NOTES
SENSORY NERVOUS SYSTEM

SENSORY RECEPTOR FUNCTION

osms.it/sensory-receptor-function

- 1st order neurons carry information from somatosensory receptors
  - *Pseudounipolar*: no separate dendrites, axons
  - Single axon splits into central branch, peripheral branch
  - Peripheral branch goes from cell body in dorsal root ganglia to receptive field on peripheral tissue
  - Small receptive field = ↑ resolution
  - Large receptive field = ↓ resolution
  - Ion channels open, close in response to stimulus → membrane depolarizes → voltage gated channels open → triggers action potential
  - To prevent multiple neurons firing, neurons have inhibitory interneurons, AKA lateral inhibition
  - Stimulus strength, duration determined by frequency of nerve firing
- *Adaption:* fewer signals sent in response to same stimulus over time
  - *Fast adapting/phasic*: high sensitivity; falls off quickly
  - *Slow adapting/tonic*: constant sensitivity

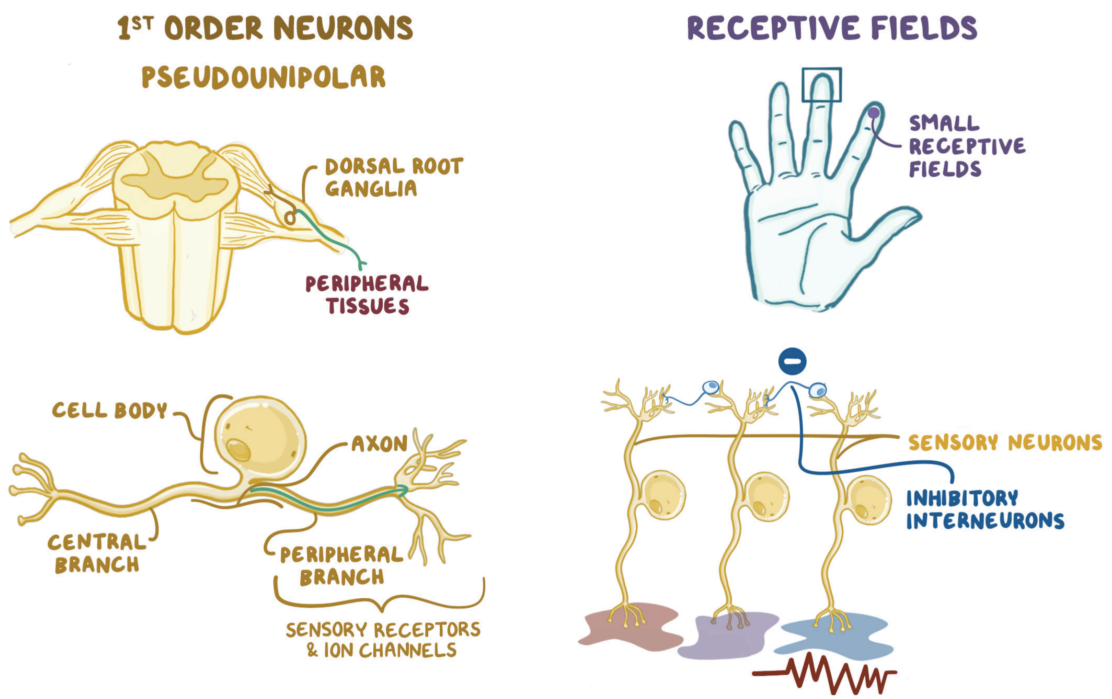

Figure 55.1 Features of 1st order neurons and lateral inhibition. Interneurons suppress activity of the neurons next to one that has received a stimulus (lateral inhibition) → pin points stimulus by defining its boundaries.

SOMATOSENSORY PATHWAYS

osms.it/somatosensory-pathways

- *Somatic senses*: touch, proprioception, pain, temperature
- Types of somatosensory fibers
  - *Non-myelinated fibers (type C)*: slowest; sense burning pain, hot temperature
  - *Small myelinated fibers (type Aδ)*: faster; sense sharp pain, gross touch, cold temperature
  - *Large myelinated fibers (type A-α; A-β)*: fastest; sense proprioception, vibration, fine touch

SOMATOSENSORY PATHWAYS

- Carry somatosensory input up spinal cord to brain
- Consist of 4-neuron relay
  - *1st order neuron/afferent sensory neuron*: has sensory receptors, converts stimuli into impulse
  - *2nd order neuron*: cell body in spinal cord or brainstem, synapses with 3rd-order neuron
  - *3rd order neuron*: cell body in thalamus, sends signal to somatosensory cortex
  - *4th order neuron/cortical neuron*: cell body in sensory cortex
- Includes medial lemniscal/posterior pathway, spinothalamic/anterolateral pathway

MEDIAL LEMNISCAL PATHWAY

- Carries information about fine touch, proprioception
- Large myelinated fibers of 1st order neurons run to spinal cord
- Neurons run through posterior/dorsal funiculus of spinal cord
  - Via cuneate fascicle for arms, chest
  - Via gracilis fascicle for trunk, legs
- 1st, 2nd order neurons synapse in medulla
  - 1st synapse
- 2nd order neurons run to medial lemniscus, decussate; run through pons, midbrain to the thalamus
- 2nd, 3rd order neurons synapse in thalamus
  - 2nd synapse
- 3rd order neurons run to sensory cortex in parietal lobe
- 3rd, 4th order neurons synapse in sensory cortex
  - 3rd synapse
- Some 1st order neurons synapse with interneurons at posterior horn
  - Axons run to anterior horn, synapse directly with motor neuron
  - Important for reflexes

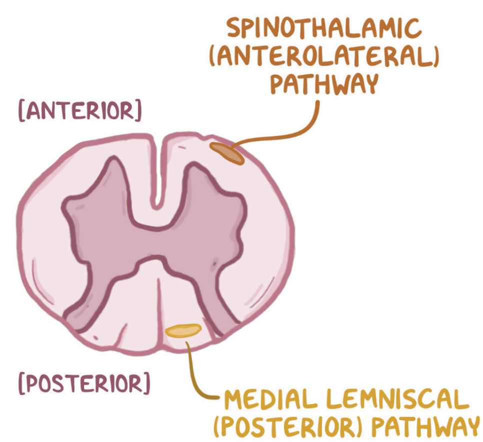

Figure 55.2 The two somatosensory pathways.

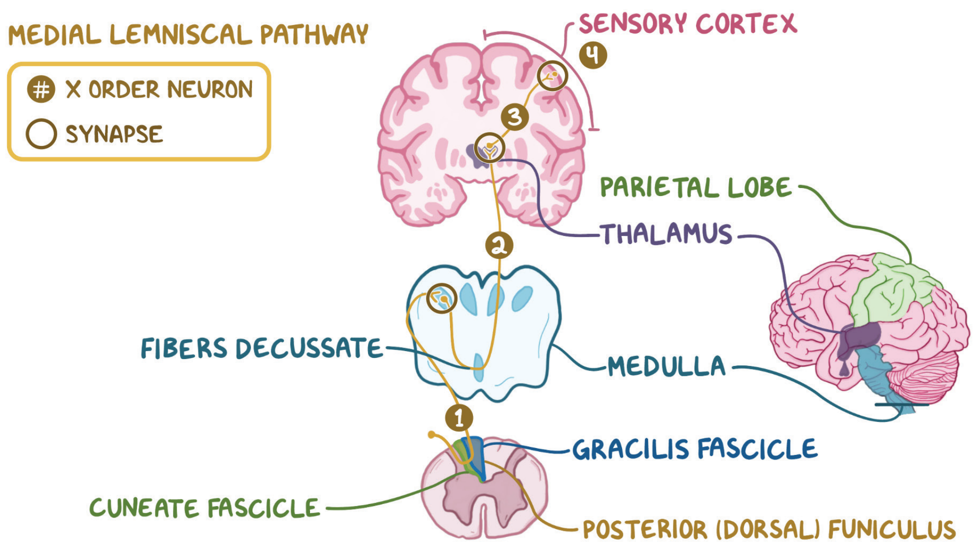

Figure 55.3 The medial lemniscal pathway carries information about fine touch and proprioception. It includes three synapses between four neurons.

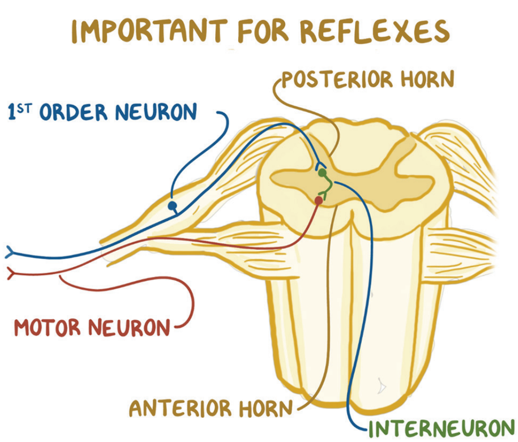

Figure 55.4 Reflex pathway occurs at the level of the spinal cord: 1st order neuron synapses with an interneuron, which synapses with a motor neuron.

