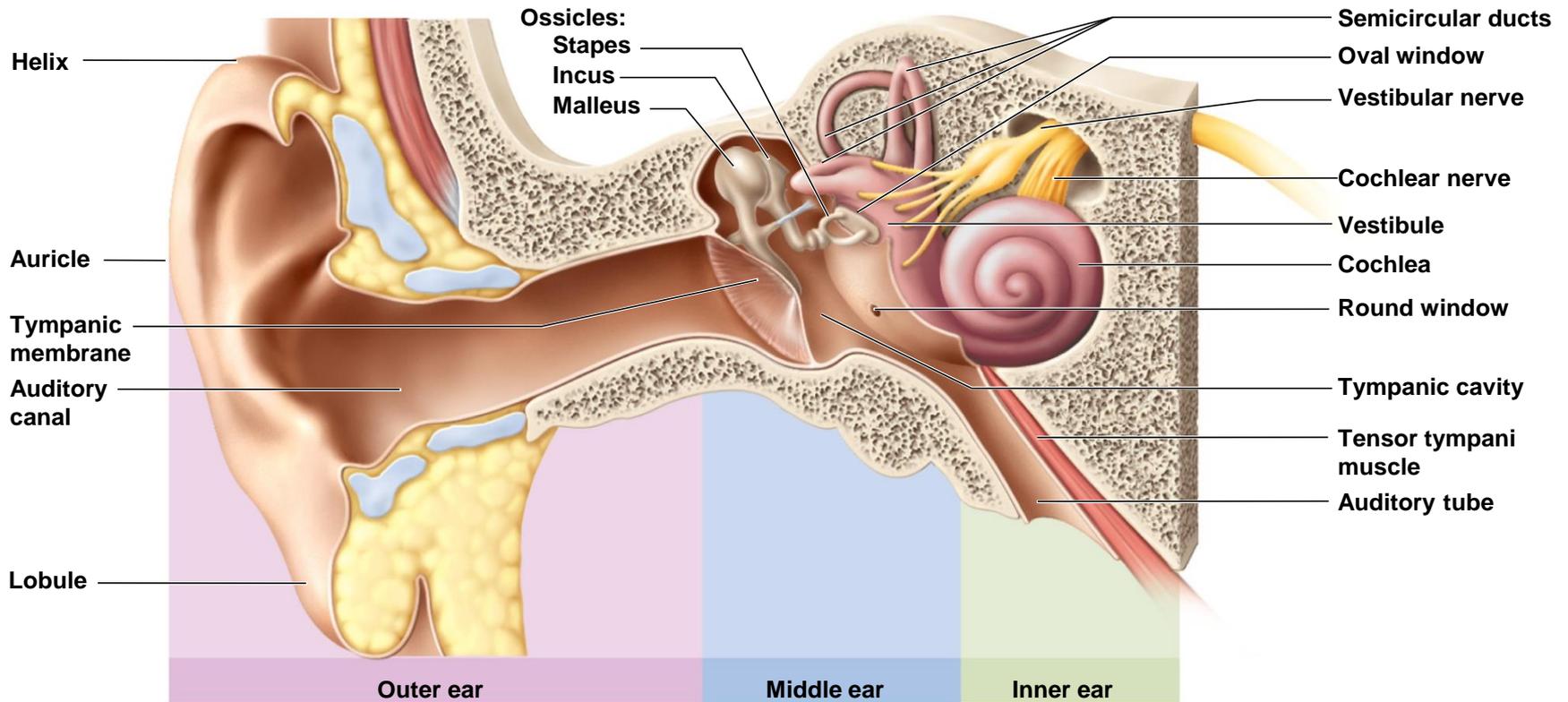


Figure 16.11

Middle-Ear Infection

- **Otitis media (middle-ear infection)** is common in children
 - Auditory tube is short and horizontal
 - Infections easily spread from throat to tympanic cavity and mastoid air cells
- **Symptoms**
 - Fluid accumulates in tympanic cavity producing pressure, pain, and impaired hearing
 - Can spread, leading to meningitis
 - Can cause fusion of ear ossicles and hearing loss
- **Tympanostomy**—lancing tympanic membrane and draining fluid from tympanic cavity

Inner Ear

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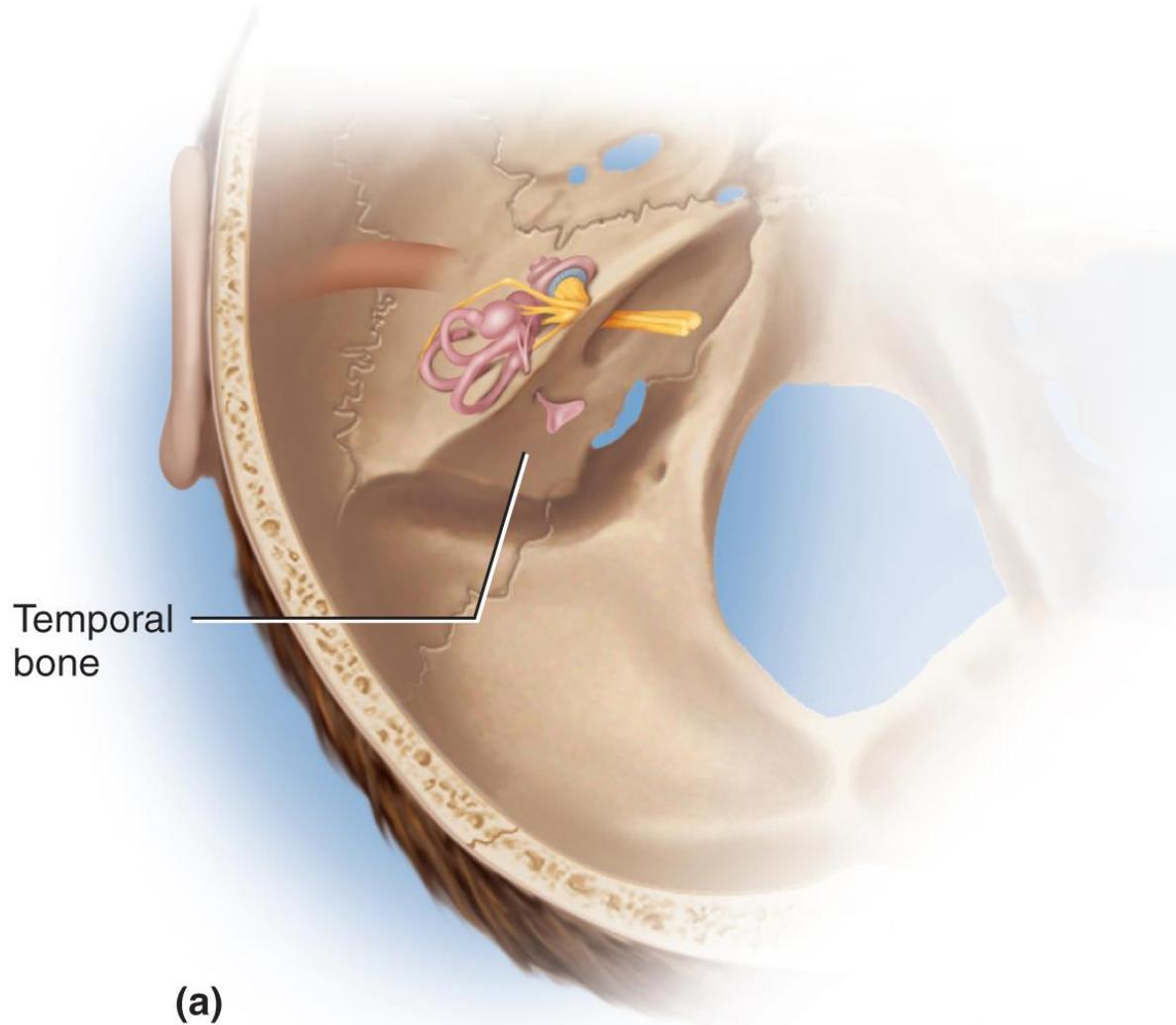


Figure 16.12a

Inner Ear

- **Bony labyrinth**—passageways in temporal bone
- **Membranous labyrinth**—fleshy tubes lining bony labyrinth
 - Filled with **endolymph**: similar to intracellular fluid
 - Floating in **perilymph**: similar to cerebrospinal fluid

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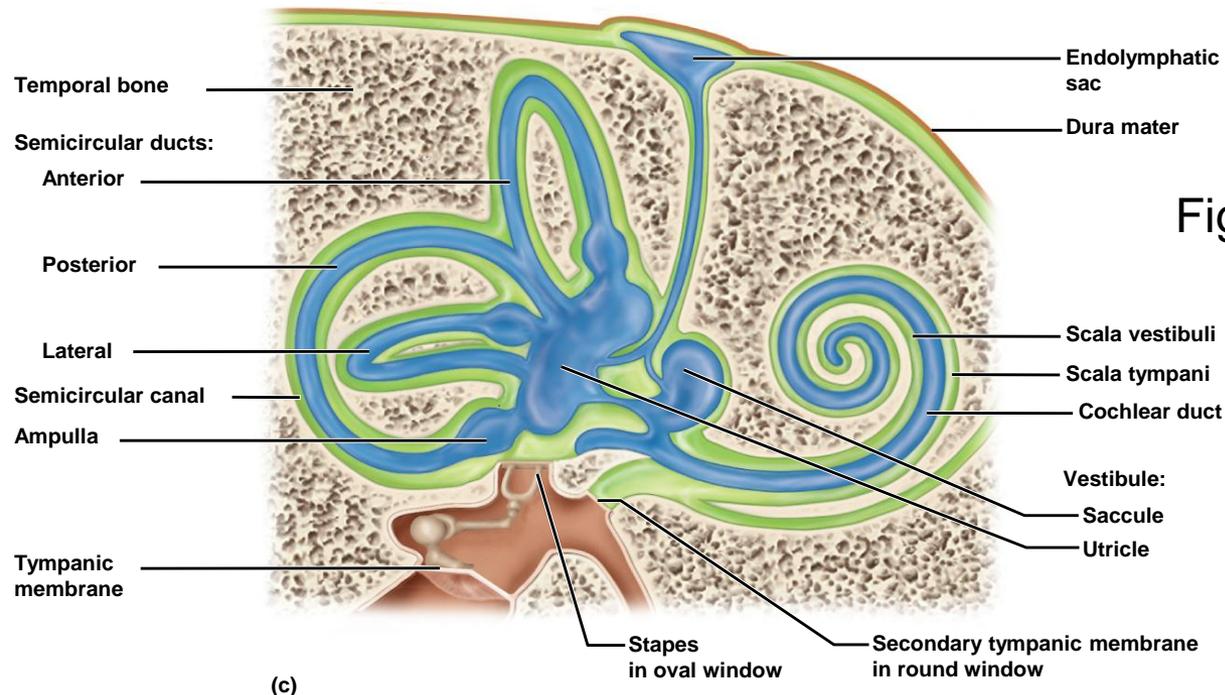


Figure 16.12c

Inner Ear

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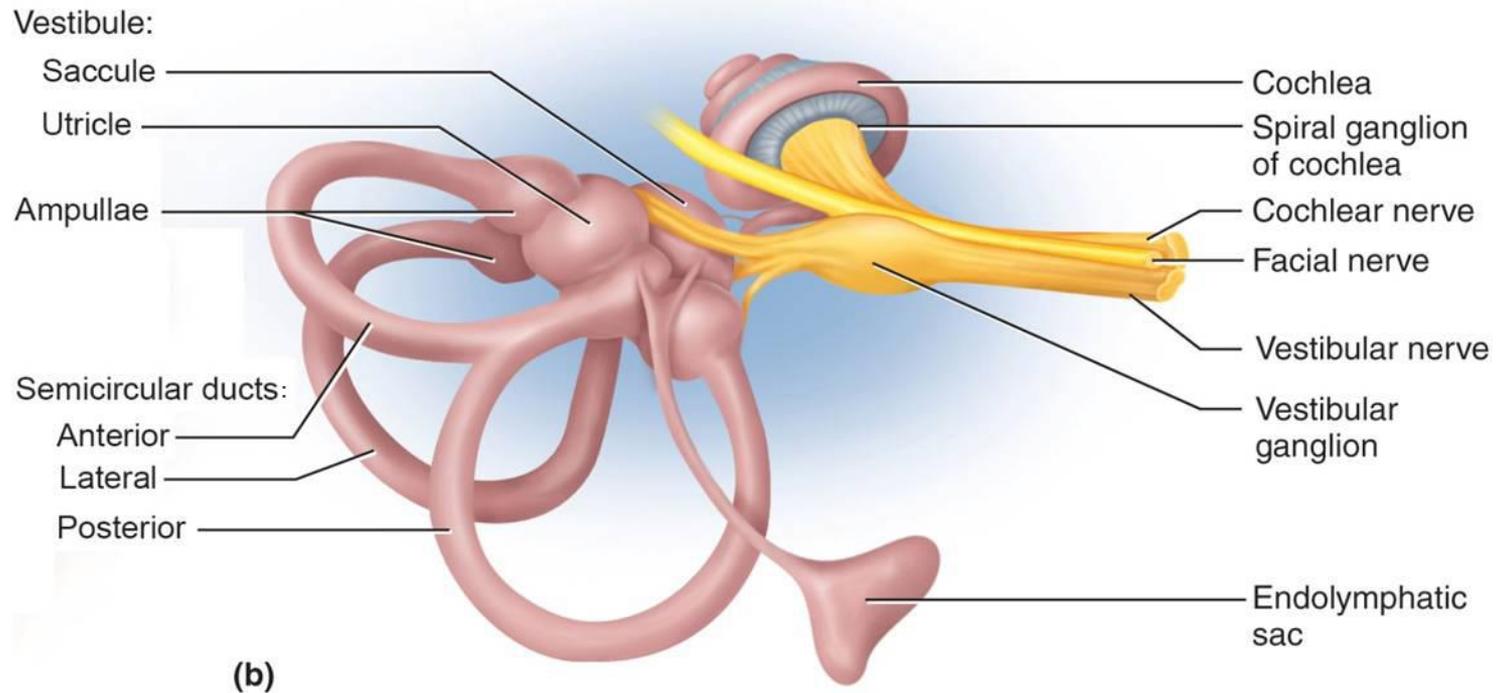


Figure 16.12b

- **Labyrinth**—vestibule and three semicircular ducts
- **Cochlea**—organ of hearing
 - Winds 2.5 coils around a screw-like axis of spongy bone, the **modiolus**
 - Threads of the screw form a spiral platform that supports the fleshy tube of the cochlea

Inner Ear

- **Cochlea has three fluid-filled chambers separated by membranes**
 - **Scala vestibuli:** superior chamber
 - Filled with **perilymph**
 - Begins at oval window and spirals to apex
 - **Scala tympani:** inferior chamber
 - Filled with **perilymph**
 - Begins at apex and ends at round window
 - **Secondary tympanic membrane:** covers round window
 - **Scala media (cochlear duct):** middle chamber
 - Filled with **endolymph**
 - Separated from:
 - Scala vestibuli by **vestibular membrane**
 - Scala tympani by thicker **basilar membrane**
 - Contains spiral organ—**organ of Corti:** acoustic organ that converts vibrations into nerve impulses

Inner Ear

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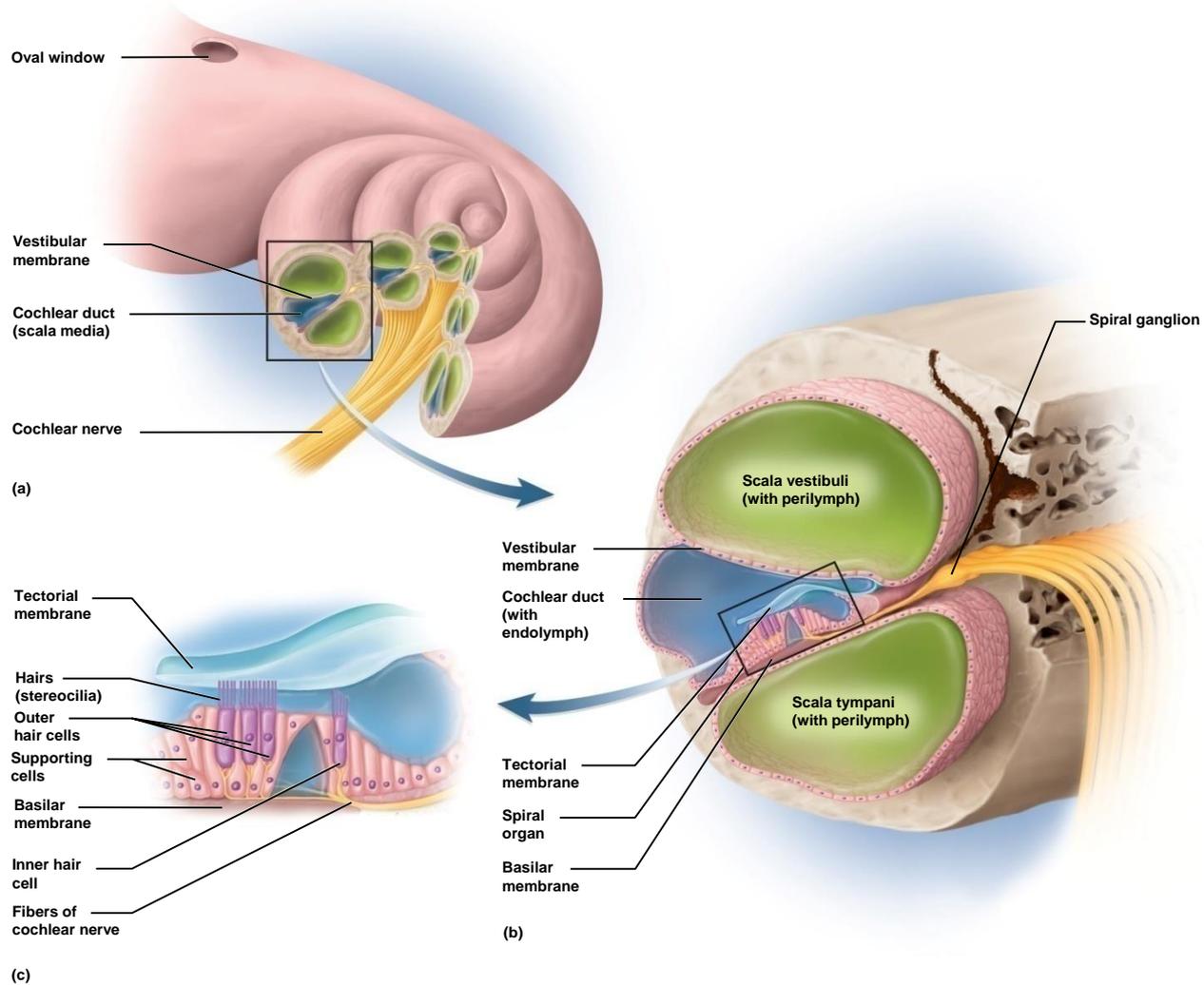