SPINOTHALAMIC PATHWAY

- Carries information about pain, temperature, crude touch
- Small/non-myelinated fibers of 1st order neurons run to spinal cord
  - *Small myelinated fibers*: sharp pain, cold temperature
  - *Non-myelinated fibers*: hot temperature, burning pain, crude touch
- 1st, 2nd order neurons synapse in posterior horn of spinal cord/1st synapse
  - *Small myelinated fibers*: enter through dorsal root, bend upwards, travel through two vertebral segments
  - *Non-myelinated fibers*: follow same pathway but synapse with interneurons first, AKA before reaching posterior horn
- 2nd order neurons decussate, cross to anterior horn through central canal
- Neurons then carried through one of two tracts to thalamus
  - *Lateral tract*: carries information for pain, pressure, temperature through lateral funiculus
  - *Anterior tract:* carries information for crude touch through anterior funiculus
- 2nd, 3rd order neurons synapse in thalamus/2nd synapse
- 3rd order neurons run to sensory cortex in parietal lobe
- 3rd, 4th order neurons synapse in sensory cortex/3rd synapse

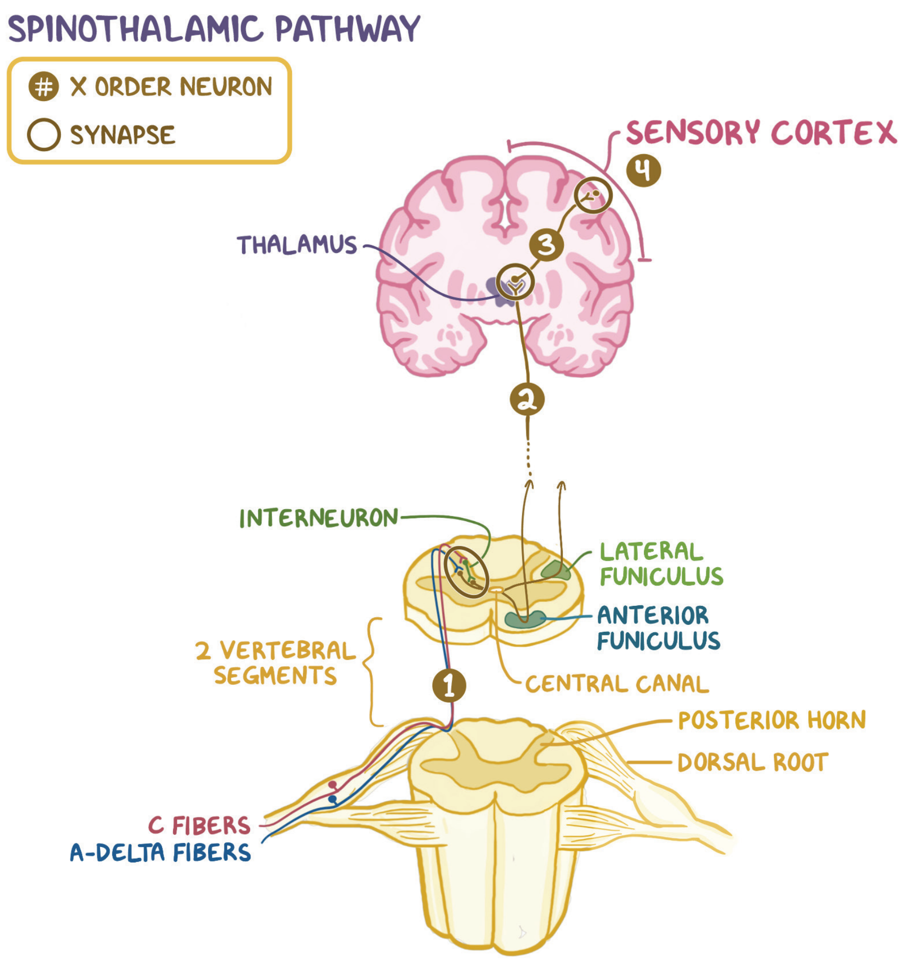

Figure 55.5 The spinothalamic pathway carries information about pain, temperature, and crude touch. It includes three synapses between four neurons. The 1st order C fibers synapse with an interneuron, which then synapses with the 2nd order neuron.

SOMATOSENSORY RECEPTORS

osms.it/somatosensory-receptors

- Perceive general somatic senses
- Include mechanoreceptors, AKA both mechanosensors and proprioceptors, thermoreceptors, nociceptors

MECHANOSENSORS

- Used for touch; several types

Meissner/tactile corpuscles

- Sensitive to light touch
- Encapsulated; located in dermis of hairless skin
- Fast adapting; small receptive fields

Merkel (tactile) discs

- Sensitive to pressure
- Non-encapsulated; located in epidermis of hairless skin
- Slow adapting; small receptive fields

Ruffini (bulbous) corpuscles

- Sensitive to skin stretching
- Encapsulated; located in dermis of all skin
- Slow adapting; big receptive fields

Pacinian (lamellar) corpuscles
- Sensitive to vibration
- Encapsulated; located deep in dermis/ subcutaneous tissue of all skin
- Fast adapting; big receptive fields

PROPRIOCEPTORS
- Used for proprioception; several types

Muscle spindle
- Detect when muscle stretched
- Located throughout perimysium, AKA connective tissue around muscle cells

Golgi tendon organ
- Detect when tendon stretched
- Located in tendons close to muscle insertion

Joint receptors
- Detect joint position, motion
- Located in joint

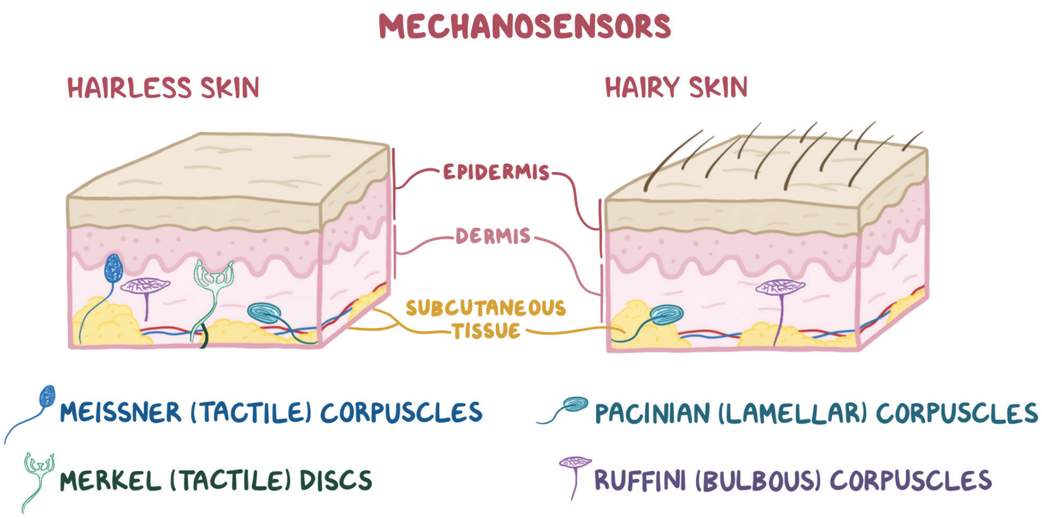

Figure 55.6 The four types of mechanosensors. Only Pacinian and Ruffini corpuscles are present in all kinds of skin (hairless and hairy).

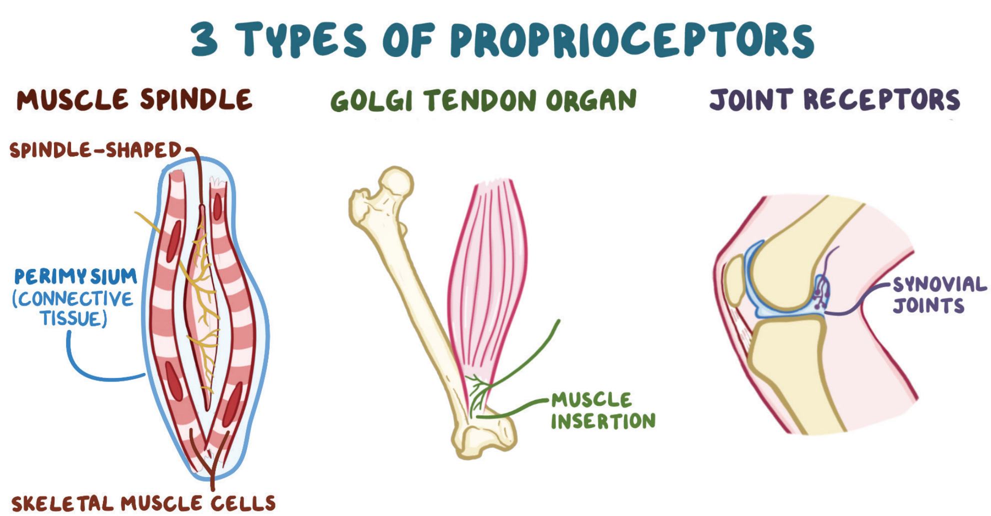

Figure 55.7 The three types of proprioceptors.

THERMORECEPTORS

- Used for temperature
- Transient receptor potential channels mediate sensations
  - Transduction of heat involves TRPV channels; activated at 32–48°C/90–118°F
  - Transduction of cold involves TRPM8; activated at 10–40°C/ 50–104°F
- At extremely cold/hot temperatures, nociceptors take over

NOCICEPTORS

- Used for pain; several types
  - *Thermals*: sense extremely cold/hot temperatures
  - *Mechanical*: sense excess pressure/ deformation
  - *Polymodal*: Sense combination of both

PHOTORECEPTION

osms.it/photoreception

- Process by which rods, cones convert light waves into electrical signals
- *Photoreceptors*: modified neurons, AKA rods/cones
  - *Have outer segment:* detects light
  - Inner segment: cell body
  - *Synaptic terminal:* connects to interneurons
- Photoreceptors located in retina
- 10 retina layers; numbered from deepest outwards
  - Pigment epithelium
  - Photoreceptor
  - Outer limiting membrane
  - Outer nuclear
  - Outer plexiform
  - Inner nuclear
  - Inner plexiform
  - Ganglion cell
  - Nerve fiber
  - Inner limiting membrane

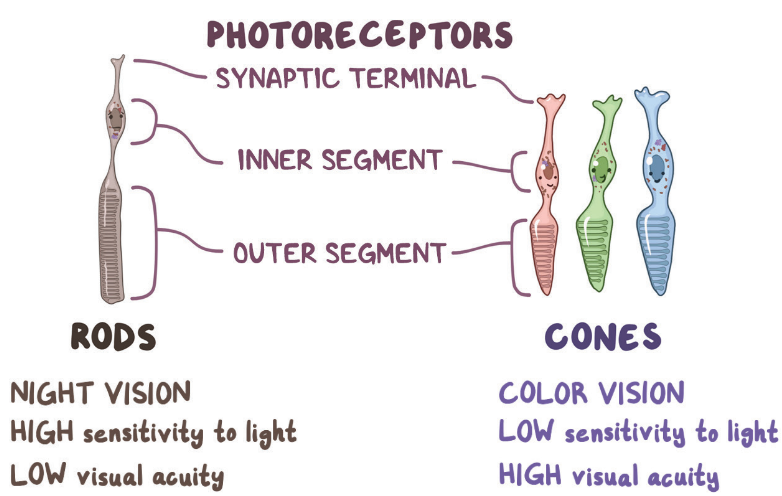

Figure 55.8 The two types of photoreceptors (rods and cones) and their main features.

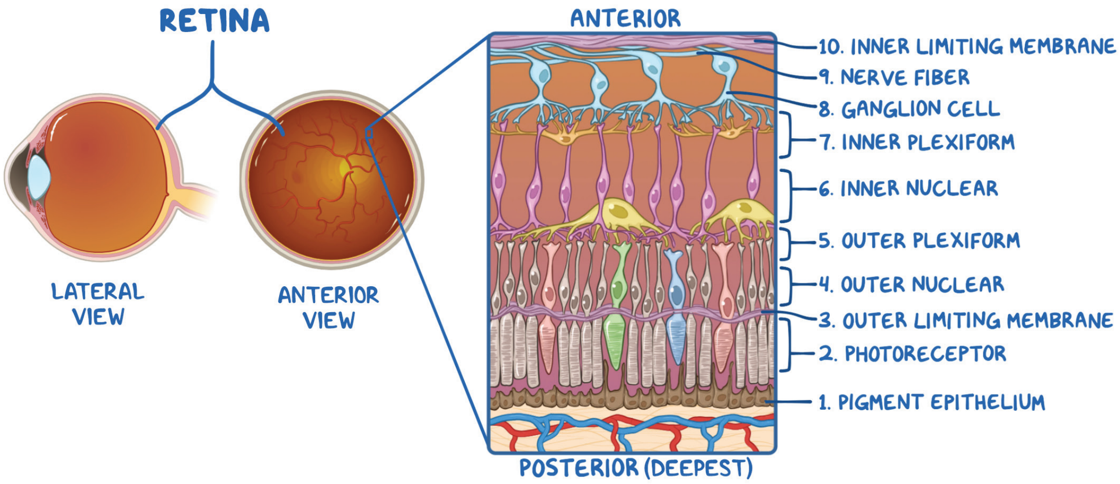

Figure 55.9 Retina = light-sensitive neural layer of tissue at back of eye, composed of 10 layers. Axons of ganglion cells exit eye through optic disc, form optic nerve (CN II).

OPTIC PATHWAYS

osms.it/optic-pathways-and-visual-fields

- *Visual phototransduction:* light waves on retina → electrical signals
- Rods, cones send electrical signal through optic nerve (cranial nerve II)
  - Exits via the optic disc on the retina
- Optic nerves meet at optic chiasm
- Axons from nasal retina cross over to opposite sides → optic tract (synapses with cells in lateral geniculate nucleus in both sides of thalamus) → primary visual cortex/ occipital lobe

VISUAL FIELD

- Everything seen by single eye
- Split into two parts
  - *Nasal visual field:* projected onto temporal retina, axons stays on that side of brain
  - *Temporal visual field*: projected onto nasal retina, axons cross to opposite side of brain at optic chiasm
- Information from left visual fields of both eyes goes to right half of brain, vice versa
  - Due to axons from nasal retina crossing over

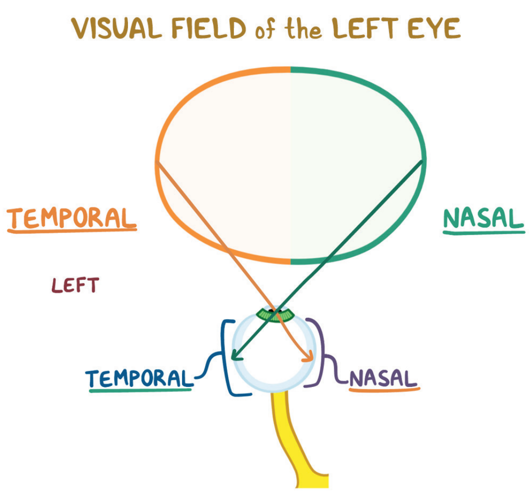

Figure 55.10 The nasal portion of the eye's visual field is projected onto the temporal retina, and the temporal portion of the eye's visual field is projected onto the nasal retina. Axons from the nasal retina cross to the opposite side of the brain at the optic chiasm so that all the information from the left and right visual fields stay together.