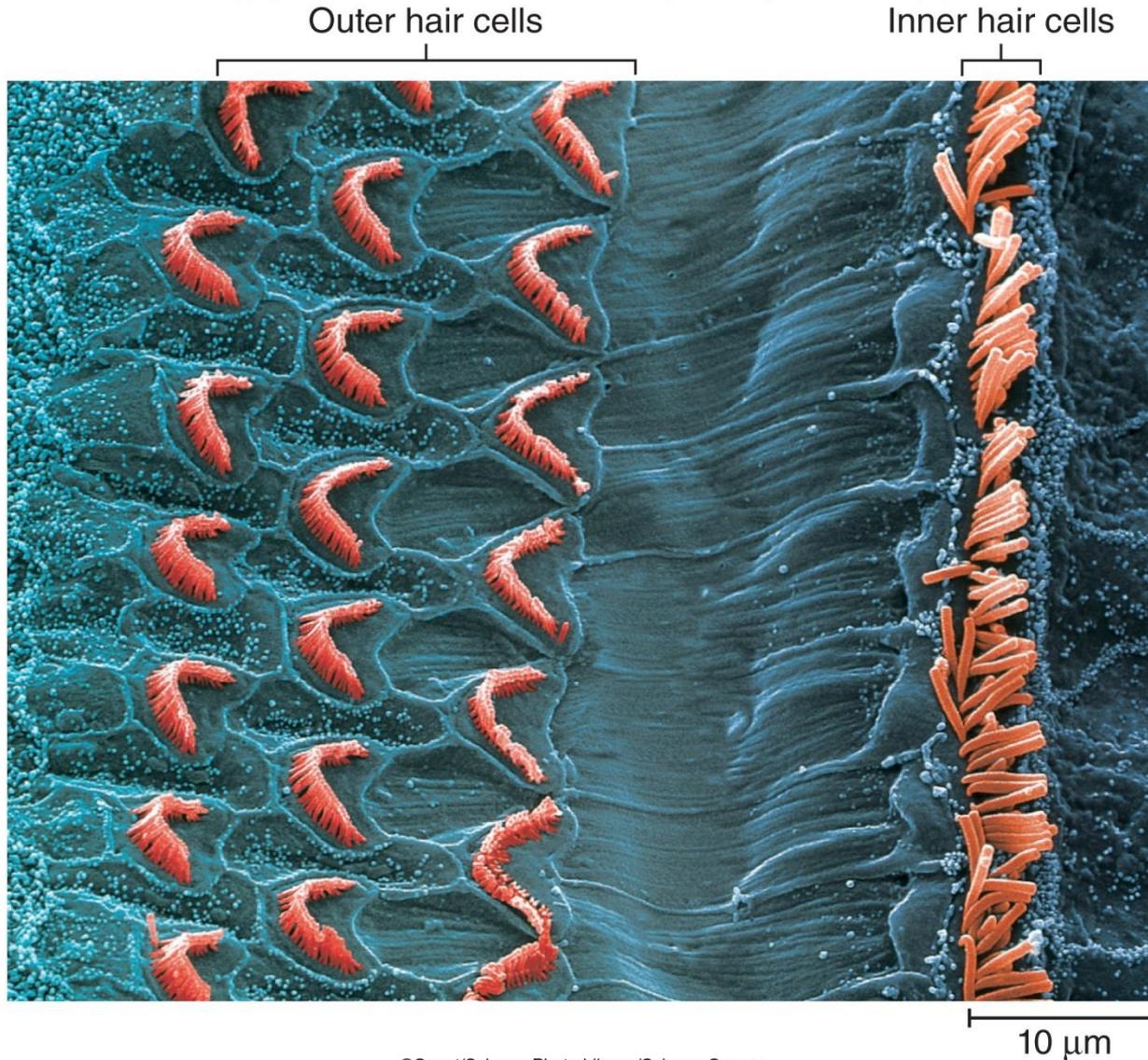
Figure 16.13

Inner Ear

- **Spiral organ** has epithelium composed of **hair cells** and **supporting cells**
- Hair cells have long, stiff microvilli called **stereocilia** on apical surface
 - Gelatinous **tectorial membrane** rests on top of stereocilia
- **Spiral organ has four rows of hair cells spiraling along its length**
 - **Inner hair cells:** single row of about 3,500 cells
 - Provides for hearing
 - **Outer hair cells:** three rows of about 20,000 cells
 - Adjusts response of cochlea to different frequencies
 - Increases precision

SEM of Cochlear Hair Cells

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Figure 16.14

The Physiology of Hearing

- **Tympanic membrane**

- Has 18 times area of oval window
- **Ossicles** concentrate the energy of the vibrating tympanic membrane on an area 1/18 that size
- Ossicles create a greater force per unit area at the oval window and overcome the inertia of the perilymph
- Ossicles and their muscles have a protective function
 - Lessen the transfer of energy to the inner ear

The Physiology of Hearing

- **Tympanic reflex**

- During loud noise, the **tensor tympani** pulls the tympanic membrane inward and tenses it
- **Stapedius muscle** reduces motion of the stapes
- Muffles the transfer of vibration from tympanic membrane to oval window
- Middle-ear muscles also help to coordinate speech with hearing
 - Dampens the sound of your own speech

Stimulation of Cochlear Hair Cells

- **Vibration of ossicles causes vibration of basilar membrane under hair cells**
 - As often as 20,000 times per second
 - Hair cells move with basilar membrane

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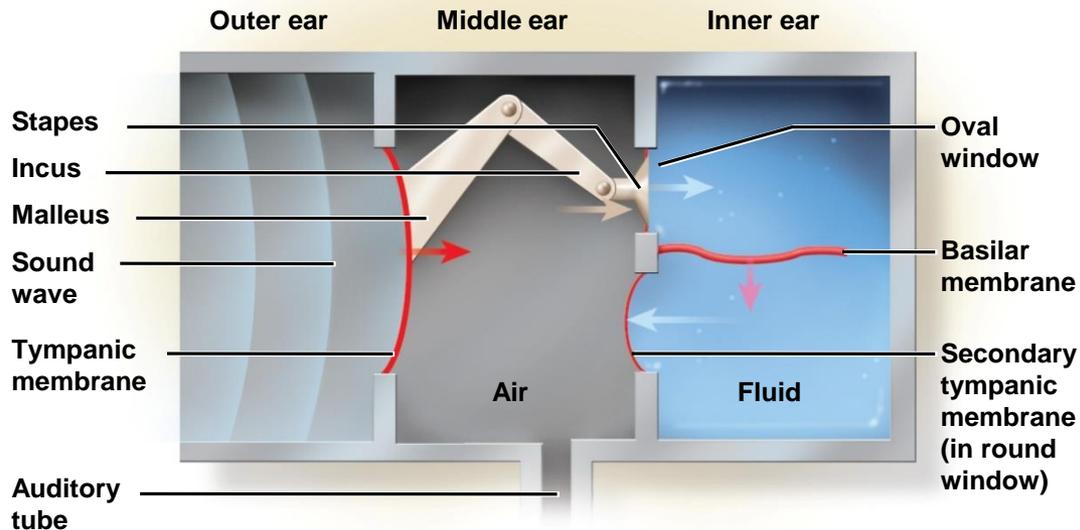


Figure 16.15

Stimulation of Cochlear Hair Cells

- **Stereocilia** of outer hair cells
 - Bathed in high K^+ fluid, the endolymph
 - Creating electrochemical gradient
 - Outside of cell is +80 mV and inside of cell is near -40 mV
 - Tip embedded in tectorial membrane

Stimulation of Cochlear Hair Cells

- **Stereocilium** on inner hair cells
 - Single transmembrane protein at tip functions as a mechanically gated ion channel
 - Stretchy protein filament (**tip link**) connects ion channel of one stereocilium to the sidewall of the next
 - Tallest stereocilium is bent when basilar membrane rises up toward tectorial membrane
 - Pulls on tip links and opens ion channels
 - K^+ flows in—depolarization causes release of neurotransmitter
 - Stimulates sensory dendrites and generates action potential in the cochlear nerve

Potassium Channels

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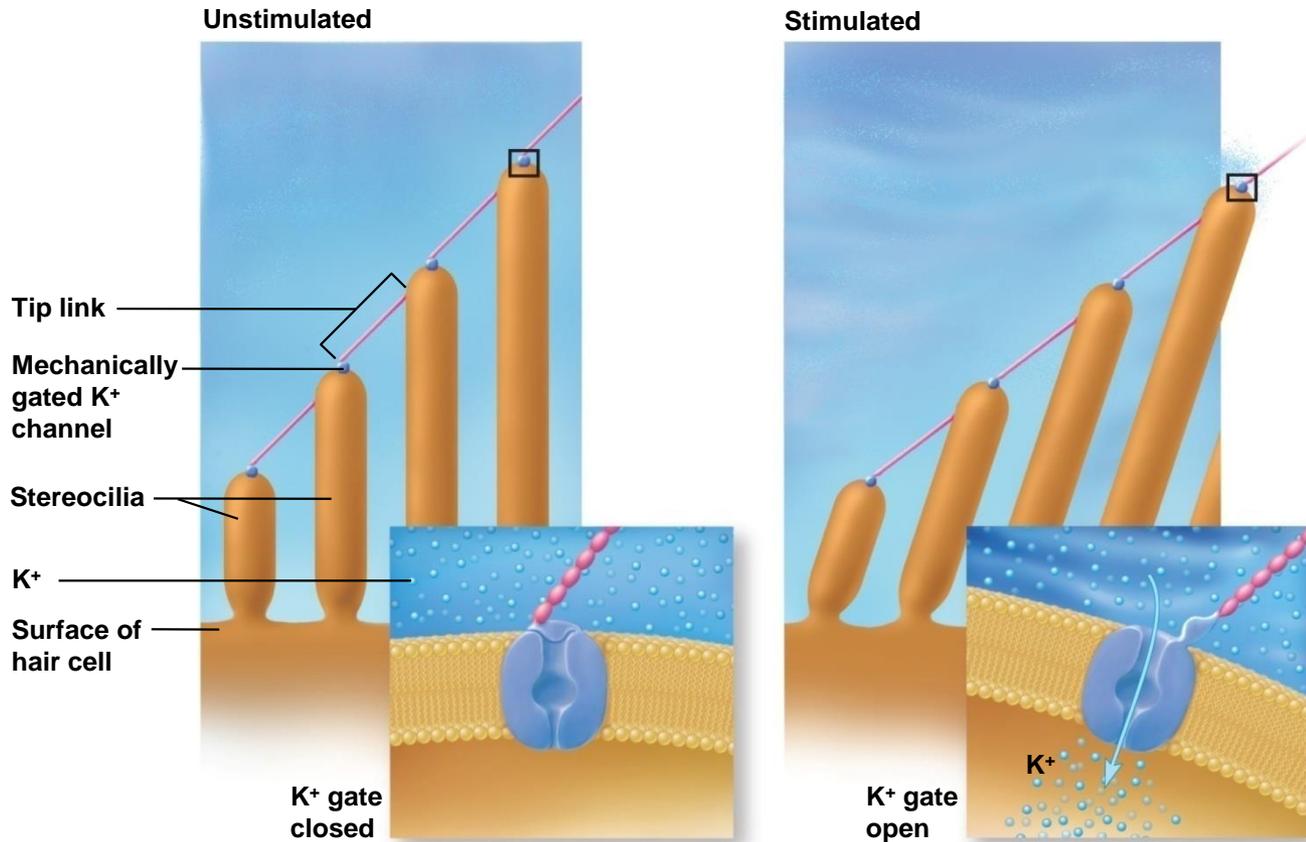


Figure 16.16

Sensory Coding

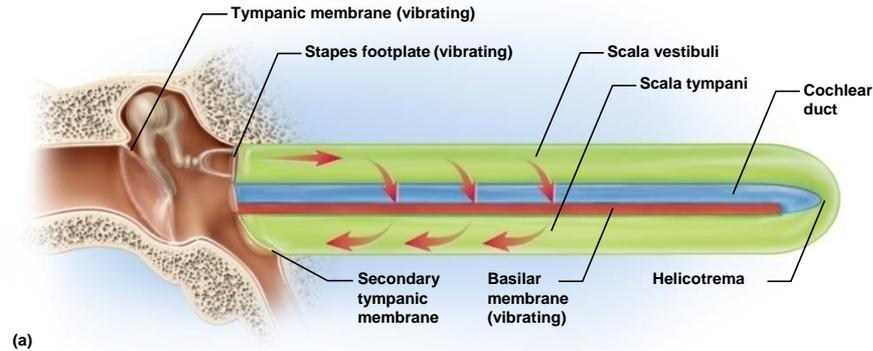
- Variations in **loudness (amplitude)** cause variations in the intensity of cochlear vibrations
 - Soft sound produces relatively slight up-and-down motion of the basilar membrane
 - Louder sounds make the basilar membrane vibrate more vigorously
 - Triggers higher frequency of action potentials
 - Brain interprets this as louder sound

Sensory Coding

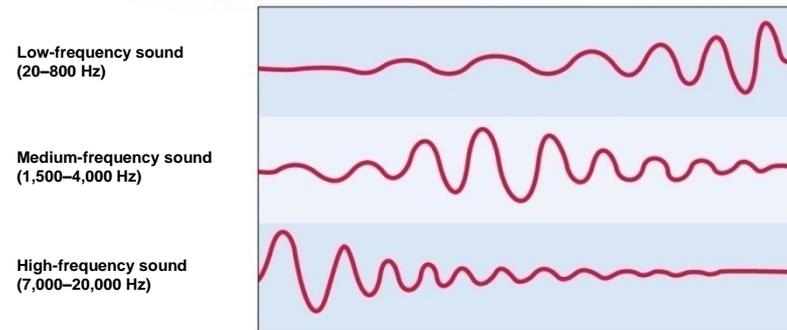
- **Pitch** depends on which part of basilar membrane vibrates
 - **At basal end**, membrane attached, narrow and stiff
 - Brain interprets signals as high-pitched
 - **At distal end**, 5 times wider and more flexible
 - Brain interprets signals as low-pitched

Basilar Membrane Frequency Response

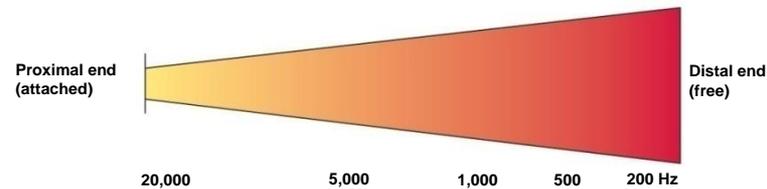
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(a)



(b)



(c)

Figure 16.17

- Notice high- and low-frequency ends

Cochlear Tuning

- **Increases ability of cochlea to receive some sound frequencies**
- **Outer hair cells** shorten, (10% to 15%) reducing basilar membrane's mobility
 - Fewer signals from that area allow brain to distinguish between more and less active areas of cochlea
- Pons has inhibitory fibers that synapse near the base of **inner hair cells**
 - Inhibits some areas and increases contrast between regions of cochlea

Deafness

- **Deafness**—hearing loss
 - **Conductive deafness:** conditions interfere with transmission of vibrations to inner ear
 - Damaged tympanic membrane, otitis media, blockage of auditory canal, and otosclerosis
 - **Otosclerosis:** fusion of auditory ossicles that prevents their free vibration
 - **Sensorineural (nerve) deafness:** death of hair cells or any nervous system elements concerned with hearing
 - Factory workers, musicians, construction workers

The Auditory Projection Pathway

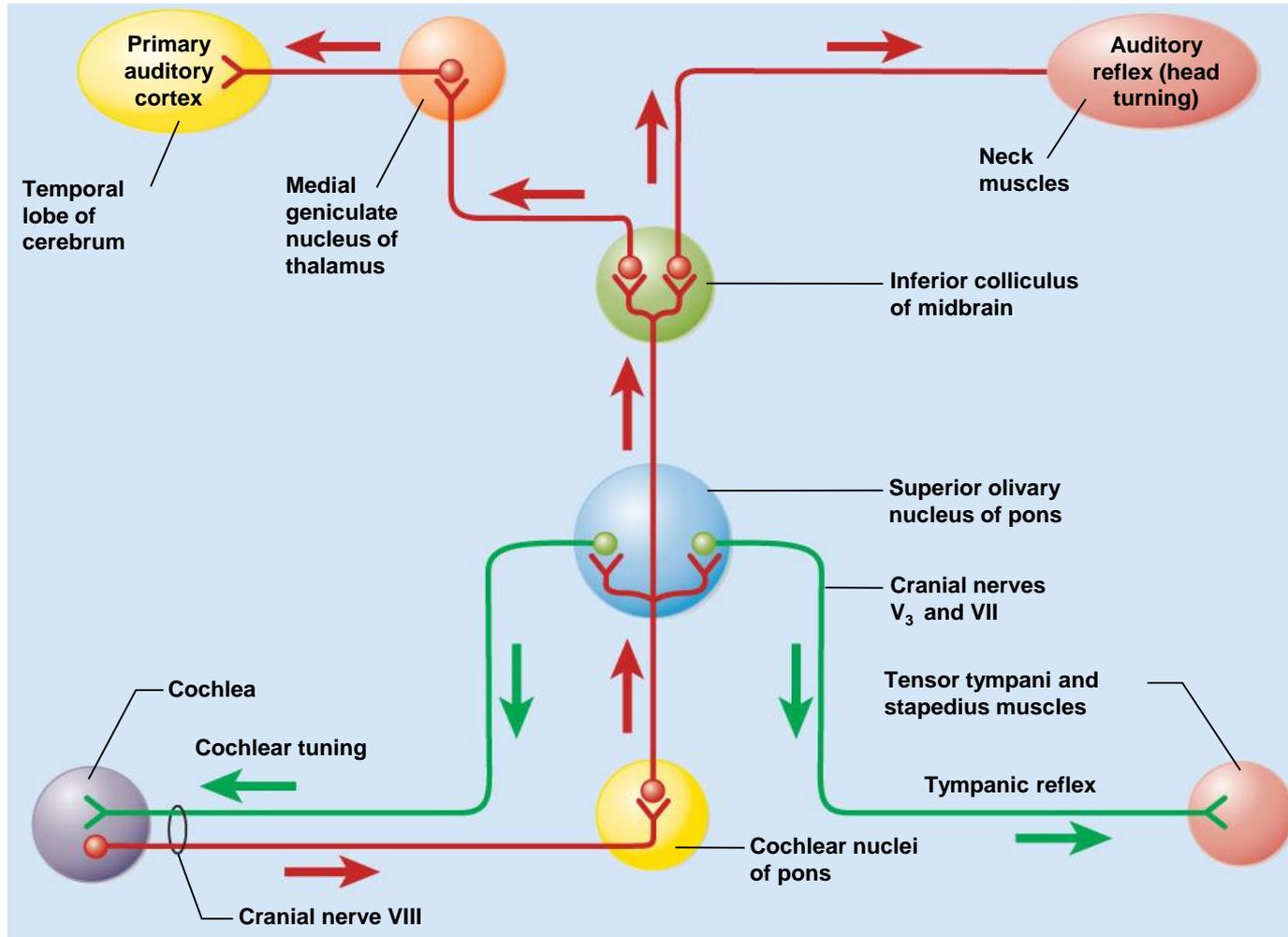
- Sensory fibers begin at the **bases of hair cells**
 - Somas form the **spiral ganglion** around the modiolus
 - Axons lead away from cochlea as the **cochlear nerve**
 - Joins with the vestibular nerve to form the **vestibulocochlear nerve (cranial nerve VIII)**
 - Each ear sends nerve fibers to both sides of the pons
 - End in cochlear nuclei
- Synapse with **second-order neurons** that ascend to the nearby **superior olivary nucleus**
 - Superior olivary nucleus issues efferent fibers back to the cochlea to tune cochlea
 - Superior olivary nucleus also functions in **binaural hearing**—comparing signals from the right and left ears to identify the direction from which a sound is coming