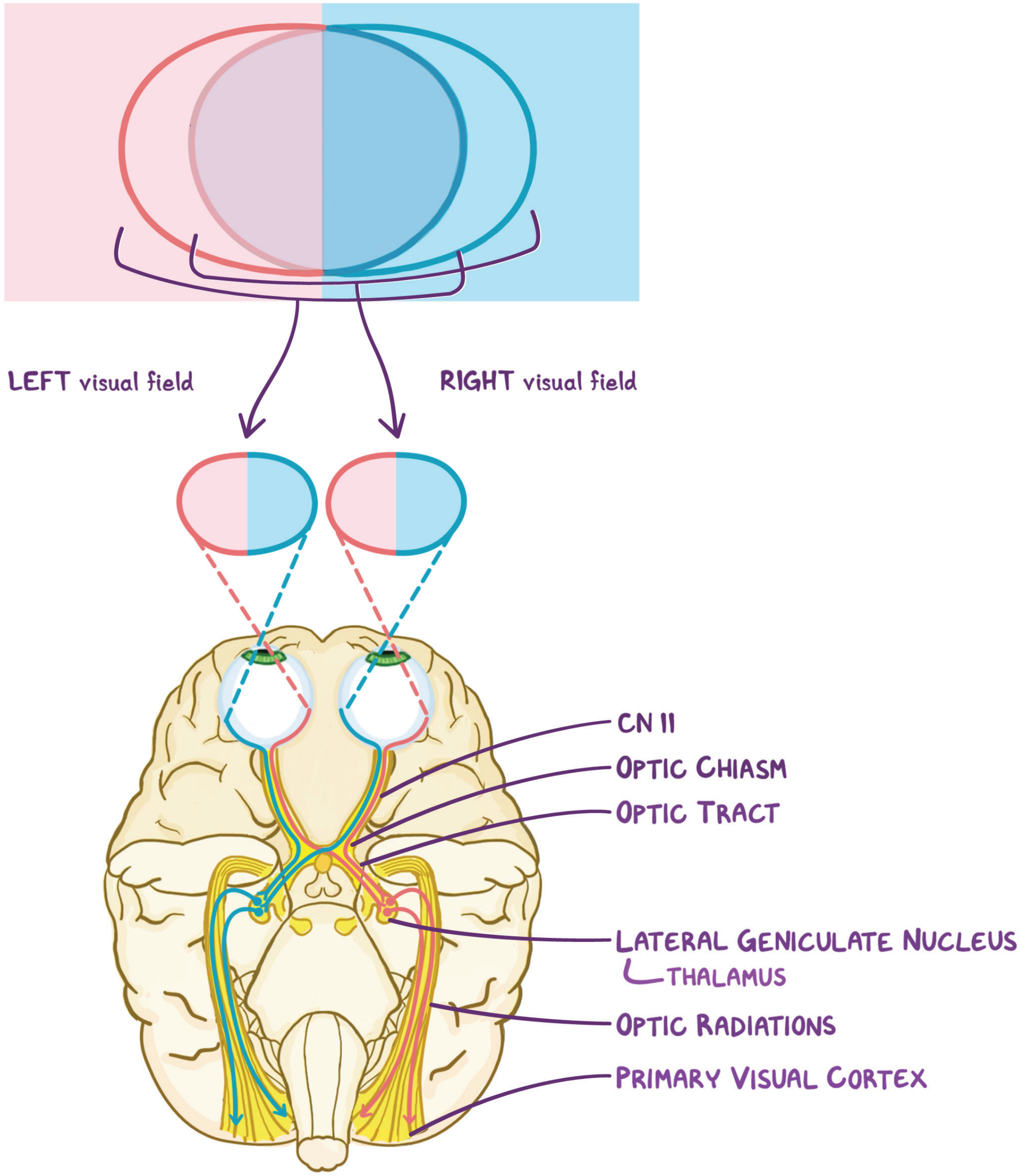

Figure 55.11 Visual field projections onto the retinas and the primary optic pathway, which carries information from the retina to the primary visual cortex in the occipital lobe of the brain.

AUDITORY TRANSDUCTION & PATHWAYS

osms.it/auditory-transduction-and-pathways

- Process by which ear converts sound waves into electrical pulses

OUTER EAR

- Amplifies sound, directs sound waves
  - Pinna → external auditory canal → eardrum vibrates

MIDDLE EAR

- Transmits airborne sound waves to inner ear
  - Malleus (attached to eardrum) → incus → stapes → oval window → cochlea/ inner ear

COCHLEA

- Coils around the modiolus/bone
- Base is contiguous with middle ear through vestibule
- Has bony outer shell
  - Contains perilymph
- Cochlear duct is inside bony shell
  - Contains endolymph
  - Above is scala vestibuli, below is scala tympani
- Cochlear duct, scala vestibuli, scala tympani communicate through helicotrema
- Oval window amplifies, transfers sounds waves to scala vestibuli → perilymph → helicotrema → cochlear duct → displaces basilar membrane towards scala tympani
  - *Higher frequencies*: early membrane
  - *Lower frequencies*: late membrane

ORGAN OF CORTI

- Stimulated by vibration of basilar membrane
- Made up of mechanosensory/hair cells
- Project out 30–300 stereocilia, AKA sensory organelles
  - Tips of stereocilia embedded in tectorial membrane
- Inner hair cells closer to medialis
  - Innervated by sensory nerve fibers

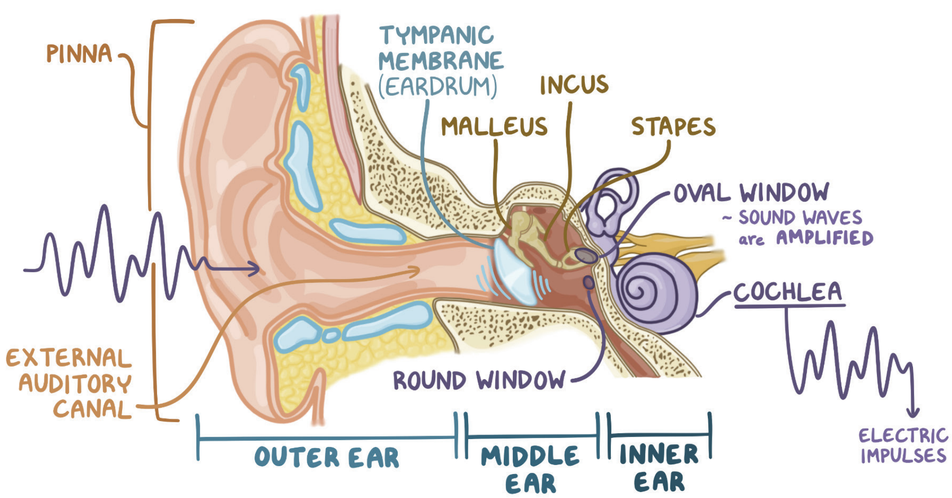

Figure 55.12 Anatomy of the ear.

- Outer hair cells closer to spiral ligament
  - Innervated by motor nerve fibers
  - Changes stiffness of membrane to adjust auditory signal
- Vibration of basilar membrane pushes organ of Corti, hair cells against tectorial membrane
- Pressure on basilar membrane allows protein filaments/tip links to reach, open potassium channels
- Potassium flows in → membrane depolarizes → voltage-gated calcium channels open → glutamate vesicles released into synaptic space → sends electrical impulse to auditory cortex, AKA Brodmann's areas 41 and 42, via auditory nerve

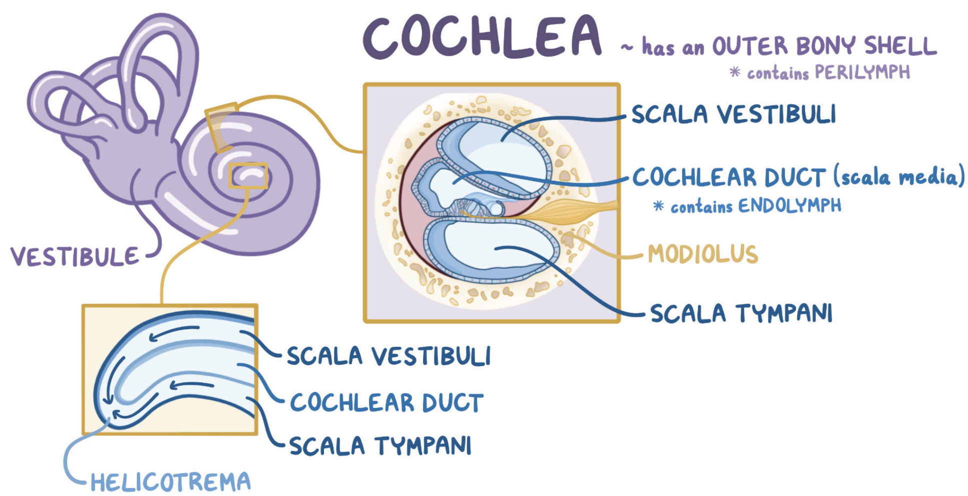

Figure 55.13 Anatomy of the cochlea.

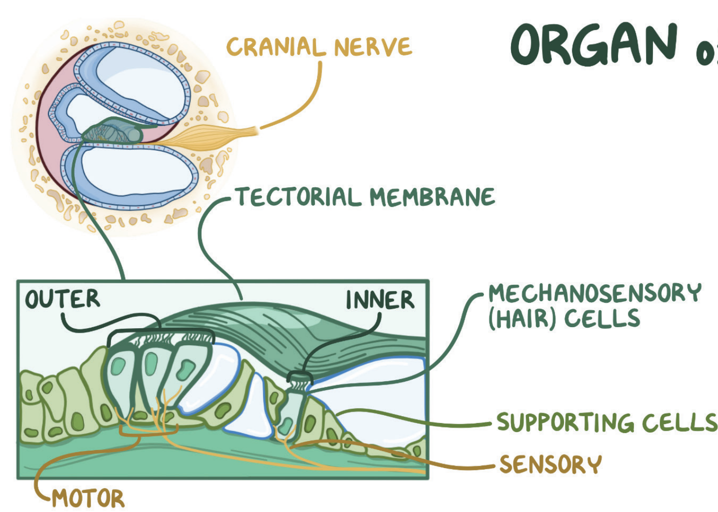

Figure 55.14 Anatomy of the organ of Corti.