The Auditory Projection Pathway

- Other cochlear nucleus fibers ascend to the **inferior colliculi** of the midbrain
 - Helps to locate the origin of the sound, processes fluctuation in pitch, and mediates the startle response and rapid head turning in response to loud noise
- **Third-order neurons** begin in the inferior colliculi and lead to the thalamus
- **Fourth-order neurons** from the thalamus to primary auditory cortex at superior margin of temporal lobe
 - Functions in conscious perception of sound
 - Auditory system has extensive decussations, so damage to one side of cortex does not cause unilateral hearing loss

The Auditory Projection Pathway

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(a)

Figure 16.18a

The Auditory Projection Pathway

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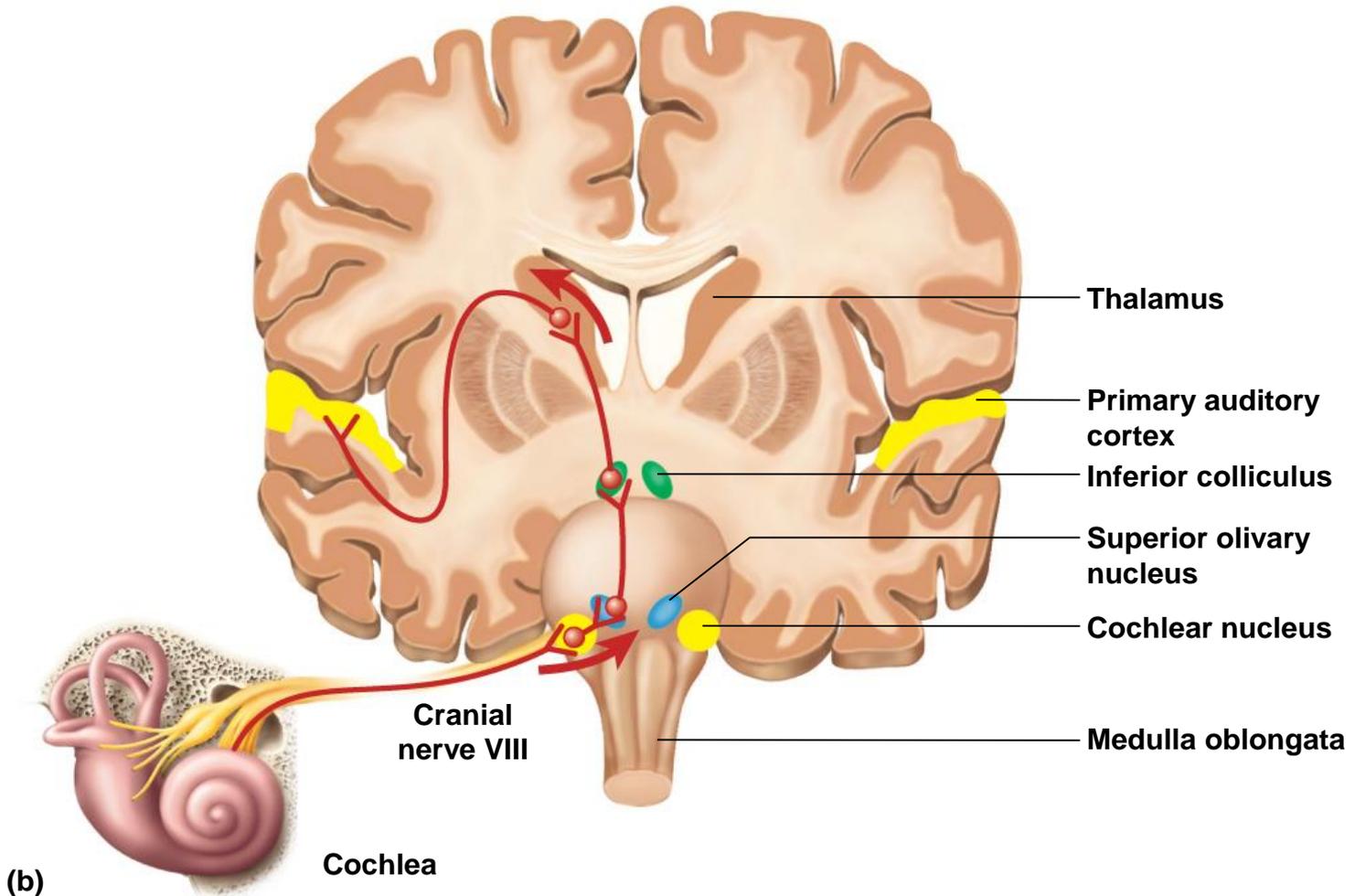


Figure 16.18b

Equilibrium

- **Equilibrium**—coordination, balance, and orientation in three-dimensional space
- **Vestibular apparatus**—constitutes receptors for equilibrium
 - **Three semicircular ducts**
 - Detect only angular acceleration
 - **Two chambers**
 - Anterior saccule and posterior utricle
 - Responsible for static equilibrium and linear acceleration

Equilibrium

- **Static equilibrium**—the perception of the orientation of the head when the body is stationary
- **Dynamic equilibrium**—perception of motion or acceleration
 - **Linear acceleration**—change in velocity in a straight line (elevator)
 - **Angular acceleration**—change in rate of rotation (car turns a corner)

The Sacculle and Utricle

- **Macula**—a 2 by 3 mm patch of hair cells and supporting cells in the sacculle and utricle
 - **Macula sacculi:** lies vertically on wall of sacculle
 - **Macula utriculi:** lies horizontally on floor of utricle

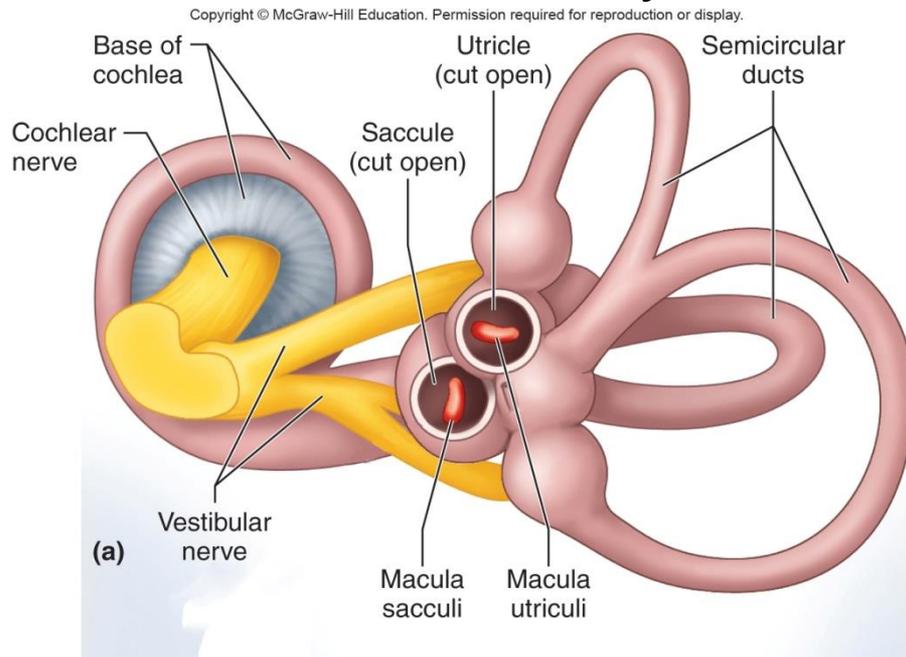
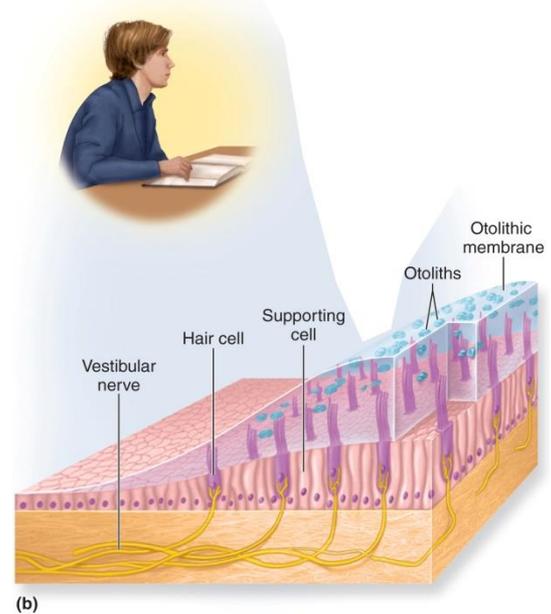


Figure 16.19a

The Sacculle and Utricule

- Each hair cell has 40 to 70 **stereocilia** and one true cilium—**kinocilium** embedded in a gelatinous **otolithic membrane**
 - **Otoliths**: calcium carbonate–protein granules that add to the weight and inertia and enhance the sense of gravity and motion

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(b)

Figure 16.19b

The Sacculle and Utricule

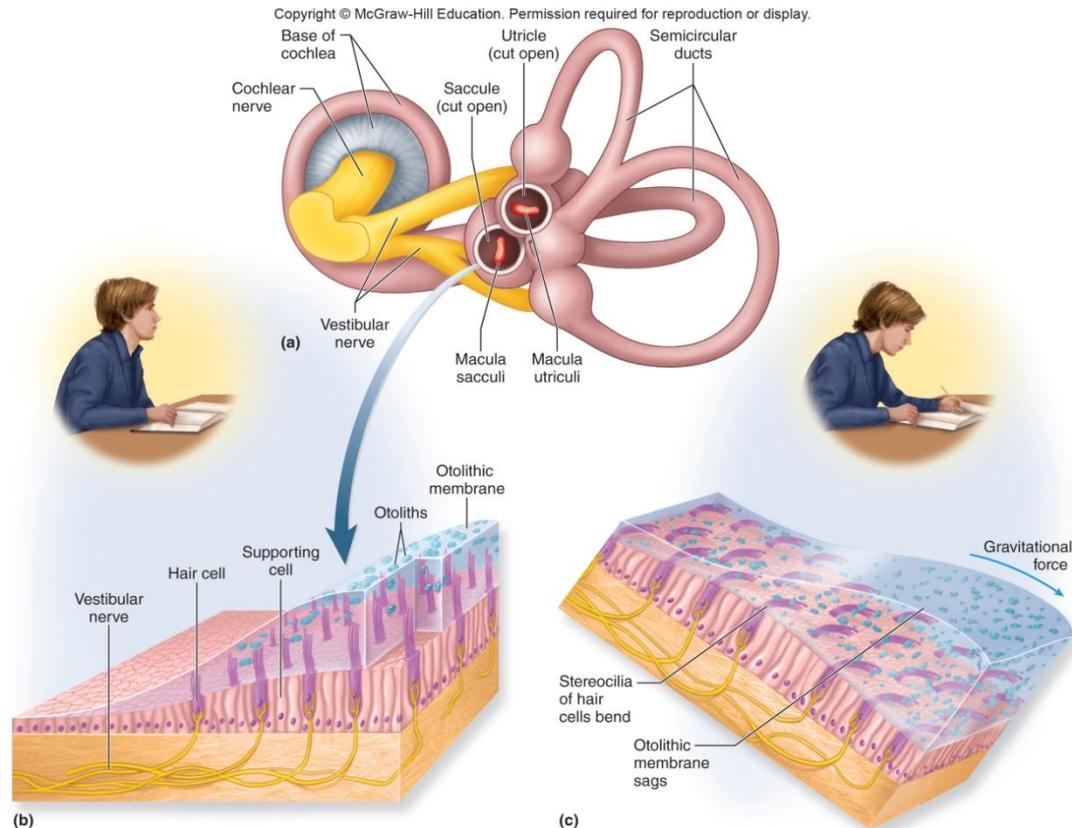


Figure 16.19

- **Static equilibrium**—when head is tilted, heavy otolithic membrane sags, bending the stereocilia and stimulating the hair cells
- **Dynamic equilibrium**—in car, linear acceleration detected as otoliths lag behind, bending the stereocilia and stimulating the hair cells
- **Because macula sacculi is nearly vertical, it responds to vertical acceleration and deceleration**

The Semicircular Ducts

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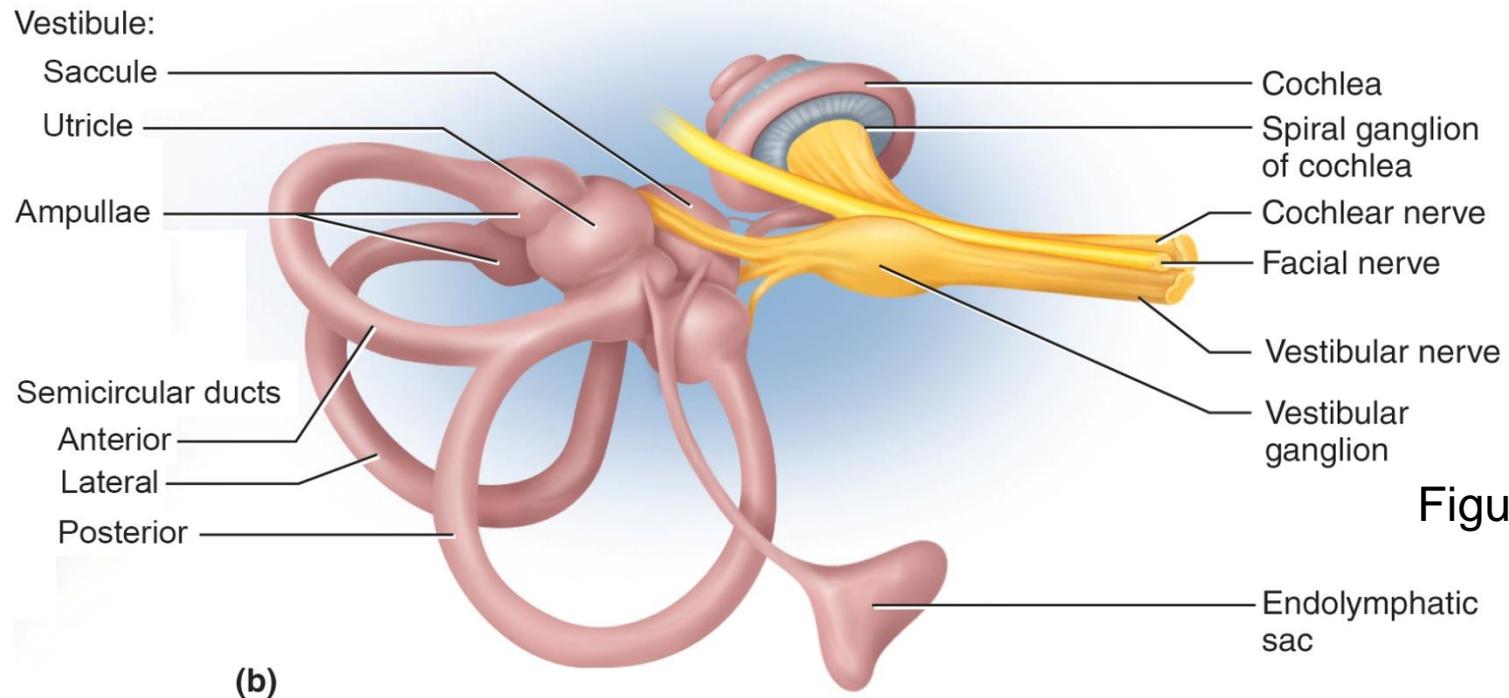


Figure 16.12b

- **Rotary movements** detected by the three semicircular ducts
- Bony **semicircular canals** of temporal bone hold membranous **semicircular ducts**
- Each duct is filled with **endolymph** and opens up as a dilated sac (**ampulla**) next to the utricle
- Each ampulla contains **crista ampullaris**—mound of hair cells and supporting cells

The Semicircular Ducts

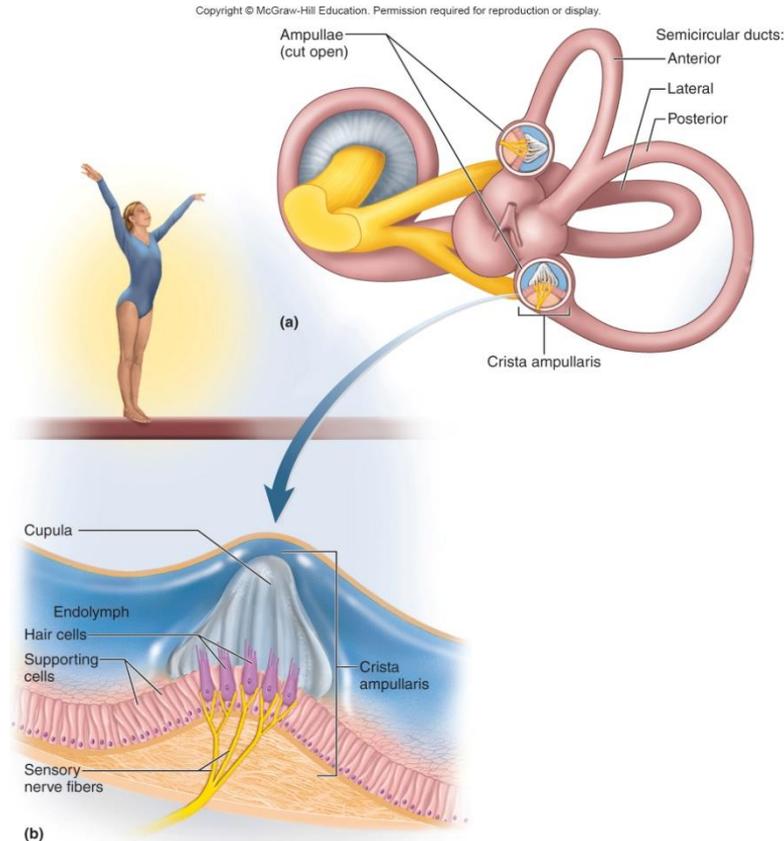


Figure 16.20a,b

- **Crista ampullaris**
 - Consists of hair cells with stereocilia and a kinocilium buried in a mound of gelatinous membrane called the **cupula** (one in each duct)
- **Spatial orientation of canals causes ducts to be stimulated by rotation in different planes**