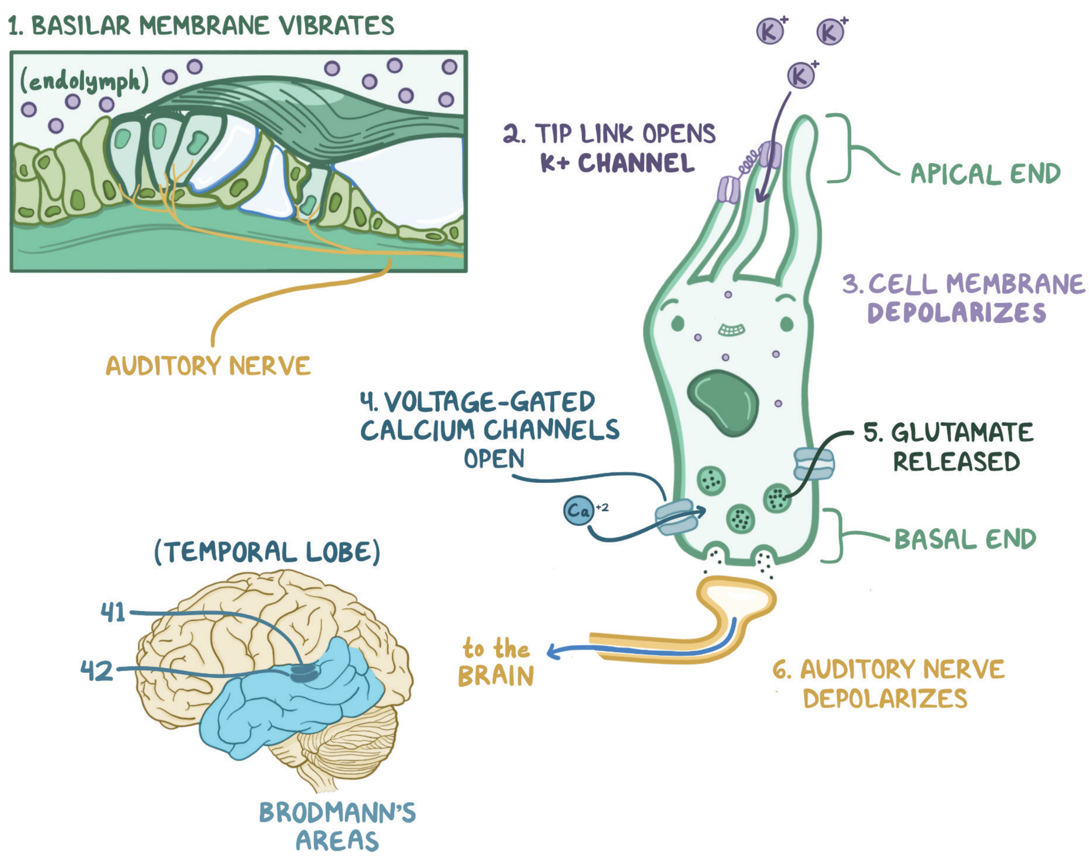

Figure 55.15 Electrical impulse production via organ of Corti hair cells.

VESTIBULAR TRANSDUCTION

osms.it/vestibular-transduction

- Process by which the ear determines spatial equilibrium and converts it into electrical signals
  - Signals are sent to brain via vestibular branch of vestibulocochlear nerve
- Vestibular apparatus located in inner ear
  - Includes semicircular canals (dynamic equilibrium), utricle, saccule (static equilibrium)

STATIC EQUILIBRIUM

- Managed by otolith organs (utricle, saccule)
  - Both contain round macula
- Contains balance receptors/hair cells with stereocilia, kinocilium
- Tips of cilia embedded in otolithic membrane
- Bottom of each cell connected to sensory neurons
- Striola divides hair cells into two sections
  - Receptors arranged to face striola
- Movement pushes protein filaments/tip links on cilia on one side of striola to reach, open potassium channels on kinocilium
  - Potassium flows in → membrane depolarizes → voltage-gated calcium channels open → glutamate vesicles are released into the synaptic space → sends electrical impulse to brain

UTRICULAR MACULA

- *Horizontally oriented*: detects horizontal movement
- *Receptors arrangement*: kinocilia face towards striola

SACCULAR MACULA

- *Vertically oriented*: detects vertical movement
- *Receptor arrangement*: kinocilia face away from striola

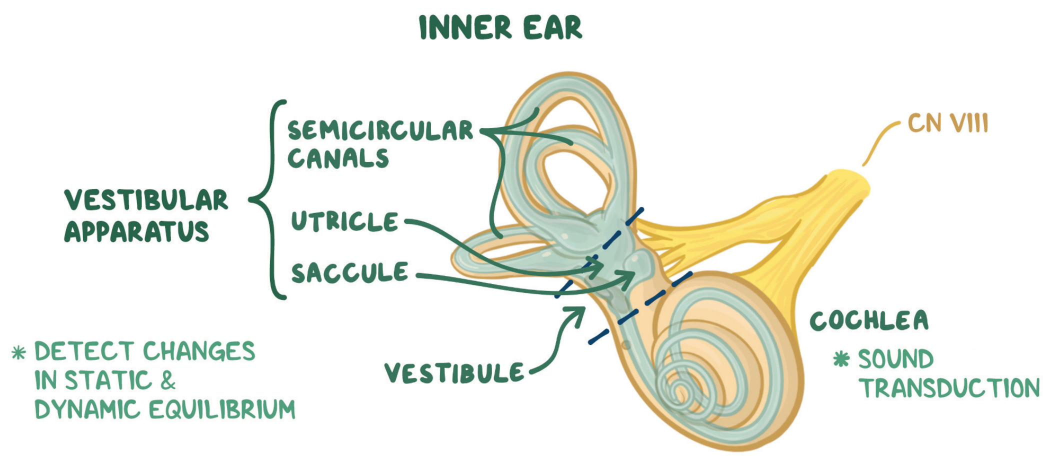

Figure 55.16 Anatomy of the inner ear.

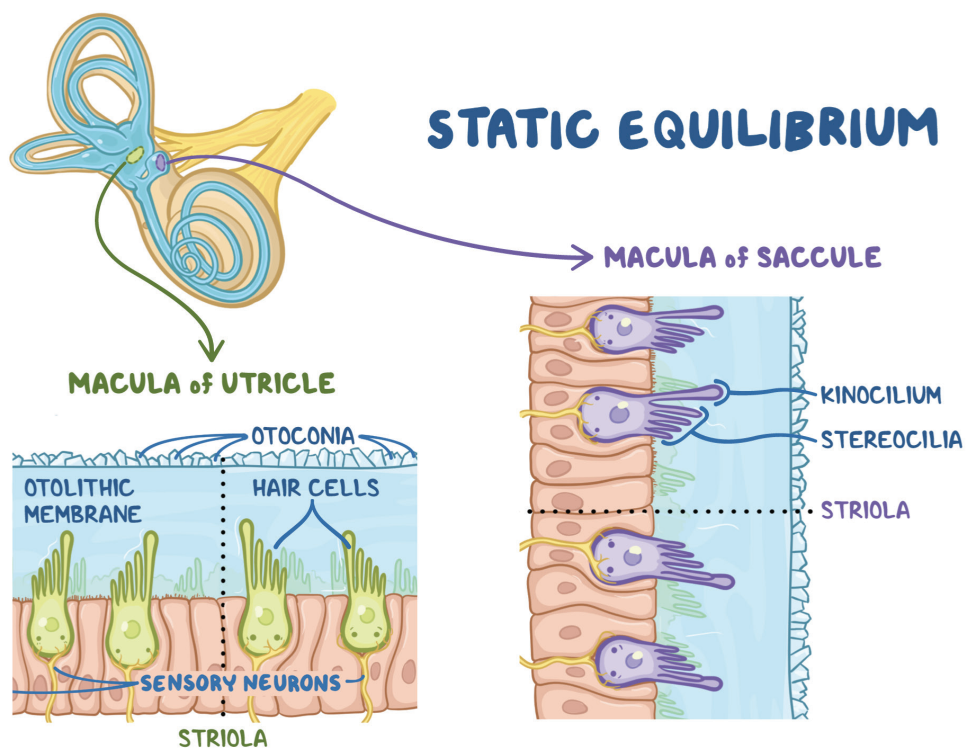

Figure 55.17 Orientation of hair cells relative to the striola in the macula and saccule.

DYNAMIC EQUILIBRIUM

- Managed by semicircular canals
    - U-shaped ducts containing endolymph; oriented at 90° to each other
- Ampulla
    - Houses crista ampullaris
    - Contains balance receptors/hair cells with stereocilia, surrounded by cupula
    - Bottom of each cell connected to sensory neurons
    - Axial rotation in plane of a semicircular canal drags cupula in opposite direction due to inertia → depolarization/ hyperpolarization of hair cells → sends electrical impulse to brain
- Brain uses combination of signals from both ears to determine equilibrium

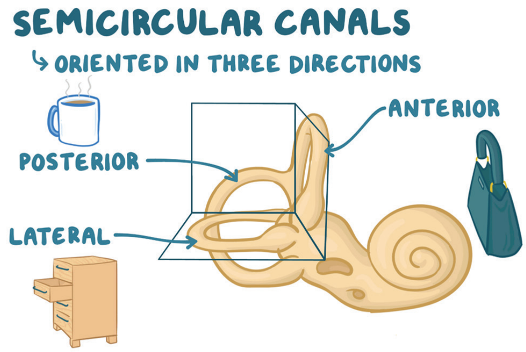

Figure 55.18 Orientation of the three semicircular canals.

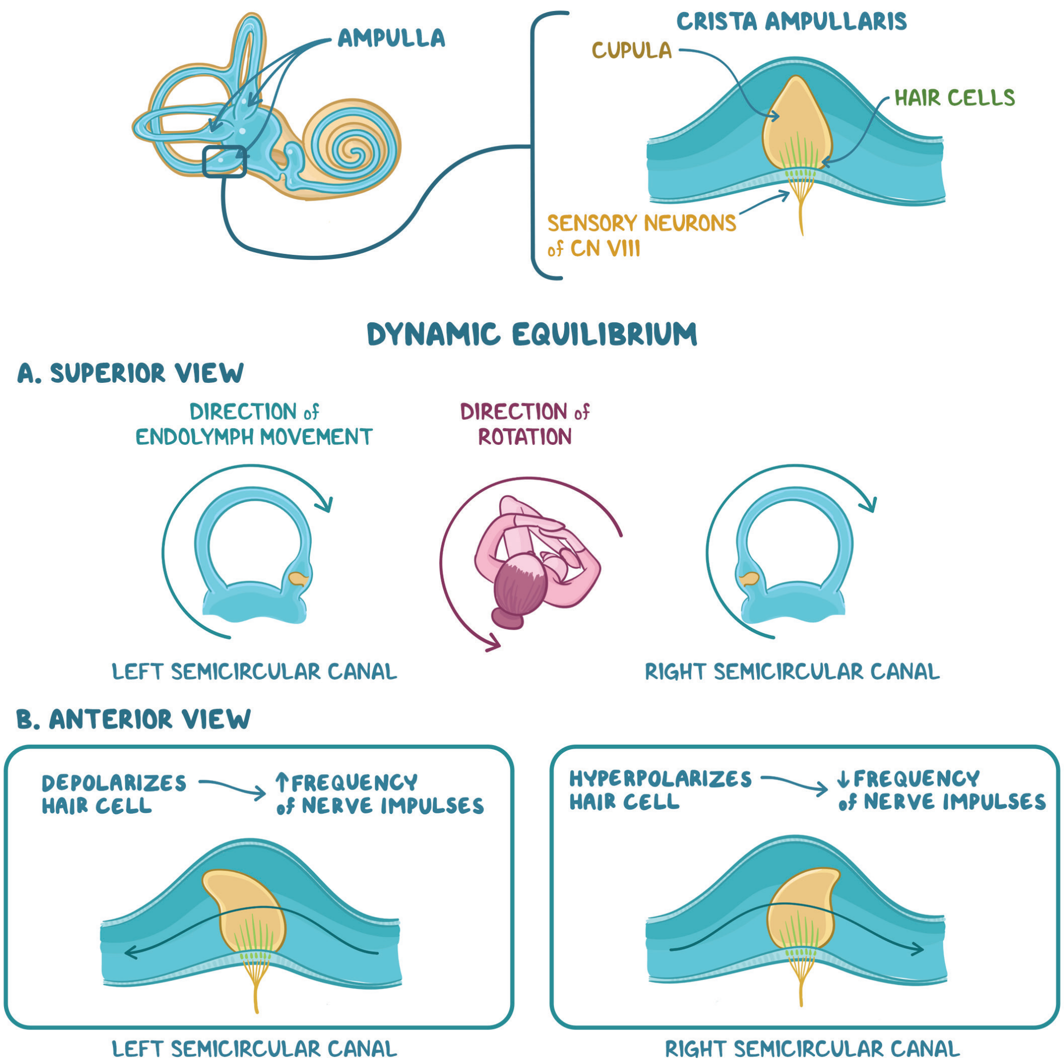

Figure 55.19 Simultaneous depolarization, hyperpolarization of hair cells in left, right ears allows brain to determine direction of movement.

VESTIBULO-OCULAR REFLEX & NYSTAGMUS

osms.it/vestibulo-ocular_reflex_nystagmus

- Reflex occurs in response to head movement by the vestibular apparatus; results in eye movement in the opposite direction of the head
  - Stabilizes position of the eye in the line of sight during head movement
- Semicircular canals within the vestibular apparatus respond to rotation and angular acceleration/deceleration of the head
- Contains hair cells (receptors) that create action potential when stimulated

AFFERENT PATHWAY

- Sensory signals generated by hair cells → action potential travels along nerves → vestibular branch of the vestibulocochlear nerve (CN VIII) → vestibular nuclei in pons

EFFERENT PATHWAY

- From the right vestibular nucleus, nerves cross over to contralateral (left) abducens nucleus → lateral rectus muscle stimulated via abducens nerve/CN VI → left lateral rectus muscle contracts → left eye moves to left
- Other fibers from left abducens act as interneurons → travel to right oculomotor nucleus → left lateral, right medial rectus muscles move eyes to left
- Eyes move all the way to the left → creates physiological form of nystagmus (involuntary back-and-forth eye movement) where eyes move slowly to the left, then rapidly to the right

OLFACTORY TRANSDUCTION & PATHWAYS

osms.it/olfactory-transduction-and-pathways

OLFACTION

- Process by which nose converts smells into electrical signals
- Perceived by sensory neurons in roof of nasal cavity, AKA olfactory region
- Carried by olfactory nerve (CN I)

OLFACTORY REGION

- Lined by olfactory epithelium
- Consists of olfactory receptor cells
  - AKA chemoreceptors; respond to odorants
- Supported by columnar epithelial cells
- Mucus produced in Bowman's glands in connective tissue below, AKA lamina propria

OLFACTORY RECEPTOR CELLS

- Bipolar neurons
- Send dendrites to bottom of the epithelium
  - Dendrites project out as cilia
- Olfactory receptor proteins/G-protein coupled receptors embedded in cilia
- Specific odorants bind onto receptors → G-olfactory protein activates → opens calcium, sodium channels via G-protein coupled receptor pathway

- Calcium-activated chloride channels open → chloride ions flow out → cell membrane depolarizes → neuron fires
- Neuron sends axons that join up to form olfactory nerves (collectively called CN1)
- CN1 passes through olfactory foramina to olfactory bulb
  - Second order neurons send signals to olfactory cortex via olfactory tract

OLFACTORY TRACT

- Lateral tract runs to ipsilateral piriform complex
  - Some fibers go to limbic system
- Medial tract crosses to contralateral piriform complex
- *Adaption*: fewer signals sent in response to same odorants over time