The Semicircular Ducts

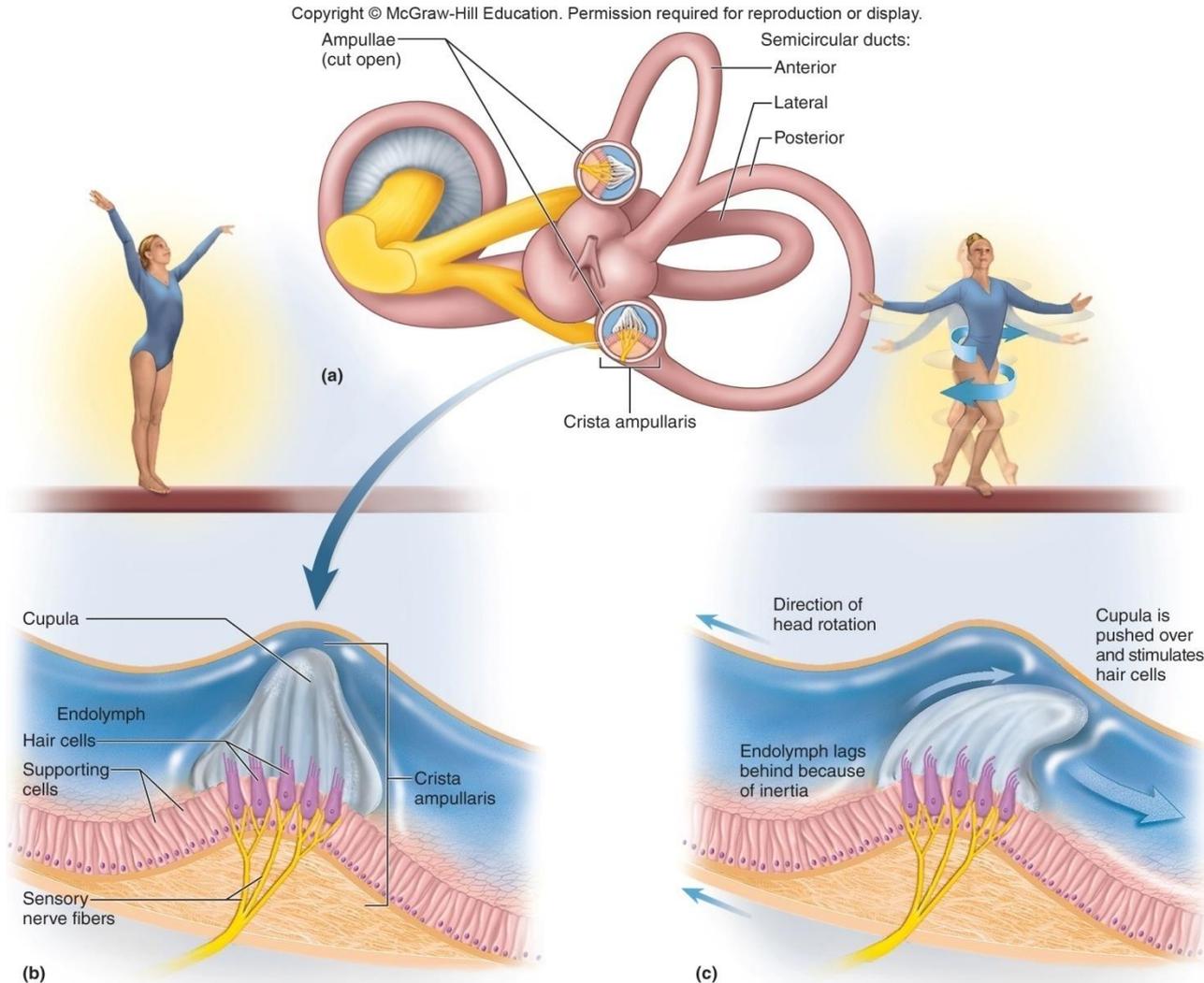


Figure 16.20

- As head turns, endolymph lags behind, pushes cupula, stimulates hair cells

Vestibular Projection Pathways

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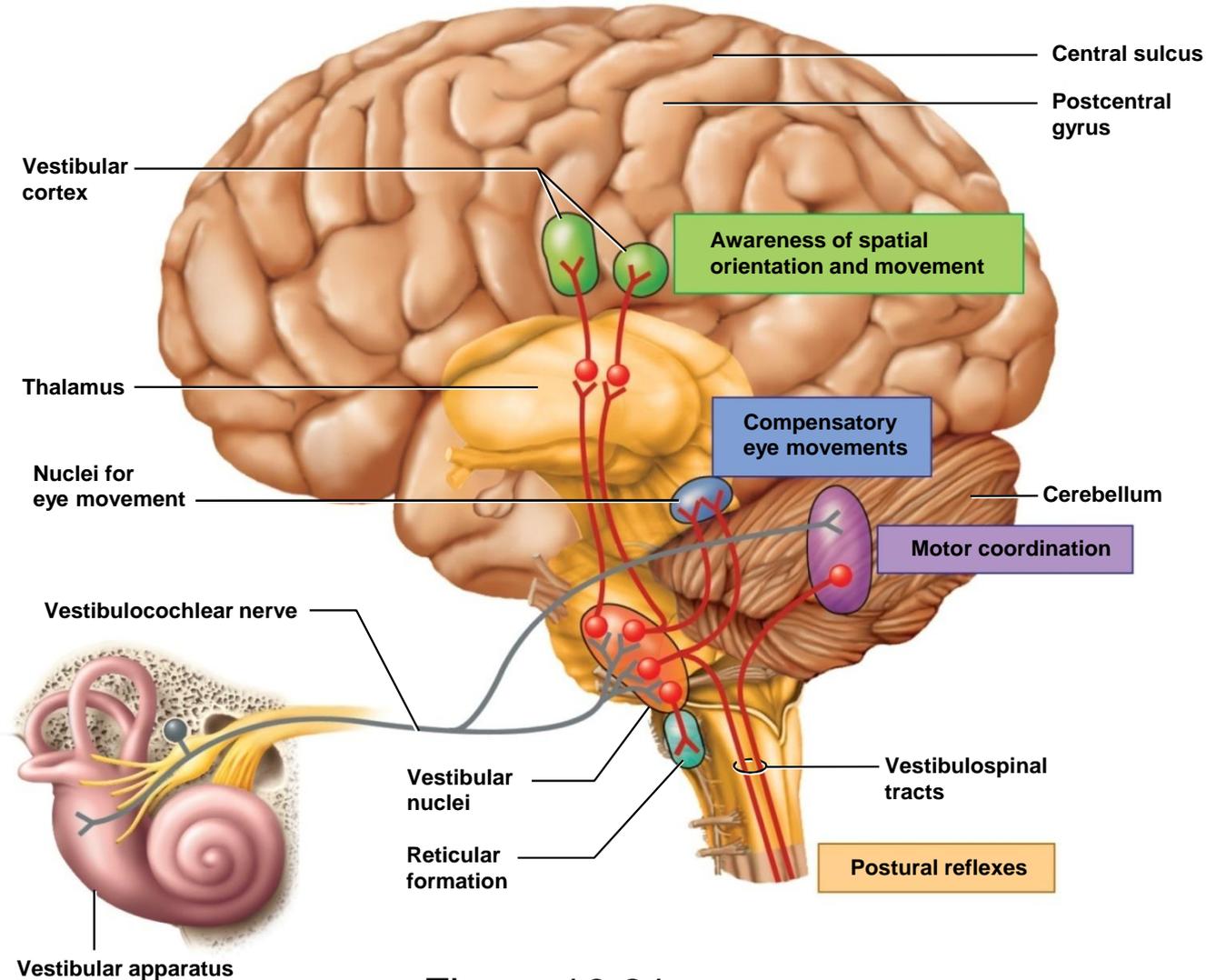


Figure 16.21

Vestibular Projection Pathways

- **Hair cells** of macula sacculi, macula utriculi, and semicircular ducts synapse on **vestibular nerve (part of CN VIII)**
- **Fibers end in a complex of four vestibular nuclei on each side of the pons and medulla**
 - Left and right nuclei receive input from both ears
- Process signals about the position and movement of the body and relay information to **five target areas**

Vestibular Projection Pathways

- **Five target areas**

- **Cerebellum:** integrates vestibular information into its control of head and eye movements, muscle tone, and posture
- **Nuclei of oculomotor, trochlear, and abducens nerves** (CN III, IV, and VI) to produce **vestibulo–ocular reflex:** keeps vision fixed on distant object while walking
- **Reticular formation:** thought to adjust blood circulation and breathing to postural changes
- **Spinal cord:** descend through two vestibulospinal tracts of spinal cord and innervate extensor (antigravity) muscles
- **Thalamus:** thalamic relay to cerebral cortex for awareness of position and motor control of head and body

Vision

- **Expected Learning Outcomes**

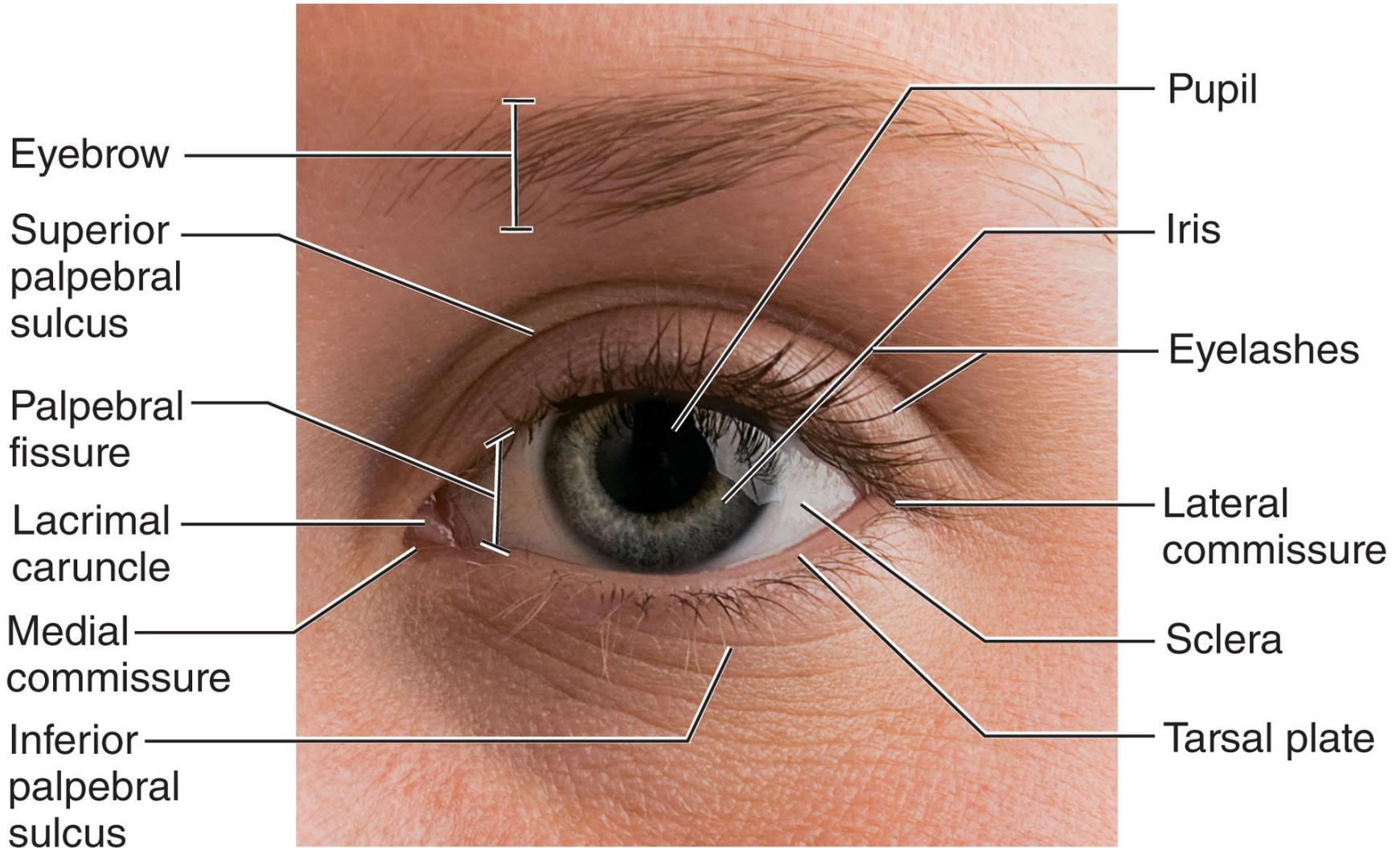
- Describe the anatomy of the eye and its accessory structures.
- Discuss the structure of the retina and its receptor cells.
- Explain how the optical system of the eye creates an image on the retina.
- Discuss how the retina converts this image to nerve signals.
- Explain why different types of receptor cells and neural circuits are required for day and night vision.
- Describe the mechanism of color vision.
- Trace the visual projection pathways in the brain.

Light and Vision

- **Vision (sight)**—perception of objects in the environment by means of light they emit or reflect
- **Light**—visible electromagnetic radiation
 - Human vision: limited to wavelengths of light from 400 to 700 nm
 - Light must cause a photochemical reaction to produce a nerve signal
 - **Ultraviolet radiation:** < 400 nm; has too much energy and destroys macromolecules
 - **Infrared radiation:** > 700 nm; too little energy to cause photochemical reaction, but does warm the tissues

Accessory Structures of the Orbit

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Figure 16.22

Accessory Structures of the Orbit

- Orbital region of face is the area around the eye socket (**orbit**)
- **Eyebrows** enhance facial expression
 - Protect eyes from glare and perspiration
- **Eyelids (palpebrae)**
 - Block foreign objects, help with sleep, blink to moisten
 - Meet at corners (commissures)
 - Consist of **orbicularis oculi muscle** and tarsal plate covered with skin outside and conjunctiva inside
 - **Tarsal glands** secrete oil that reduces tear evaporation
 - **Eyelashes** help keep debris from eye

Accessory Structures of the Orbit

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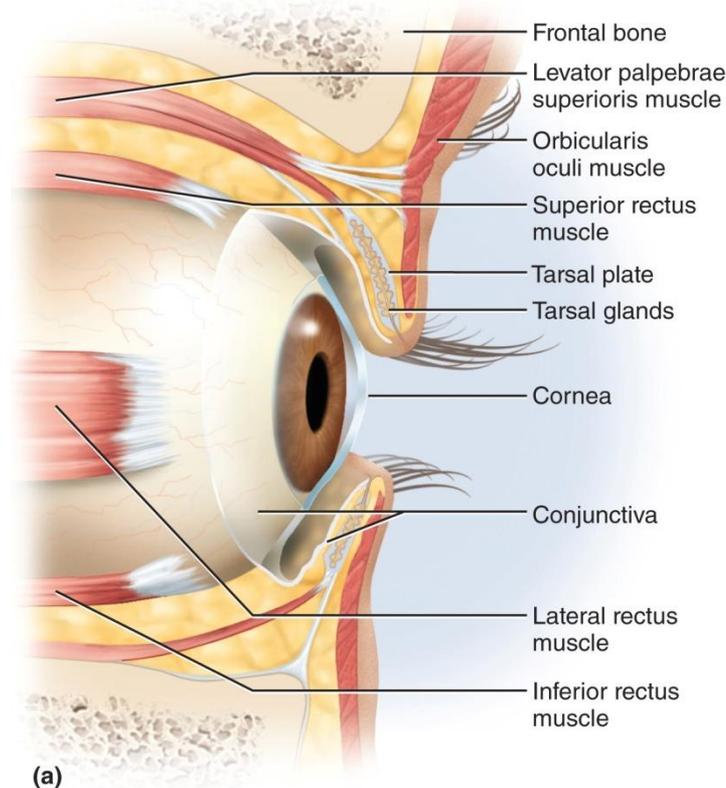


Figure 16.23a

- **Conjunctiva**—a transparent mucous membrane that lines eyelids and covers anterior surface of eyeball, except cornea
 - Richly innervated and vascular (heals quickly)
 - Secretes a thin mucous film that prevents the eyeball from drying
- **Orbital fat**—cushions eye, protects vessels and nerves of orbit

Accessory Structures of the Orbit

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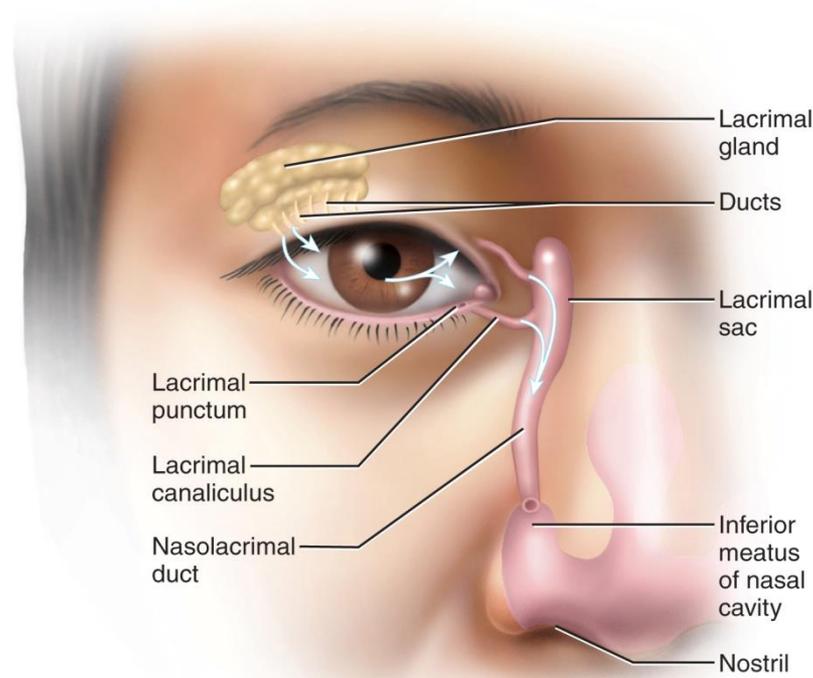