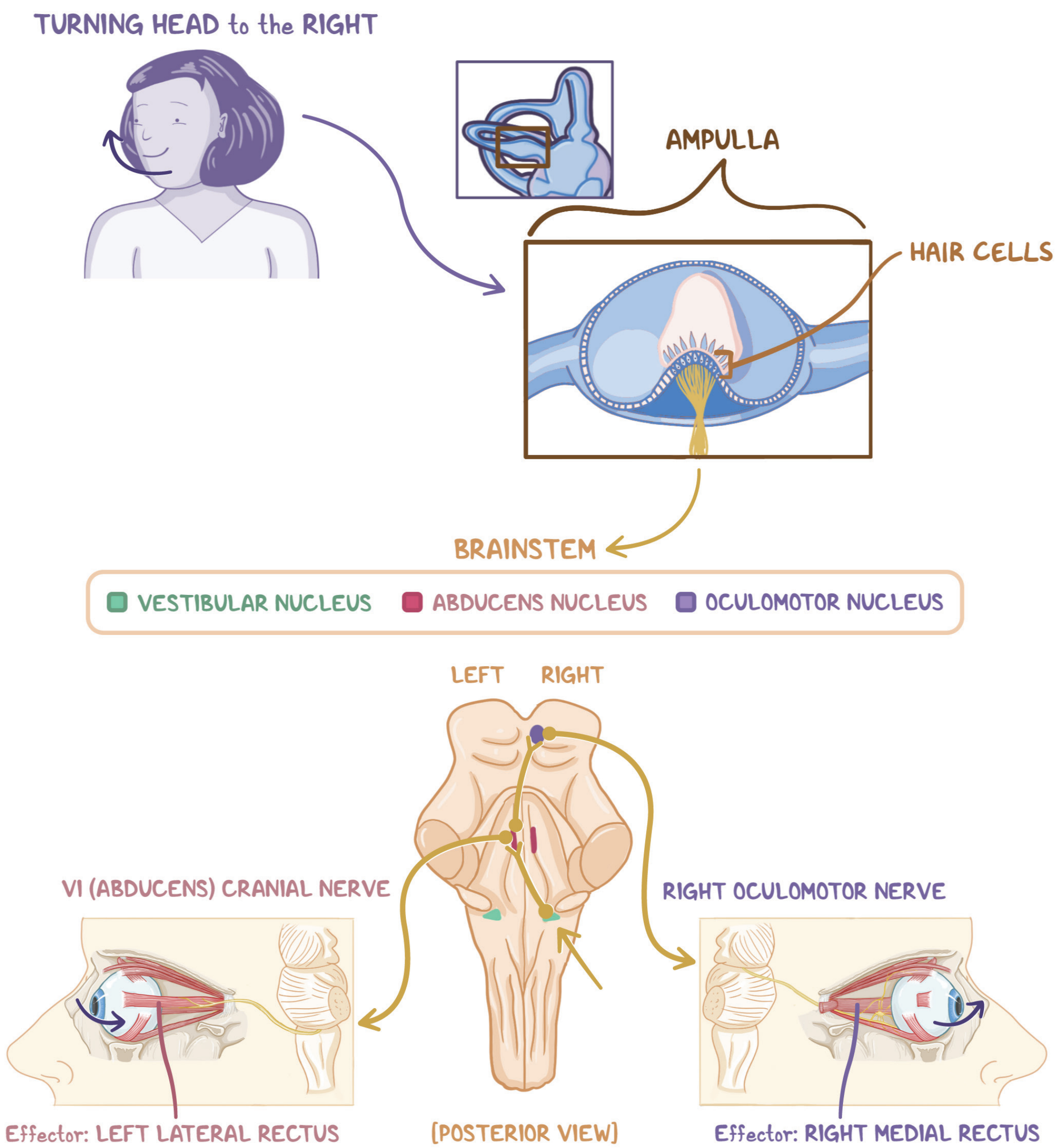

Figure 55.20 Vestibulo-ocular reflex pathway at work when an individual turns their head to the right.

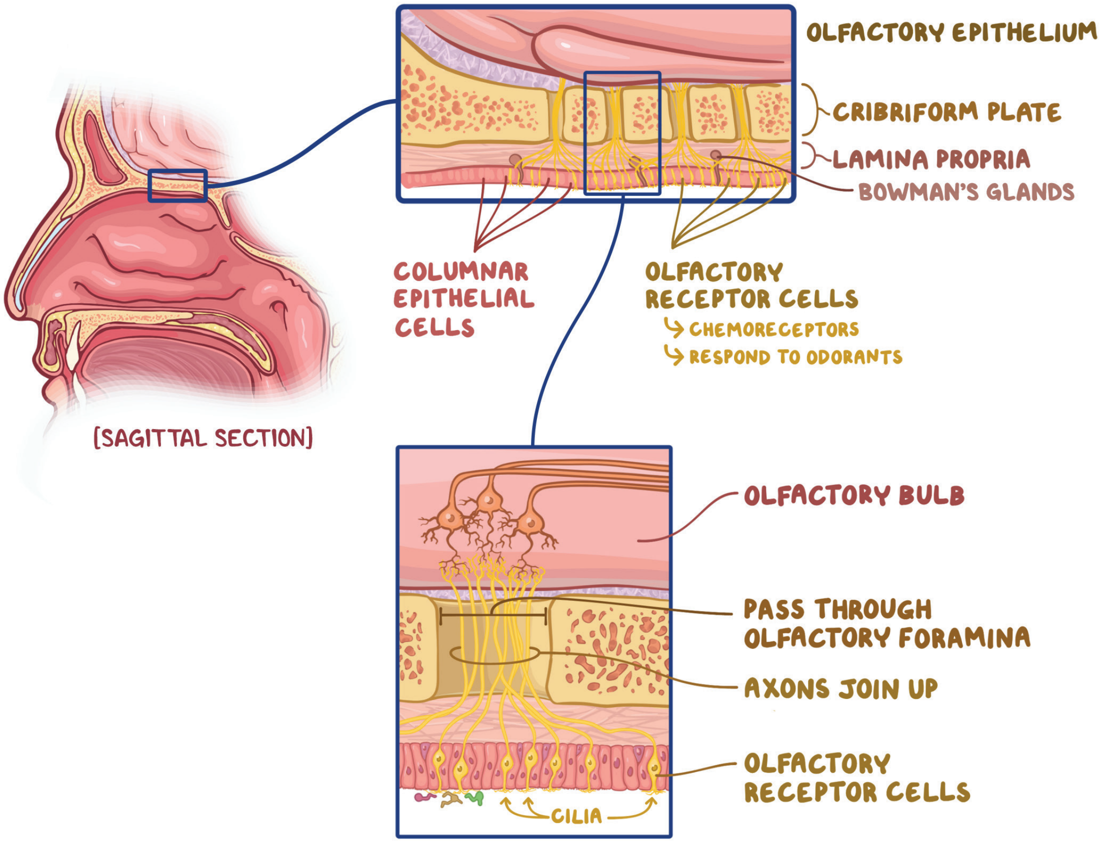

Figure 55.21 Anatomy of the olfactory region.

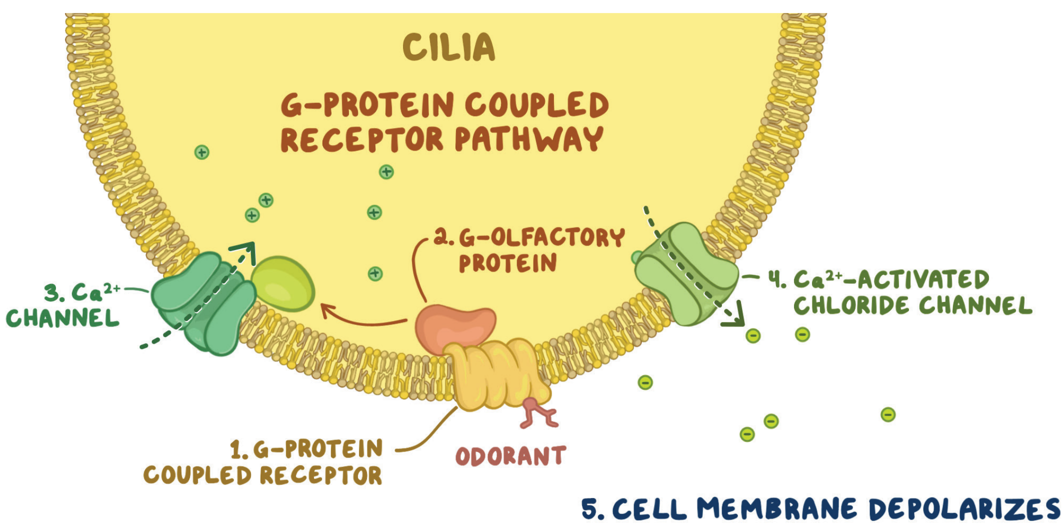

Figure 55.22 The cilia of bipolar olfactory receptor cells use a G-protein coupled receptor pathway to generate a signal.

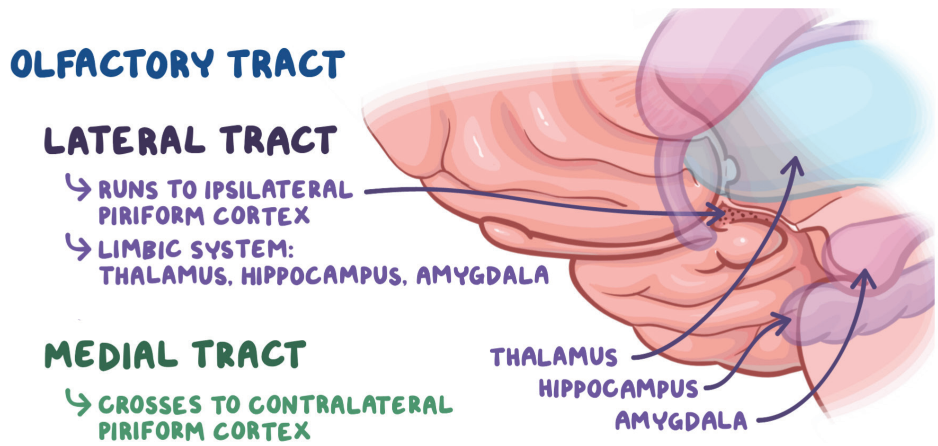

Figure 55.23 Destinations of the olfactory tract.