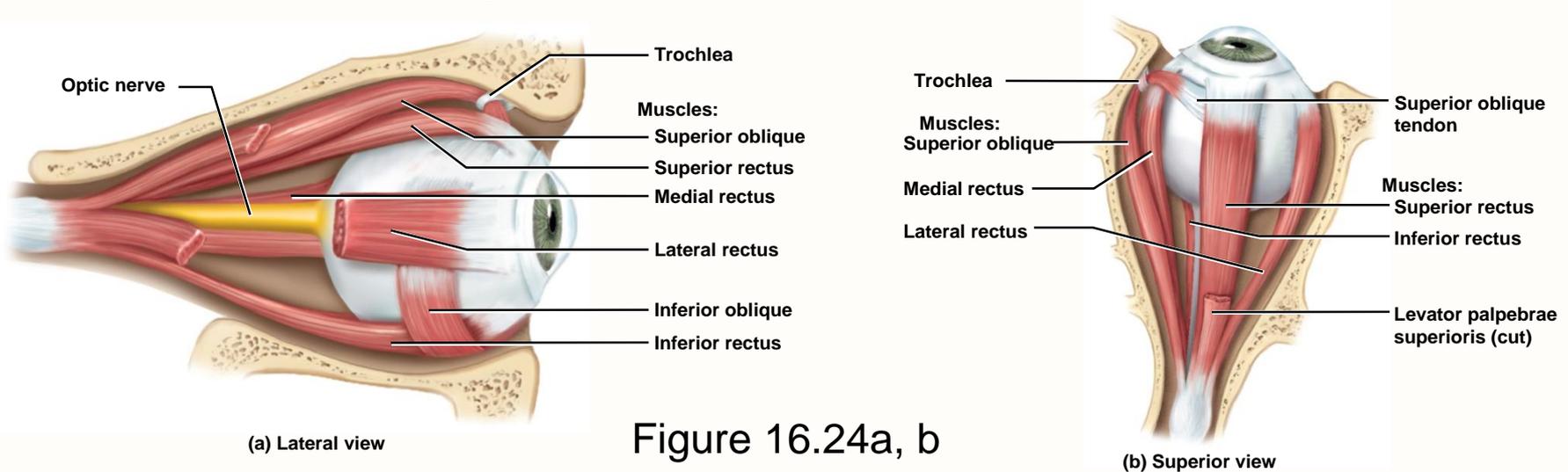
Figure 16.23b

(b)

- **Lacrimal apparatus** makes, distributes and drains tears.
- Tears from lacrimal gland wash and lubricate eye, deliver O₂ and nutrients, and prevent infection with a bactericidal lysozyme
- Tears flow through lacrimal punctum (opening on eyelid edge) to lacrimal sac, then into nasolacrimal duct emptying into nasal cavity

Accessory Structures of the Orbit

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- **Six extrinsic muscles attach to exterior surface of eyeball**
 - Superior, inferior, lateral, and medial rectus muscles, superior and inferior oblique muscles
- **Innervated by cranial nerves**
 - CN IV innervates superior oblique
 - CN VI innervates lateral rectus
 - CN III innervates other four extrinsic muscles

Accessory Structures of the Orbit

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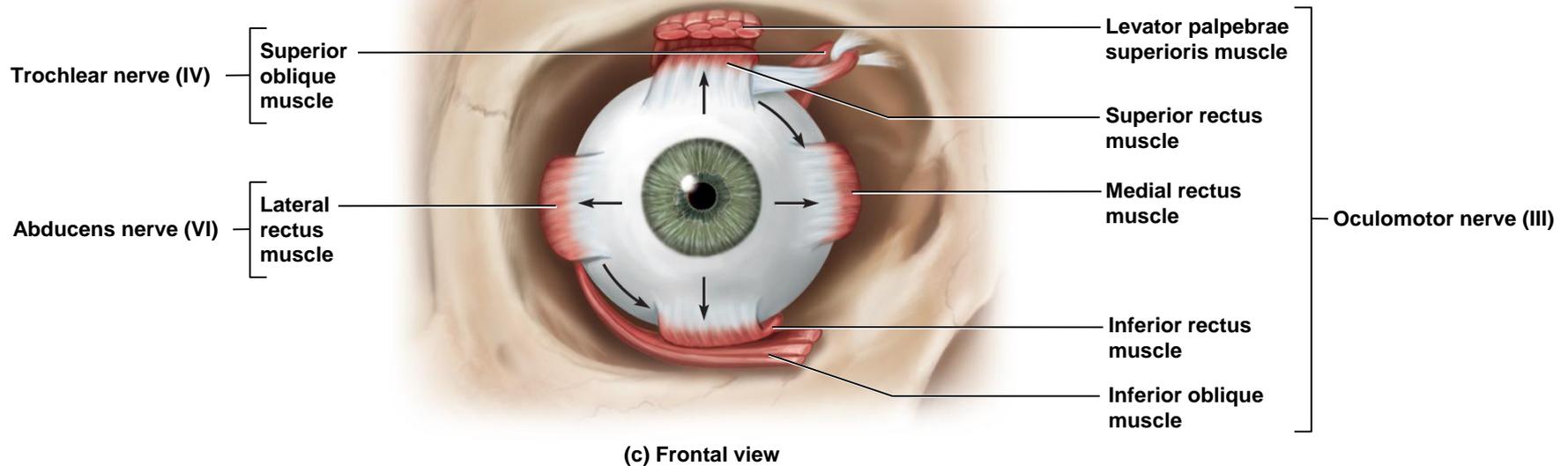


Figure 16.24c

- **Superior, inferior, medial, and lateral rectus muscles move the eye up, down, medially, and laterally (respectively)**
- **Superior and inferior obliques turn the “twelve o’clock pole” of each eye toward or away from the nose; they also produce slight elevations and depressions of the eye**

Anatomy of the Eye

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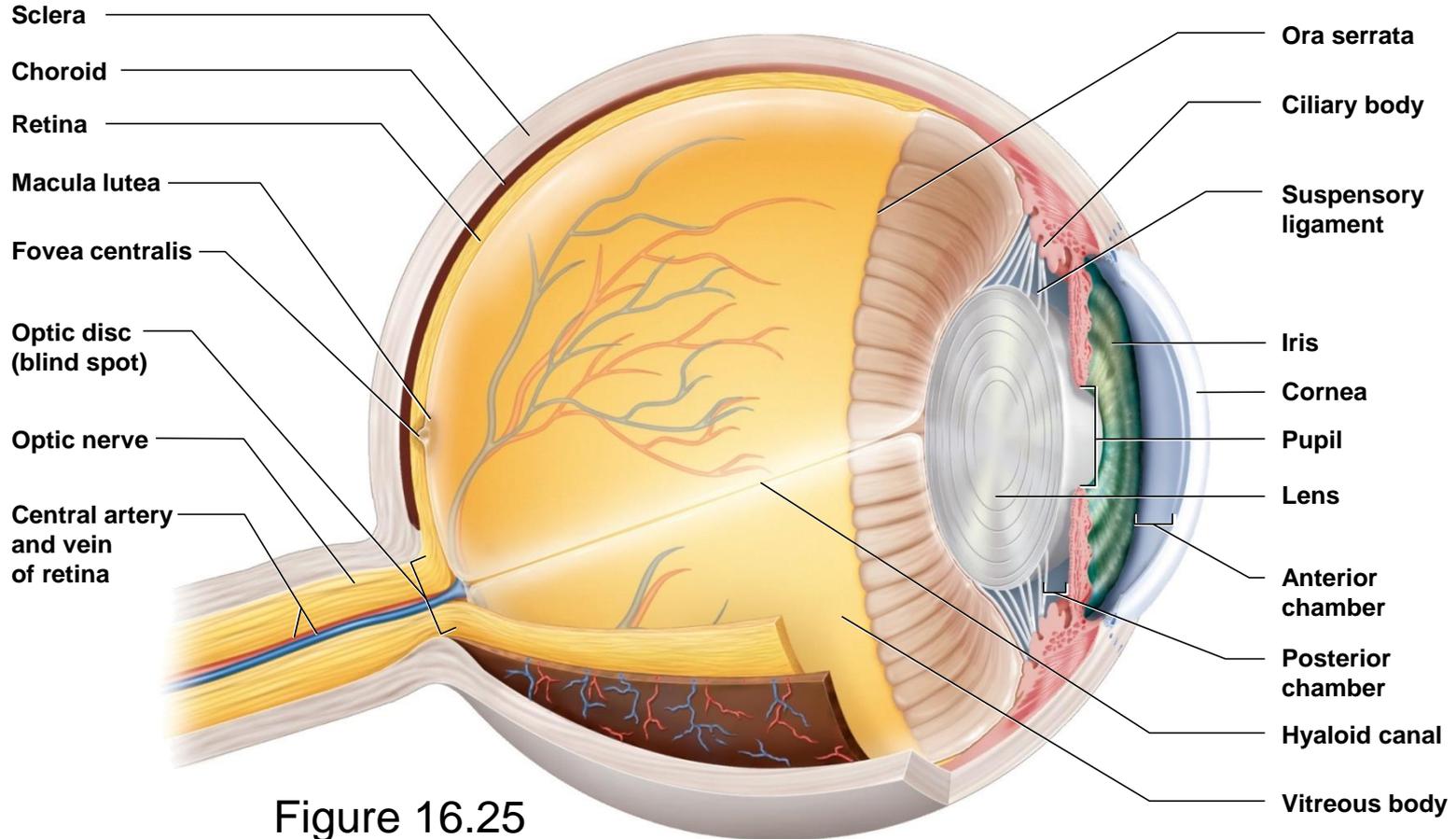


Figure 16.25

- **Three principal components of the eyeball**
 - **Three layers (tunics)** that form the wall of the eyeball
 - **Optical components** admit and focus light
 - **Neural component:** retina and optic nerve

The Tunics

- **Tunica fibrosa**—outer fibrous layer
 - **Sclera:** dense, collagenous white of the eye
 - **Cornea:** transparent region of modified sclera in front of eye that admits light
- **Tunica vasculosa (uvea)**—middle vascular layer
 - **Choroid:** highly vascular, deeply pigmented layer behind retina
 - **Ciliary body:** extension of choroid; a muscular ring around lens
 - Supports lens and iris
 - Secretes aqueous humor
 - **Iris:** colored diaphragm controlling size of pupil (opening)
 - If there is a lot of melanin in **chromatophores (cells)** of iris—brown or black eye color
 - If there is reduced melanin—blue, green, or gray eye color
- **Tunica interna**—retina and beginning of optic nerve

The Optical Components

- **Optical components—transparent elements that admit light, refract light rays, and focus images on retina: cornea, aqueous humor, lens, vitreous body**
 - **Cornea:** transparent anterior cover
 - **Aqueous humor**
 - Serous fluid secreted by ciliary body into posterior chamber—posterior to cornea, anterior to lens
 - Reabsorbed by scleral venous sinus at same rate it is secreted

The Optical Components

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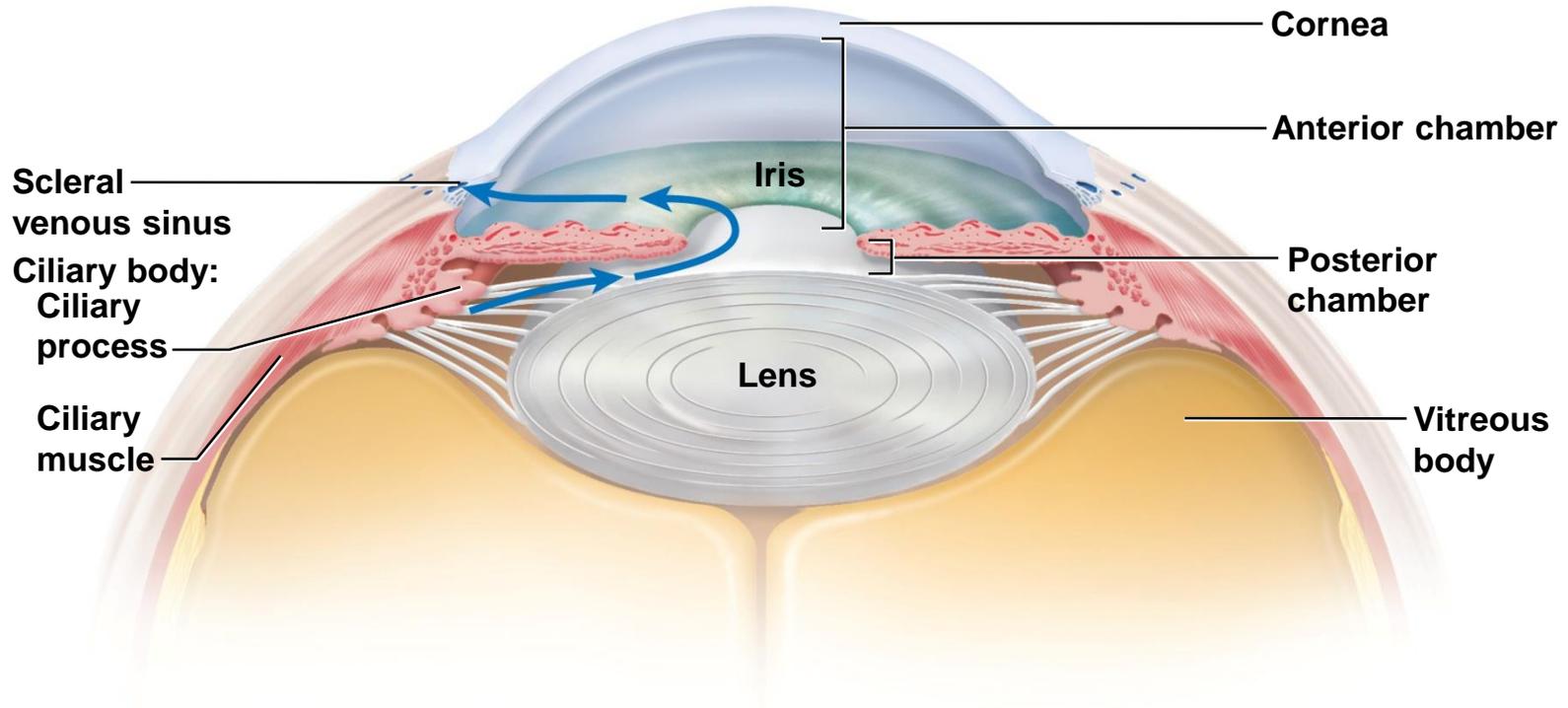


Figure 16.26

- **Aqueous humor is released by ciliary body into posterior chamber, passes through pupil into anterior chamber, then reabsorbed into scleral venous sinus**

The Optical Components

– Lens

- **Lens fibers**—flattened, tightly compressed, transparent cells that form lens
- Suspended by suspensory ligaments from ciliary body
- Changes shape to help focus light
 - Rounded with no tension or flattened with pull of suspensory ligaments

– **Vitreous body (humor)** fills vitreous chamber

- Jelly fills space between lens and retina

The Neural Components

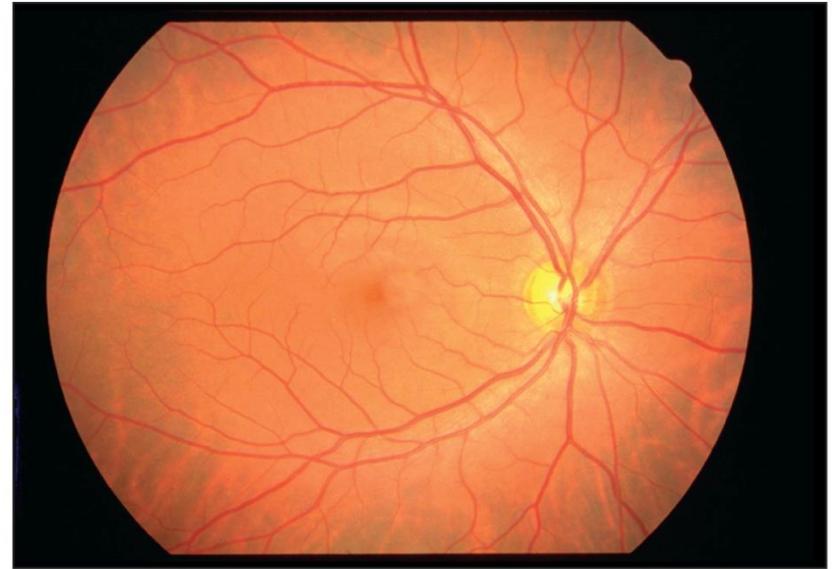
- **Include retina and optic nerve**
- **Retina**
 - Formed from optic vesicle—outgrowth of diencephalon
 - Attached to eye only at **optic disc** (posterior exit of optic nerve) and **ora serrata** (anterior edge of retina)
 - Pressed against rear of eyeball by vitreous humor
 - Detached retina causes blurry areas of vision and can lead to blindness
- **Examine retina with ophthalmoscope**
 - **Macula lutea**: patch of cells on visual axis of eye
 - **Fovea centralis**: pit in center of macula lutea
 - **Blood vessels** of the retina

The Neural Components

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(a)



(b)

a: ©Peter Dazeley/Getty Images b: ©Lisa Klancher

Figure 16.28a,b

The Neural Components

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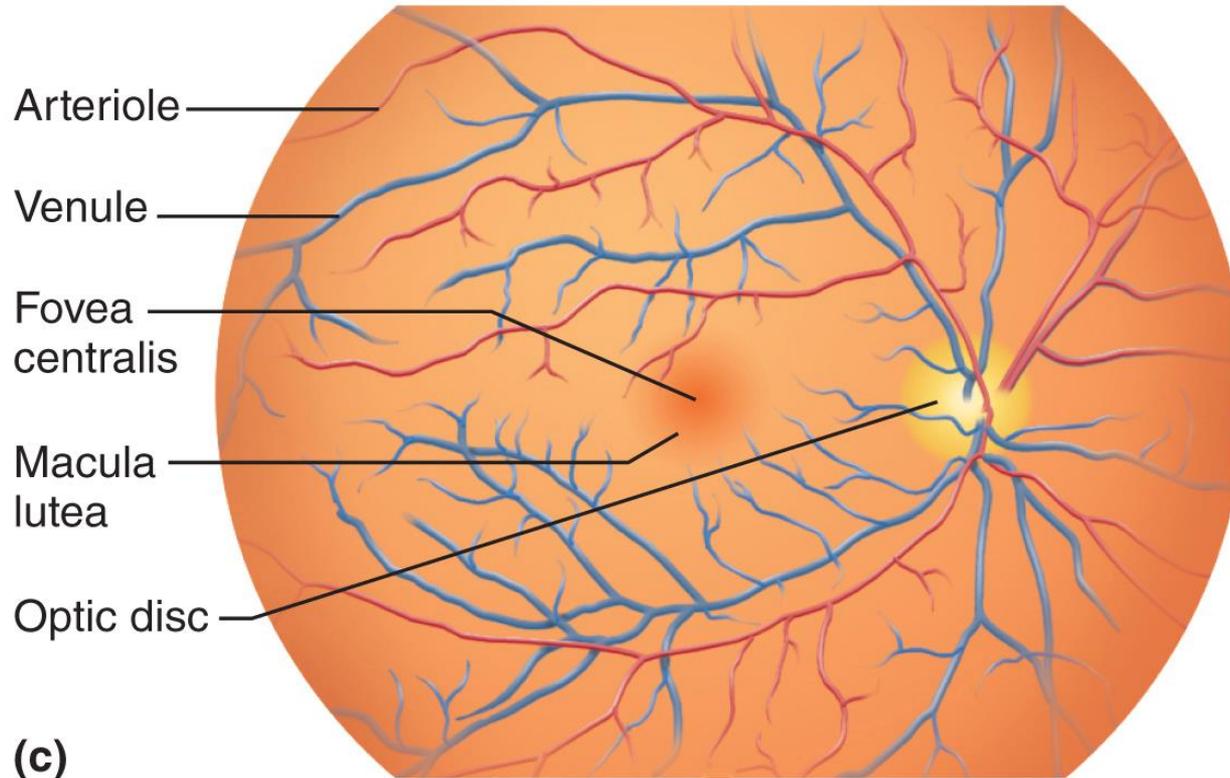


Figure 16.28c

- **Macula lutea**—patch of retina on visual axis of eye (3 mm diameter)
 - **Fovea centralis**: center of macula; finely detailed images due to packed receptor cells
- **Ophthalmoscope**—tool used to examine retina and blood vessels

The Neural Components

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Figure 16.29

- **Optic disc**—blind spot
 - Optic nerve exits retina and there are no receptors there
- **Blind spot**—use test illustration above
 - Close right eye, stare at X and red dot disappears
- **Visual filling**—brain fills in green bar across blind spot area
 - Brain ignores unavailable information until saccades (fast eye movements) redirect gaze

Cataracts and Glaucoma

- **Cataract**—clouding of lens
 - Lens fibers darken with age, fluid-filled bubbles and clefts filled with debris appear between the fibers
 - Induced by diabetes, smoking, drugs, ultraviolet radiation, and certain viruses
 - Treat by replacing natural lens with plastic one

Cataracts and Glaucoma

- **Glaucoma**—elevated pressure within the eye due to obstruction of scleral venous sinus and improper drainage of aqueous humor
 - Death of retinal cells due to compression of blood vessels and lack of oxygen
 - Illusory flashes of light are an early symptom
 - Colored halos around lights are late symptom
 - Lost vision cannot be restored
 - Intraocular pressure measured with **tonometer**

Formation of an Image

- **Light passes through lens to form tiny inverted image on retina**
- **Iris diameter** controlled by two sets of contractile elements
 - **Pupillary constrictor:** smooth muscle encircling pupil
 - **Parasympathetic** stimulation narrows pupil
 - **Pupillary dilator:** spoke-like myoepithelial cells
 - **Sympathetic** stimulation widens pupil

Formation of an Image

- **Pupillary constriction and dilation occurs:**
 - When light intensity changes
 - When gaze shifts between distant and nearby objects
- **Photopupillary reflex**—pupillary constriction in response to light
 - Mediated by autonomic reflex arc
 - Brighter light signaled to pretectal region of midbrain
 - Excites parasympathetic fibers in oculomotor nerve that travels to ciliary ganglion in orbit
 - Postganglionic parasympathetic fibers stimulate pupillary constrictor

Refraction

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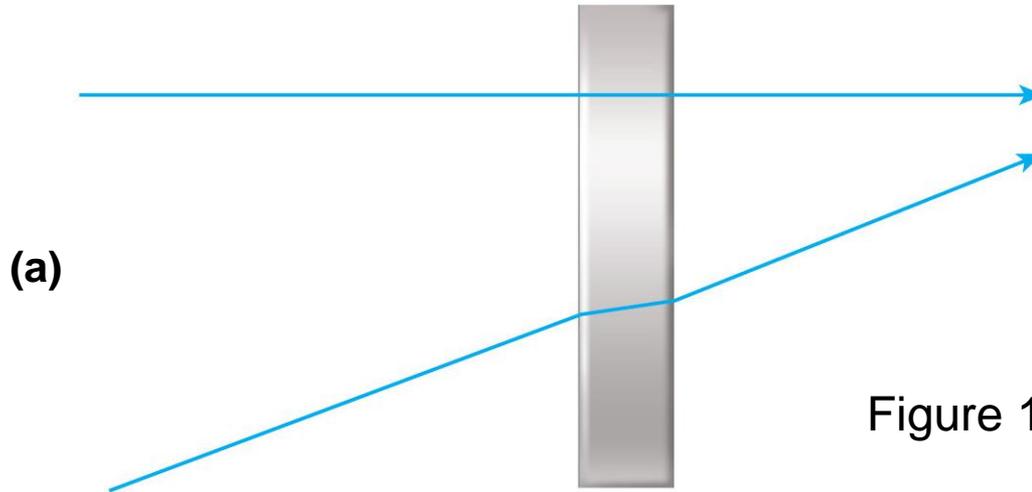


Figure 16.30a

- **Refraction**—the bending of light rays
- **Speed of light is 300,000 km/s in a vacuum, but slower in air, water, glass, or other media**
- **Refractive index** of a medium is a measure of how much it retards light rays relative to air
- **Angle of incidence** at 90° light slows but does not change course
 - Any other angle, light rays change direction (are refracted)
- **The greater the refractive index and the greater the angle of incidence, the more refraction**

Refraction

- Light passing through center of the cornea is not bent
- Light striking off-center is bent toward the center
- Aqueous humor and lens do not greatly alter the path of light
- Cornea refracts light more than lens does
 - Lens merely fine-tunes image
 - Lens becomes rounder to increase refraction for near vision

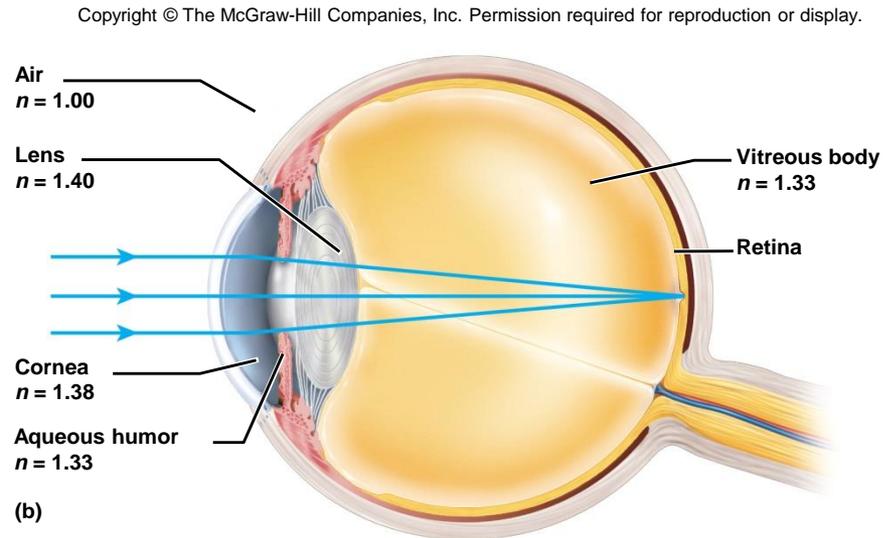


Figure 16.30b

The Near Response

- **Emmetropia**—state in which eye is relaxed and focused on an object more than 6 m (20 ft) away
 - Light rays coming from that object are essentially parallel
 - Rays focused on retina without effort
- **Light rays coming from a closer object are too divergent to be focused without effort**

The Near Response

- **Near response**—adjustment to close-range vision requires three processes
 - **Convergence of eyes**
 - Eyes orient their visual axis toward object
 - **Constriction of pupil**
 - Blocks peripheral light rays and reduces spherical aberration (blurry edges)
 - **Accommodation of lens:** change in the curvature of the lens that enables you to focus on nearby objects
 - Ciliary muscle contracts, suspensory ligaments slacken, and lens takes more convex (thicker) shape
 - Light refracted more strongly and focused onto retina
 - **Near point of vision**—closest an object can be and still come into focus (lengthens with age)

The Near Response

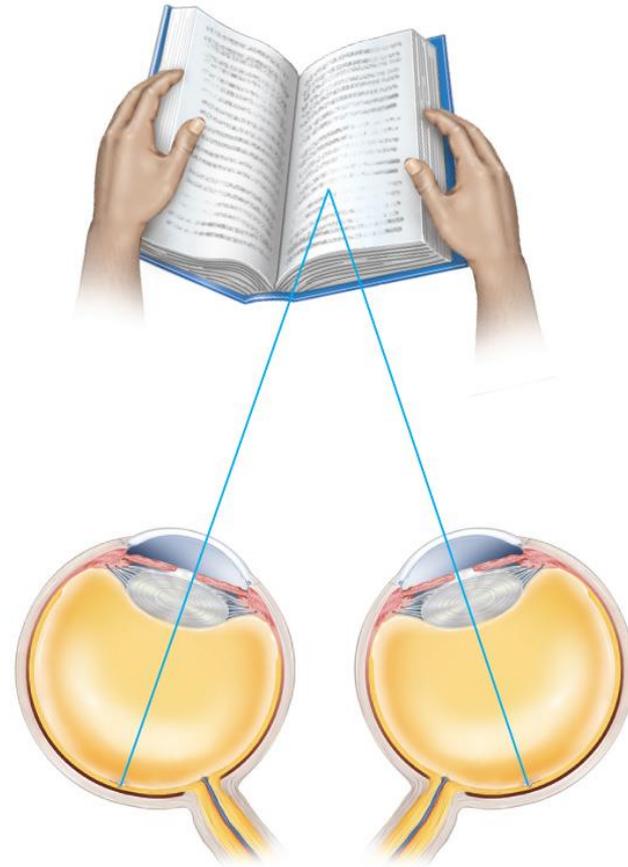
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(a)

Emmetropia

Distant object



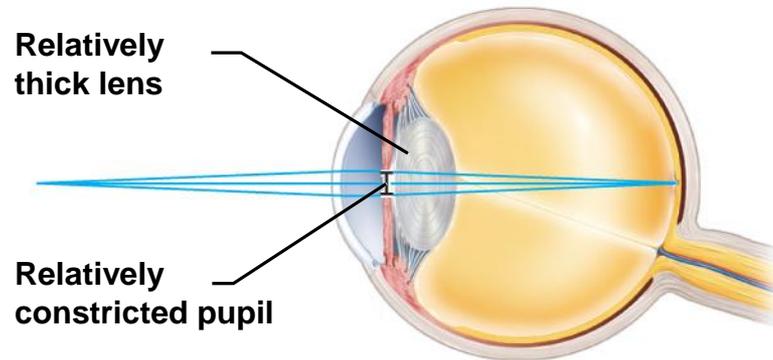
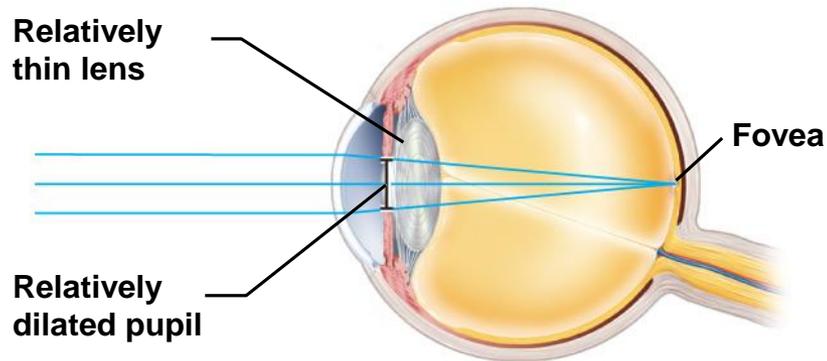
Convergence

Close object

Figure 16.31a

The Near Response

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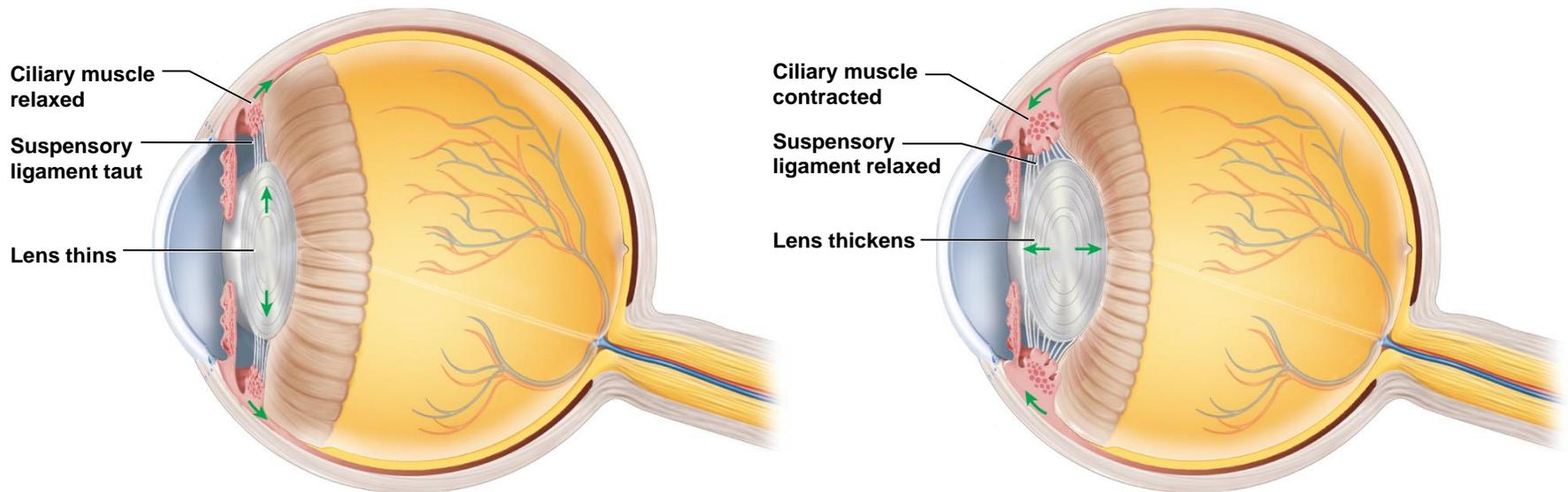


(b) Pupillary miosis and lens accommodation

Figure 16.31b

The Near Response

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(a) Distant vision (emmetropia)

(b) Near vision (accommodation)

Lens flatter

Lens thicker

Figure 16.32a,b

Common Defects of Image Formation

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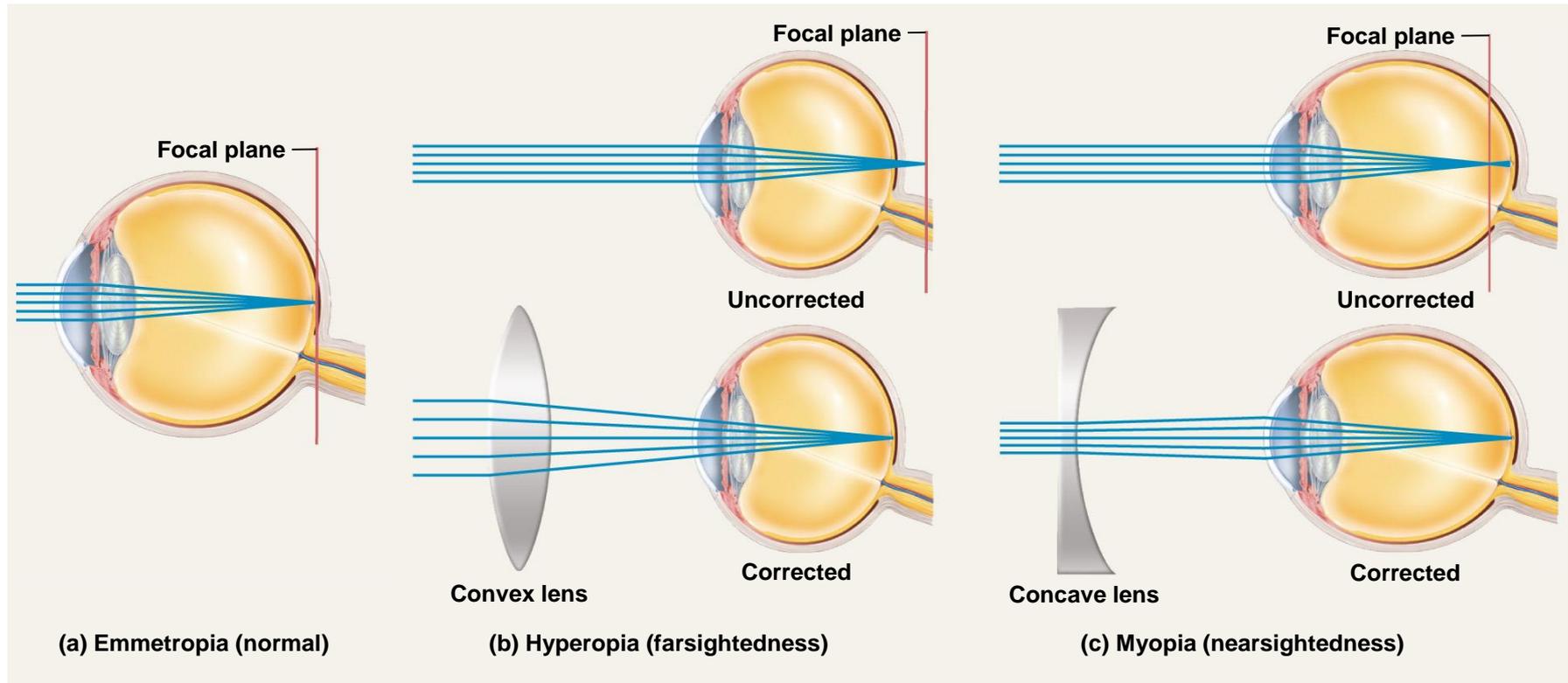


Figure 16.33

Sensory Transduction in the Retina

- **Retina converts light energy into action potentials**
- **Structure of retina**
 - **Pigment epithelium:** most posterior part of retina
 - Absorbs stray light so visual image is not degraded
 - **Neural components** of retina (from rear forward)
 - **Photoreceptor cells**—absorb light and generate a chemical or electrical signal
 - Rods, cones, and certain ganglion cells
 - Only rods and cones produce visual images
 - **Bipolar cells**—(first-order neurons) have dendrites that synapse with rods and cones and axons that synapse with ganglion cells
 - **Ganglion cells**—(second-order neurons) are largest neurons in the retina and are arranged in a single layer next to the vitreous body

Sensory Transduction in the Retina

- **Light-absorbing cells**
 - Rods and cones derive from same stem cells as ependymal cells of brain
- **Rod cells (night, or scotopic, vision or monochromatic vision)**
 - **Outer segment:** modified cilium specialized to absorb light
 - Stack of 1,000 membranous discs studded with globular protein, the visual pigment **rhodopsin**
 - **Inner segment:** contains organelles sitting atop cell body with nucleus

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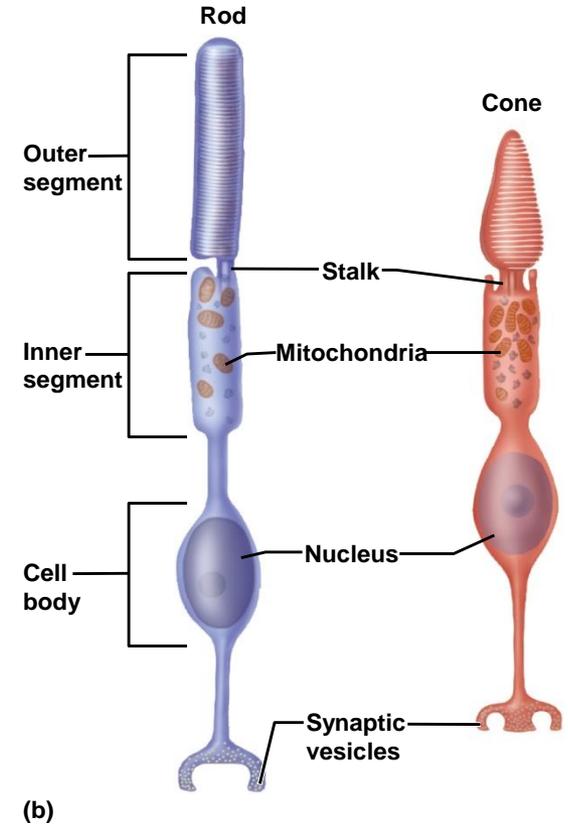