TASTE & THE TONGUE

osms.it/taste-and-the-tongue

- Taste: sensation produced when substances react with taste receptor cells, AKA gustation
  - Five primary tastes of bitter, salty, sour, sweet, umami/savory

TONGUE

- Surface is covered by mucosa
- Contains both intrinsic, extrinsic muscles
  - *Intrinsic muscles*: start, end within tongue; help change shape
  - *Extrinsic muscles*: attach to structures outside tongue; help guide movement
- Divided by a V-shaped group, AKA sulcus terminalis, into posterior third, an anterior two-thirds
- Covered with papillae
  - Small bumps/projections

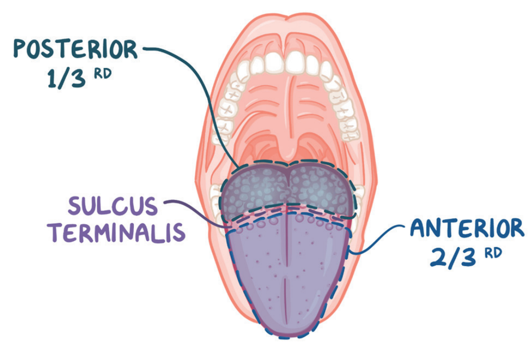

Figure 55.24 Sulcus terminalis divides tongue into posterior third and anterior two thirds.

TYPES OF PAPILLAE

Filiform papillae

- On anterior two-thirds
- Used for sensation of touch

Fungiform papillae

- On tip of tongue
- Contain taste buds
  - More sensitive to sweet, umami

Foliate papillae

- On sides of tongue
- Contain taste buds
  - More sensitive to salty, sour

Circumvallate papillae

- On back of anterior two-thirds
- Contain taste buds
  - More sensitive to bitter

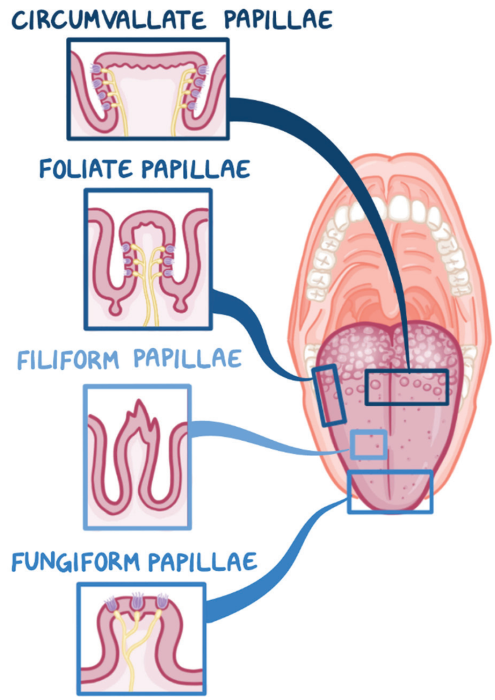

Figure 55.25 The four types of papillae and their locations on the tongue.

TASTE BUDS

- Small structures housing taste receptor cells, basal cells that differentiate into taste receptor cells
- Found on tongue as well as soft palate, pharynx, epiglottis, larynx, upper esophagus

TASTE RECEPTOR CELLS

- Used to perceive taste, AKA respond to tastants
- Arranged like orange wedges with supporting cells between
- Have thin, hair-like microvilli/gustatory hair protruding out of taste pore
- Send signals to brain via axons
  - Anterior two-thirds innervated by facial nerve
  - Posterior third, oral cavity innervated by glossopharyngeal nerve
  - Back of throat, esophagus innervated by vagus nerve

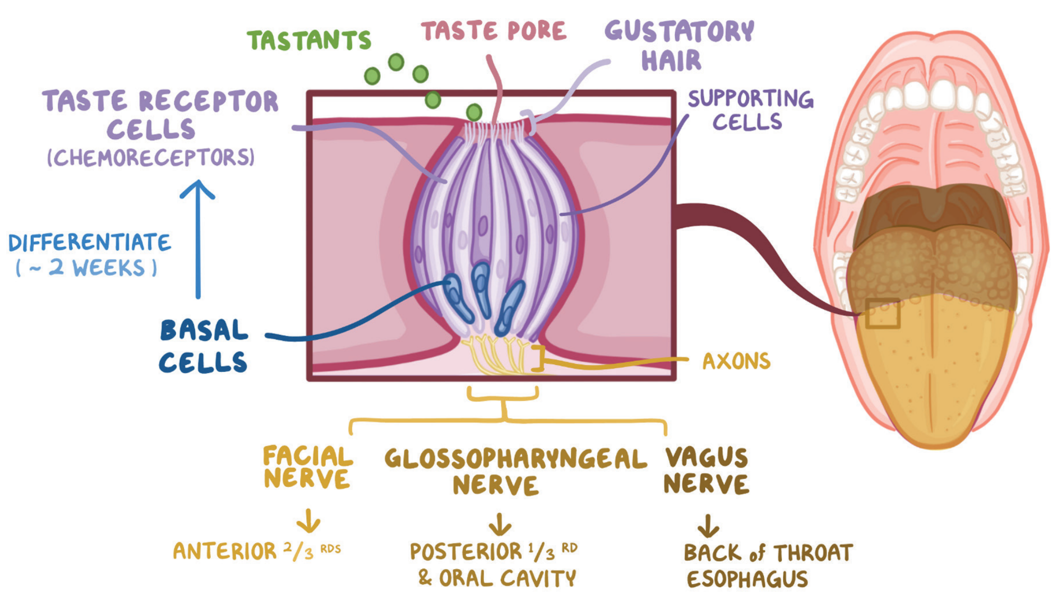

Figure 55.26 Anatomy of a taste bud.

PERCEPTION OF TASTE

- Chewed up particles → mix with saliva → travel to papillae → make contact with gustatory hairs
- For salty/sour tastes
  - Na^+, H^+ ions make contact with gustatory hair
  - Ion channels allow these ions into cell
  - Membrane depolarizes
  - Voltage gated channels open
  - Extracellular calcium flows inside
  - Neurotransmitters fuse with cell membrane
  - Nerves tell brain
- For sweet, bitter, umami tastes
  - Tastants bind to G-protein coupled receptors
  - Triggers G-protein coupled pathway
  - Calcium channels on endoplasmic reticulum open
  - Intracellular calcium ions flow into cell
  - Neurotransmitters fuse with cell membrane
  - Nerves tell brain
- *Complex tastes*: combination of taste receptors
- *Adaption*: fewer signals sent in response to same tastants over time
- Factors affecting taste
  - *Hunger*: ↑ sensitivity to sweet, salty tastes
  - *Infections, allergies*: ↓ sensitivity
  - *Age*: ↓ sensitivity; because receptor cells not replaced as quickly

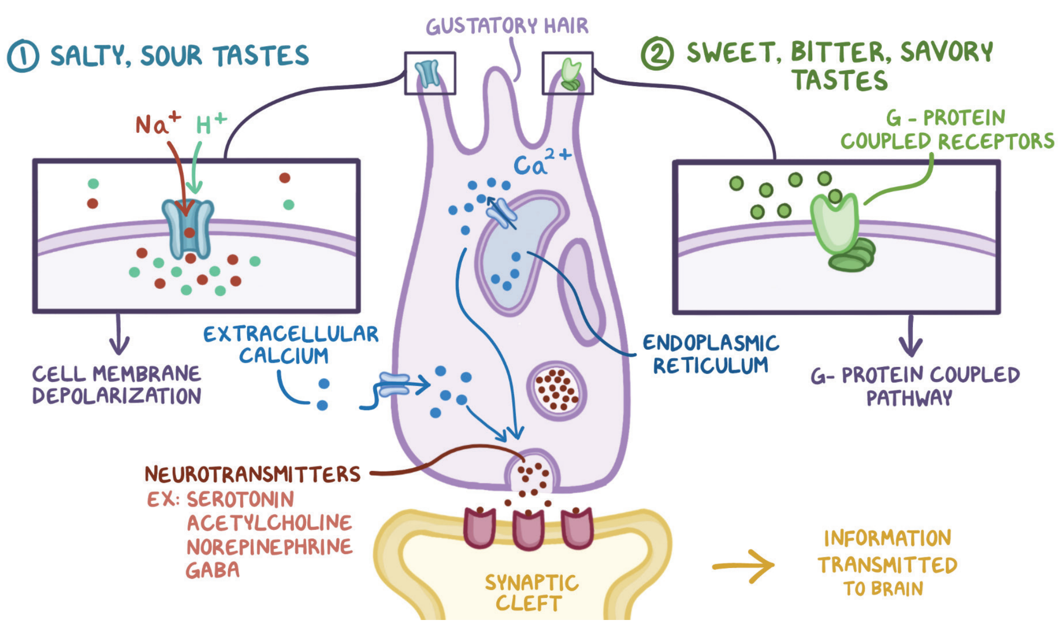

Figure 55.27 The two taste perception methods.