Figure 16.35b

Sensory Transduction in the Retina

- **Cone cell (color, photopic, or day vision)**
 - Similar to rod except:
 - Outer segment tapers to a point
 - Discs with pigment are plasma membrane infoldings (not detached)

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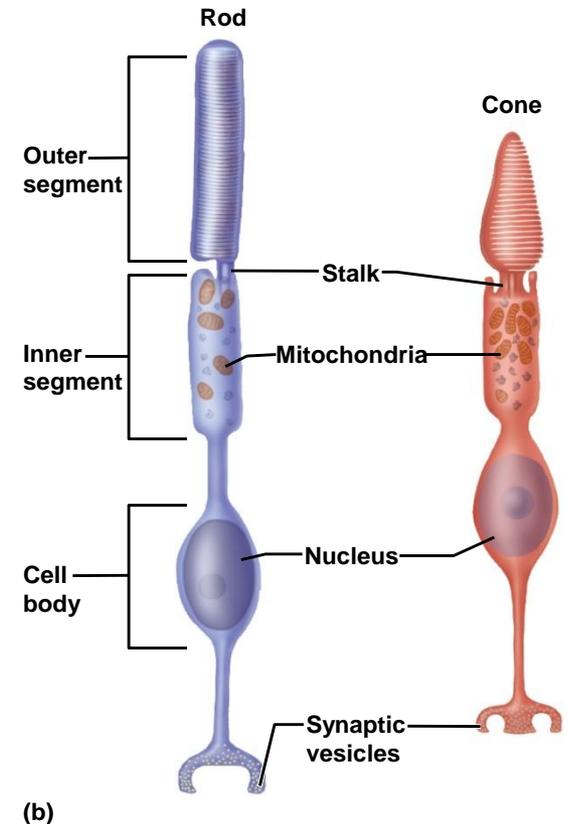


Figure 16.35b

Sensory Transduction in the Retina

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Back of eye



(a)

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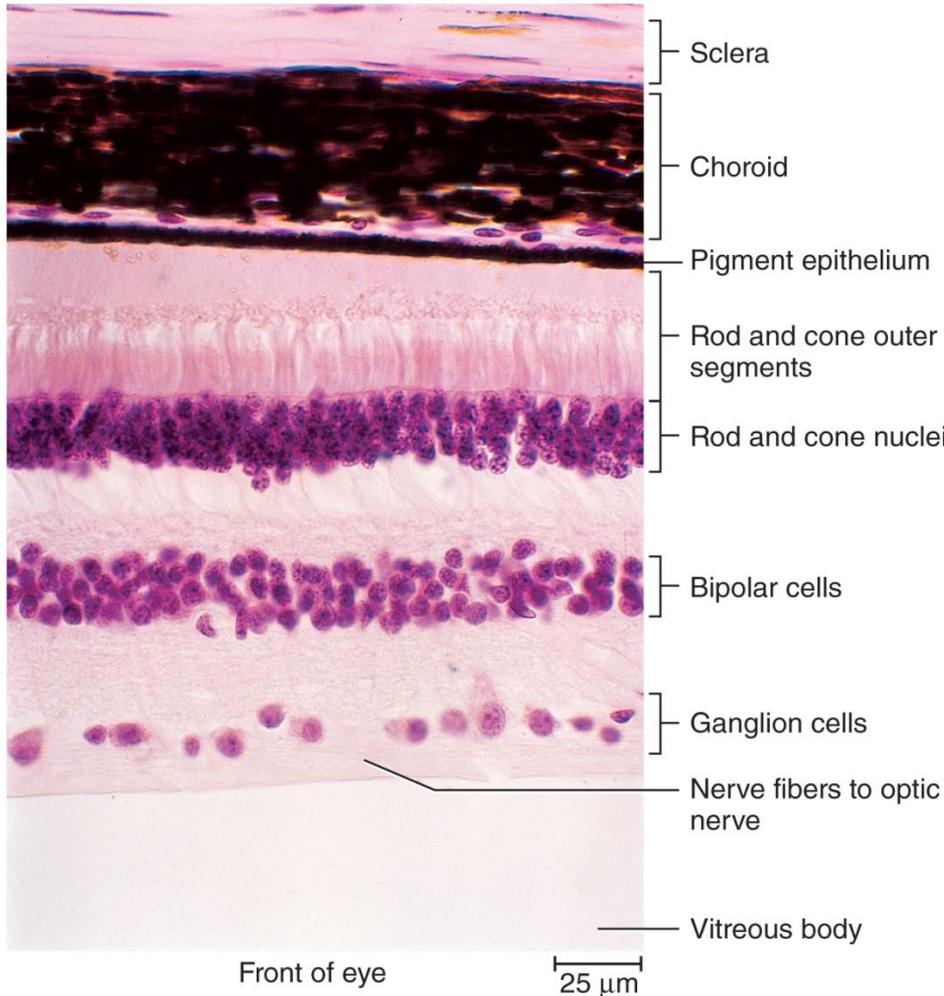
Figure 16.34a

- **Histology of the retina**
 - Pigment epithelium
 - Rod and cone cells
 - Bipolar cells
 - Rods and cones synapse on bipolar cells
 - Bipolar cells synapse on ganglion cells

Sensory Transduction in the Retina

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Back of eye



Front of eye

25 μm

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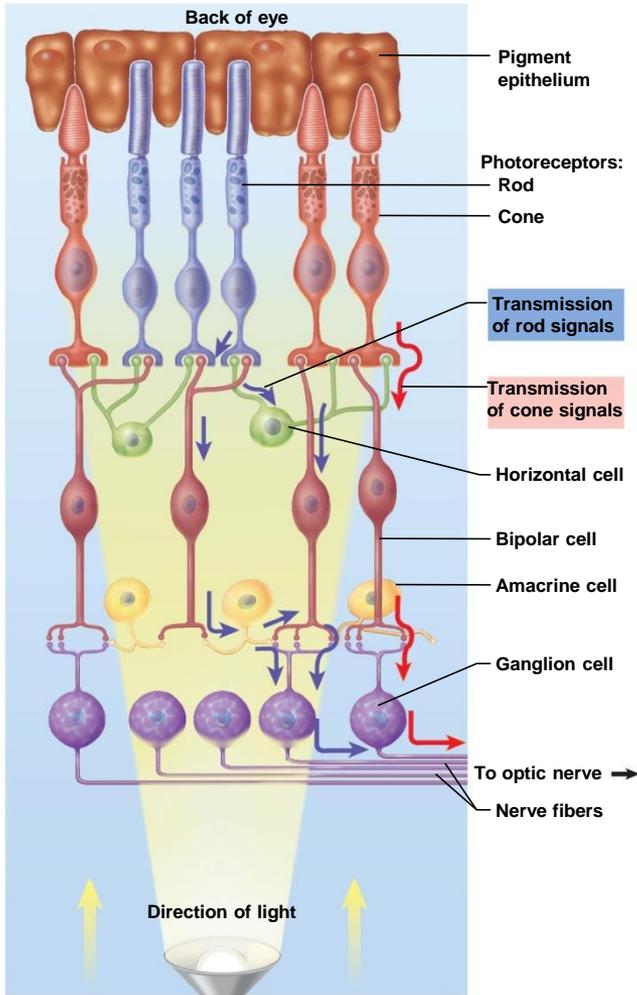
Figure 16.34a

– Ganglion cells

- Single layer of large neurons near vitreous
- Axons form optic nerve
- Some absorb light with pigment melanopsin and transmit signals to brainstem
 - Detect light intensity for pupil control and circadian rhythms; do not contribute to visual image

Sensory Transduction in the Retina

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- **130 million rods and 6.5 million cones in retina**
- **Only 1.2 million nerve fibers in optic nerve**
- **Neuronal convergence** and information processing in retina before signals reach brain
 - Multiple rod or cone cells synapse on one bipolar cell
 - Multiple bipolar cells synapse on one ganglion cell

(b)

Figure 16.34b

Sensory Transduction in the Retina

- **Horizontal cells** and **amacrine cells** are present, but do not form separate layers within retina
- **Horizontal and amacrine cells form horizontal connections between cone, rod, and bipolar cells**
 - Enhance perception of contrast, edges of objects, moving objects, and changes in light intensity
- Much of the mass of the retina is **astrocytes** and other **glial cells**

Visual Pigments

- **Rods** contain visual pigment **rhodopsin (visual purple)**
 - Two major parts of molecule
 - **Opsin**—protein portion embedded in disc membrane of rod's outer segment
 - **Retinal (retinene)**—a vitamin A derivative
 - Has absorption peak at wavelength of 500 nm
 - Rods cannot distinguish one color from another

Visual Pigments

- **Cones** contain **photopsin (iodopsin)**
 - **Retinal moiety** same as in rods
 - **Opsin moiety** contains different amino acid sequences that determine wavelengths of light absorbed
 - Three kinds of cones, identical in appearance, but absorb different wavelengths of light to produce color vision

Visual Pigments

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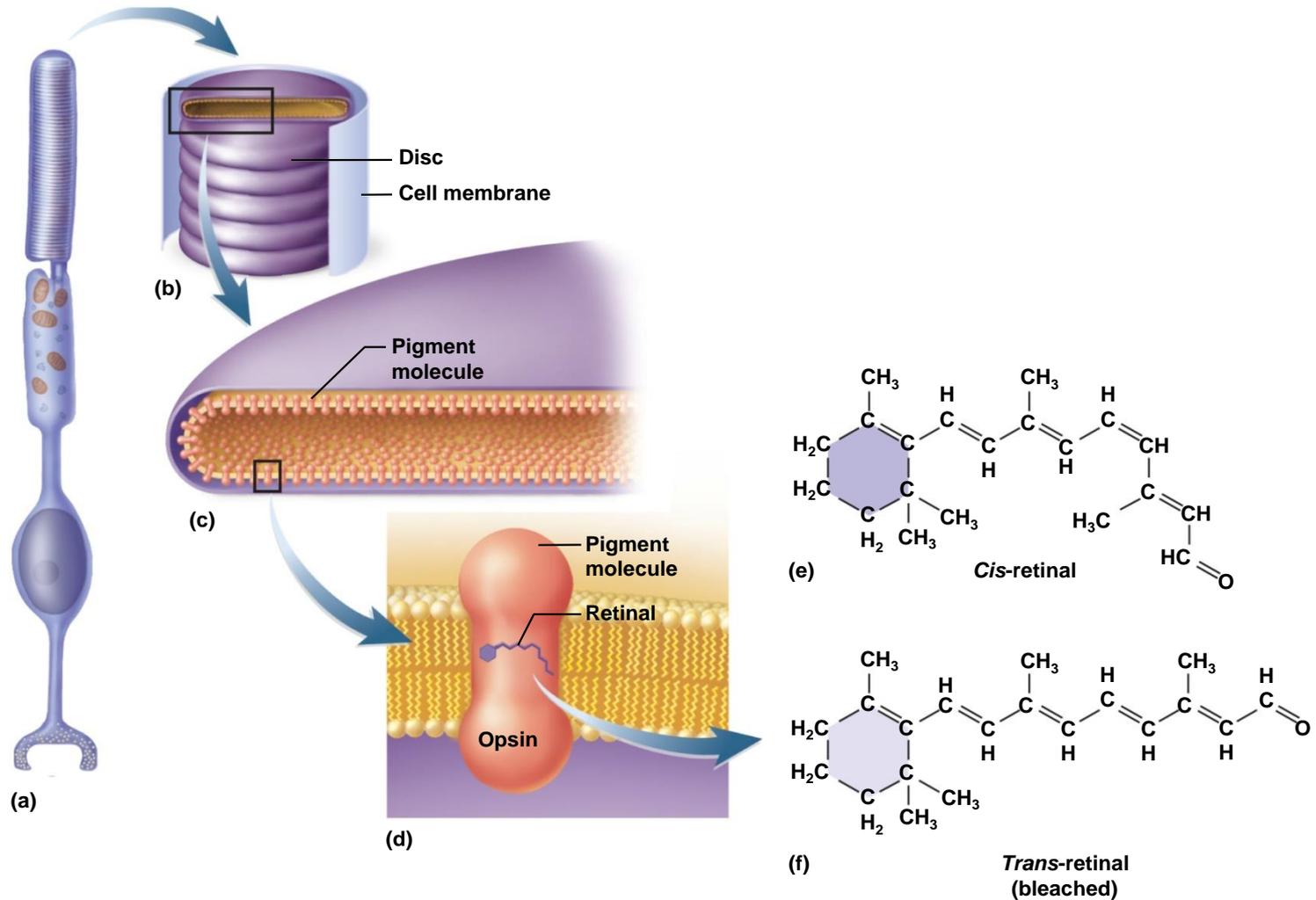


Figure 16.36a-f

Generating the Optic Nerve Signal

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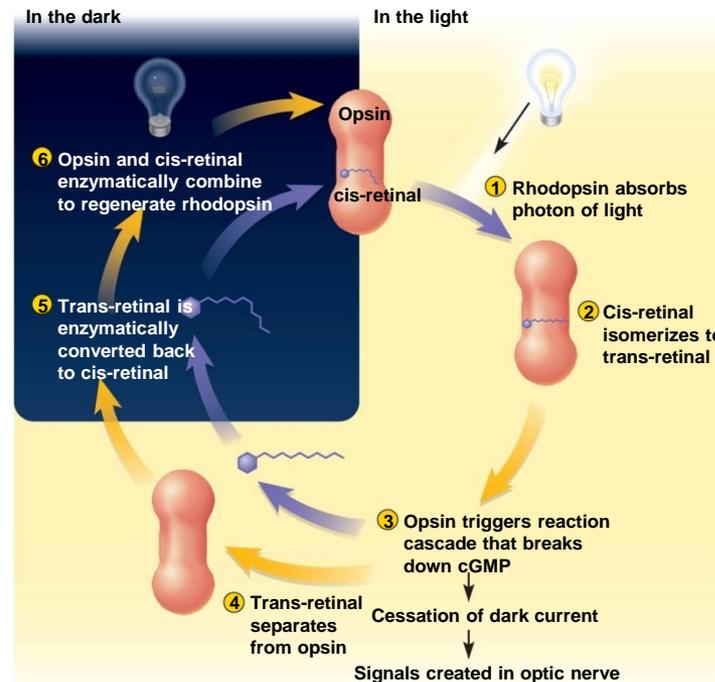


Figure 16.37

- **Light changes rhodopsin:**
 - In dark, retinal is bent (*cis*-retinal) and retinal and opsin are together
 - In light, retinal molecule straightens (*trans*-retinal), and retinal dissociates from opsin (bleaching)
 - To reset, it takes five minutes to regenerate 50% of bleached rhodopsin
- **Cones function similarly**
 - But are faster to regenerate their photopsin—90 seconds for 50%

Generating Visual Signals

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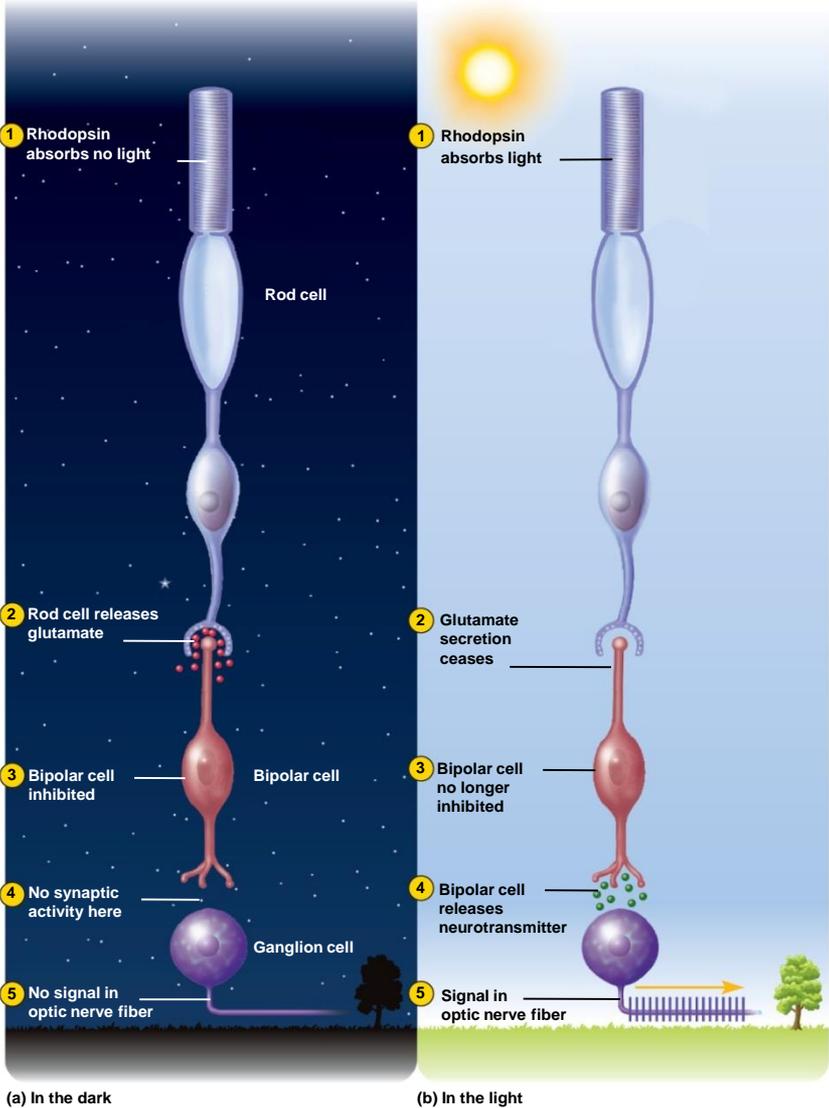


Figure 16.38

Generating the Optic Nerve Signal

- **In dark, rods steadily release the neurotransmitter glutamate from basal end of cell**
- **When rods absorb light, glutamate secretion ceases**
- **Bipolar cells are sensitive to these on and off pulses of glutamate secretion**
 - Some bipolar cells inhibited by glutamate and excited when secretion stops
 - These cells excited by rising light intensities
 - Other bipolar cells are excited by glutamate and respond when light intensity drops

Generating the Optic Nerve Signal

- **When bipolar cells detect fluctuations in light intensity, they stimulate ganglion cells directly or indirectly**
- **Ganglion cells are the only retinal cells that produce action potentials**
- **Ganglion cells respond to the bipolar cells with rising and falling firing frequencies**
- **Via optic nerve, these changes provide visual signals to the brain**

Light and Dark Adaptation

- **Light adaptation** (walk out into sunlight)
 - Pupil constriction reduces light intensity (and any discomfort that may accompany sudden brightness)
 - Color vision and acuity below normal for 5 to 10 minutes
 - Time needed for pigment bleaching to adjust retinal sensitivity to high light intensity
 - Rods quickly bleach and become nonfunctional; cones take over
- **Dark adaptation** (turn lights off)
 - Dilation of pupils occurs
 - In the dark, rhodopsin of rods is regenerated
 - In 1 to 2 minutes, night (scotopic) vision begins to function
 - After 20 to 30 minutes, amount of regenerated rhodopsin is sufficient for eyes to reach maximum sensitivity

The Dual Visual System

- **Duplicity theory of vision** explains why we have both rods and cones
 - A single type of receptor cannot produce both high sensitivity and high resolution
- **It takes one type of cell and neural circuit for sensitive night vision**
- **It takes a different cell type and neuronal circuit for high-resolution daytime vision**

The Dual Vision System

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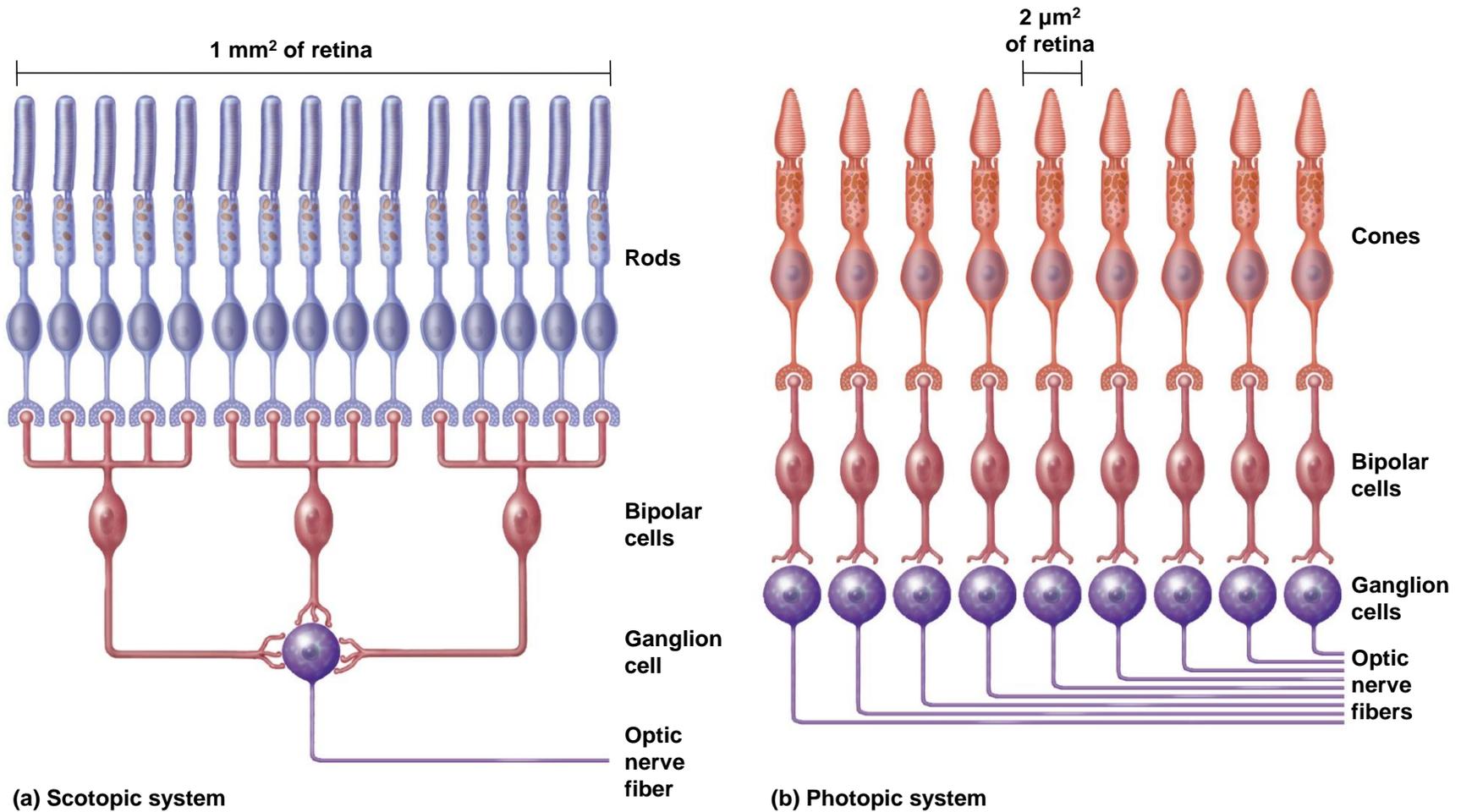


Figure 16.39a,b

The Dual Visual System

- **Rods sensitive—react even in dim light**
 - Extensive neuronal convergence
 - 600 rods converge on one bipolar cell
 - Many bipolar cells converge on each ganglion cell
 - Results in high degree of spatial summation
 - One ganglion cell receives information from 1 mm² of retina producing only a coarse image
- **Edges of retina have widely spaced rod cells that act as motion detectors**
 - Low-resolution system only
 - Cannot resolve finely detailed images

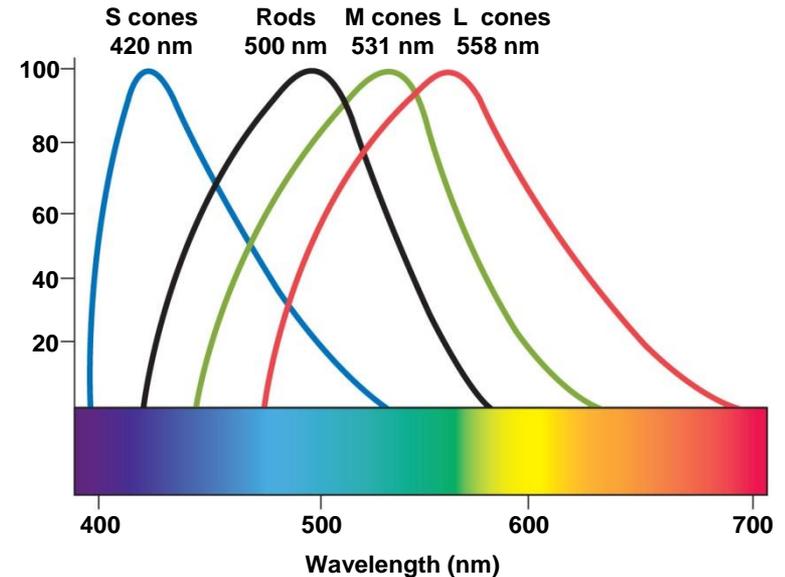
The Dual Visual System

- **Fovea contains only 4,000 tiny cone cells (no rods)**
 - No neuronal convergence
 - Each foveal cone cell has “private line to brain”
- **High-resolution color vision**
 - Little spatial summation: less sensitivity to dim light

Color Vision

- **Primates have well-developed color vision**
 - Nocturnal vertebrates have only rods
- **Three types of cones are named for absorption peaks of their photopsins**
 - **Short-wavelength (S) cones** peak sensitivity at 420 nm
 - **Medium-wavelength (M) cones** peak at 531 nm
 - **Long-wavelength (L) cones** peak at 558 nm

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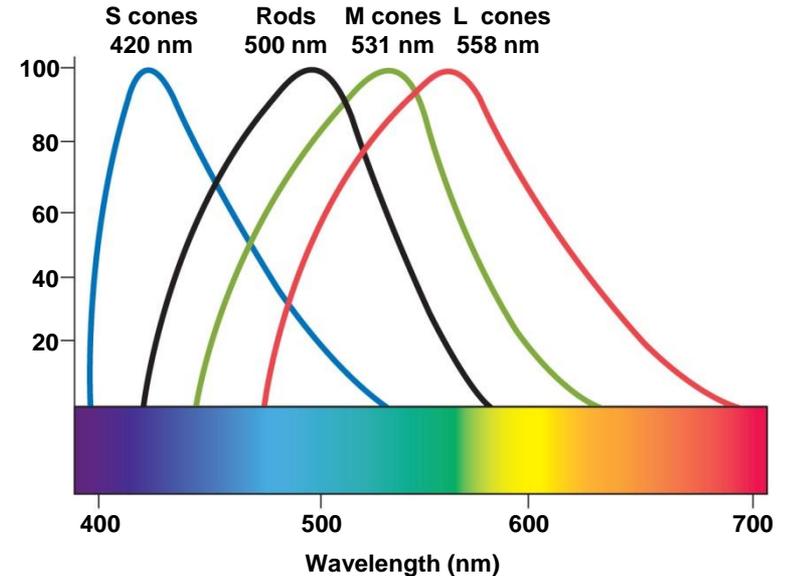
Wavelength (nm)	Percentage of maximum cone response (S : M : L)	Perceived hue
400	50 : 0 : 0	Violet
450	72 : 30 : 0	Blue
500	20 : 82 : 60	Blue-green
550	0 : 85 : 97	Green
625	0 : 3 : 35	Orange
675	0 : 0 : 5	Red

Figure 16.40

Color Vision

- **Color perception** based on mixture of nerve signals representing cones of different absorption peaks

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Wavelength (nm)	Percentage of maximum cone response (S : M : L)	Perceived hue
400	50 : 0 : 0	Violet
450	72 : 30 : 0	Blue
500	20 : 82 : 60	Blue-green
550	0 : 85 : 97	Green
625	0 : 3 : 35	Orange
675	0 : 0 : 5	Red

Figure 16.40

Color Vision

- **Color blindness**—have a hereditary alteration or lack of one photopsin or another
- **Most common is red–green color blindness**
 - Results from **lack of either L or M cones**
 - Causes difficulty distinguishing these related shades from each other
 - Occurs in 8% of males, 0.5% of females (sex linkage)

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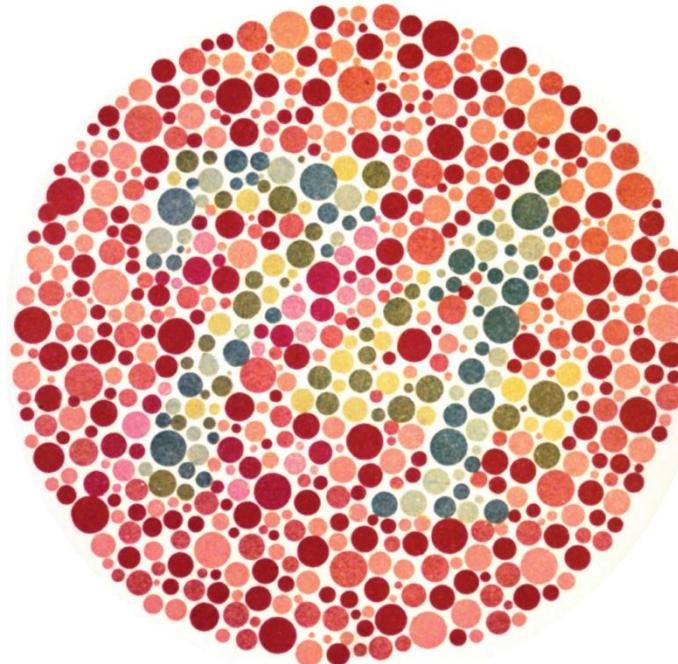


Figure 16.41

Stereoscopic Vision

- **Stereoscopic vision** is depth perception—ability to judge distance to objects
 - Requires two eyes with overlapping visual fields which allows each eye to look at the same object from different angles
 - Unlike **panoramic vision**—having eyes on sides of head (horse or rodents are alert to predators but have no depth perception)

Stereoscopic Vision

- **Fixation point**—point in space on which the eyes are focused
 - Looking at object within 100 feet, each eye views from slightly different angle
 - Provides brain with information used to judge position of objects relative to fixation point

Stereoscopic Vision

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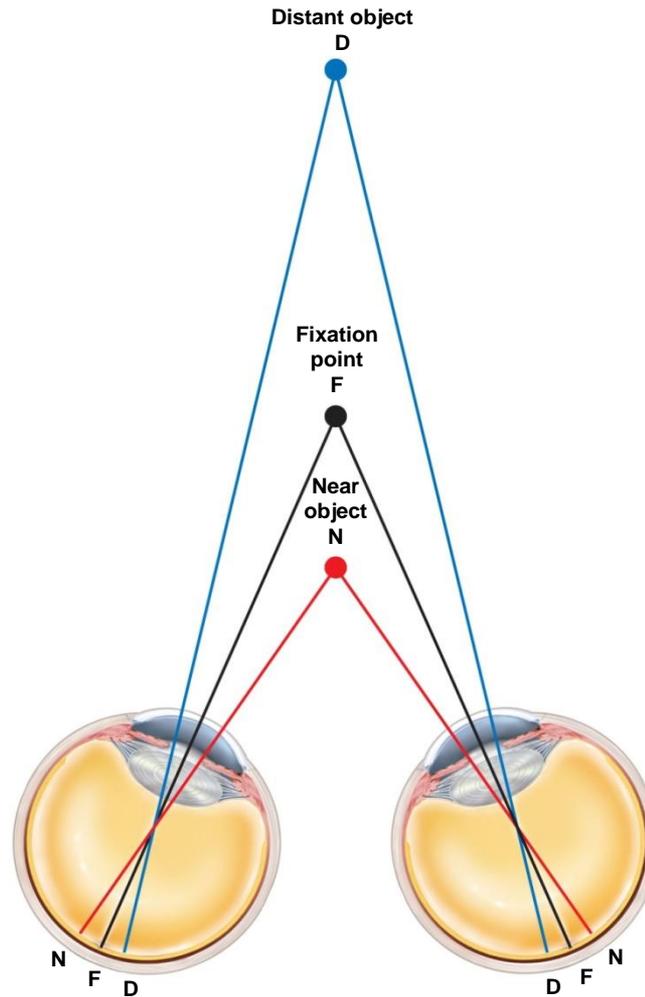


Figure 16.42

The Visual Projection Pathway

- Bipolar cells of retina are **first-order neurons**
- Retinal ganglion cells are **second-order neurons** whose axons form optic nerve
 - Two optic nerves combine to form **optic chiasm**
 - Half the fibers cross over to the opposite side of the brain (**hemidecussation**) and chiasm splits to form **optic tracts**
 - Right cerebral hemisphere sees objects in left visual field because their images fall on the right half of each retina
 - Each side of brain sees what is on side where it has motor control over limbs

The Visual Projection Pathway

- **Optic tracts** pass laterally around the hypothalamus with most of their axons ending in the lateral **geniculate nucleus** of the **thalamus**
- Third-order neurons arise here and form the **optic radiation** of fibers in the white matter of the cerebrum
 - Project to **primary visual cortex of occipital lobe** where conscious visual sensation occurs
 - A few optic nerve fibers project to **midbrain** and terminate in the superior colliculi and pretectal nuclei
 - **Superior colliculi** controls visual reflexes of extrinsic eye muscles
 - **Pretectal nuclei** are involved in photopupillary and accommodation reflexes

The Visual Projection Pathway

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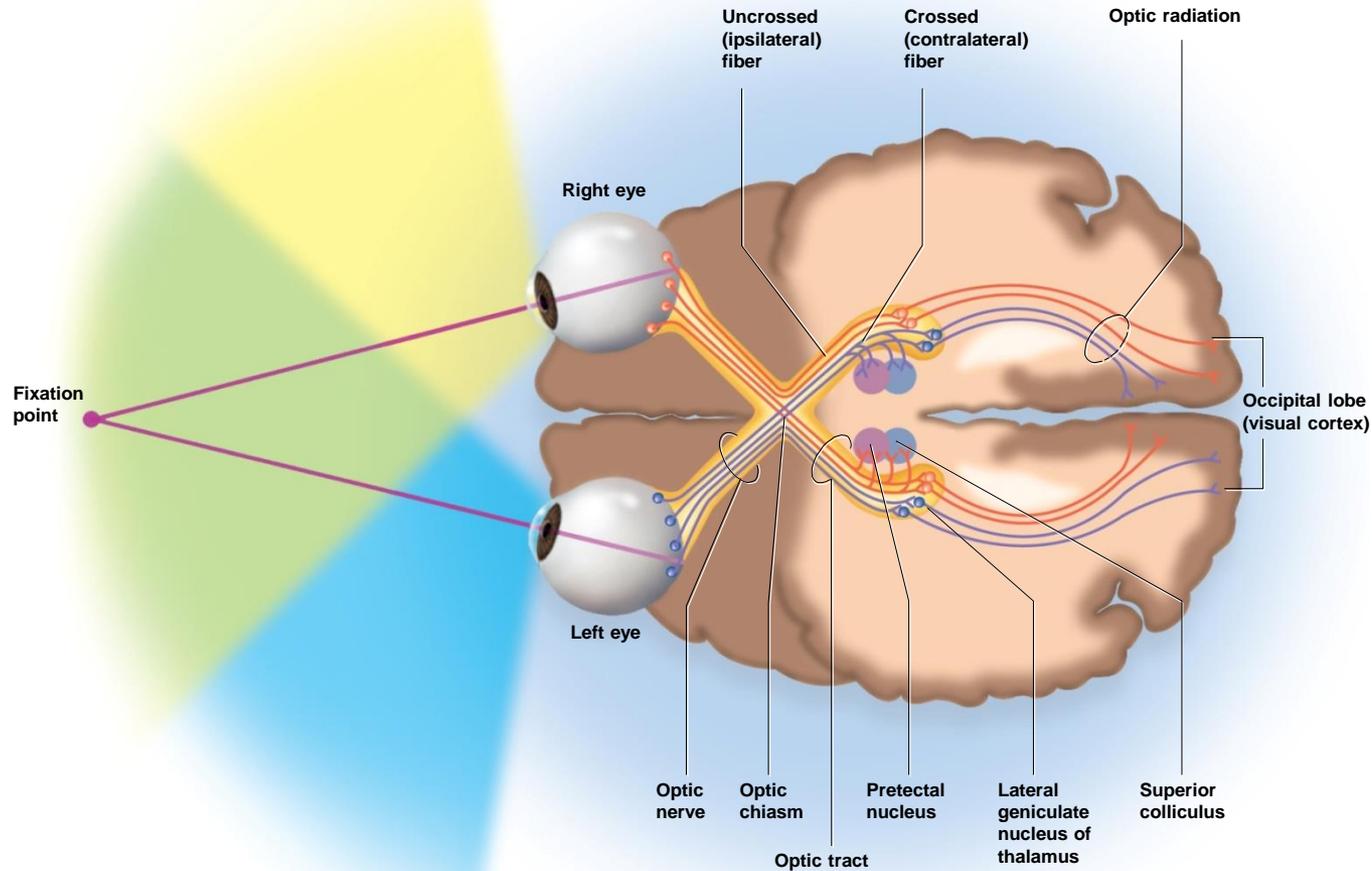


Figure 16.43

The Visual Projection Pathway

- **Some processing begins in retina**
 - Adjustments for contrast, brightness, motion, and stereopsis
- **Primary visual cortex** is connected by association tracts to **visual association areas** in parietal and temporal lobes which process retinal data from occipital lobes
 - Object location, motion, color, shape, boundaries
 - Store visual memories (recognize printed words)