NOTES
ANATOMY & PHYSIOLOGY

NERVOUS SYSTEM ANATOMY & PHYSIOLOGY

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THE NERVOUS SYSTEM

- Network of brain, spinal cords, nerves
- Sensory/afferent, integrative, motor/efferent functions

Sensory/afferent

- Receptors monitor external, internal environment
  - Conscious stimuli (e.g. vision, hearing, touch)
  - Unconscious stimuli (e.g. pH, blood pressure)

Integrative

- Sensory/afferent input received by central nervous system → information processed → interpreted → response initiated

Motor/efferent

- Brings motor information from central nervous system to periphery
- Controls actions of effector organs (e.g. muscles, glands)

ORGANIZATION OF THE NERVOUS SYSTEM

Central nervous system (CNS)

- Brain, spinal cord

Peripheral nervous system (PNS)

- Nerves connect PNS with CNS
- Includes 12 pairs of cranial nerves, 31 pairs of spinal nerves
- Efferent (motor), afferent (sensory) divisions
  - Efferent divided into somatic (voluntary), autonomic (involuntary) nervous systems
  - Autonomic nervous system comprised of sympathetic, parasympathetic nervous systems
- *Sensory receptors:* structure at nerve ending; detects physical, environmental stimulus; e.g. pain, temperature
- *Ganglia/ganglion (plural/singular):* collection of neuron cell bodies outside CNS
- *Plexuses/plexus (plural/singular):* network of nerves outside CNS

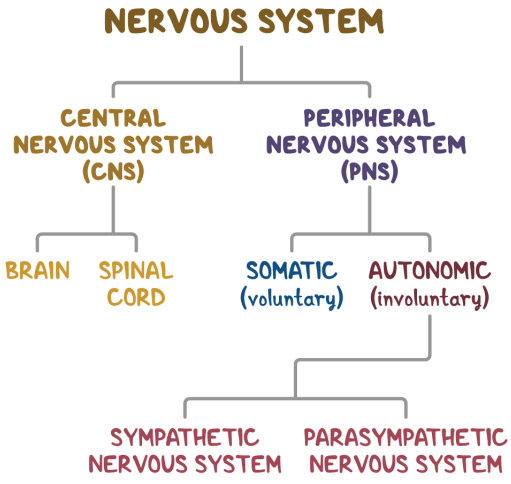

Figure 50.1 Organization of the nervous system.

CELLS OF THE NERVOUS SYSTEM: NEURON

- Specialized, excitable cell; receives, transmits signals, AKA action potentials
- Very long longevity; can last a lifetime with adequate nutrition
- Amitotic, except olfactory epithelium, some areas of hippocampus
- High metabolic rate; require steady supply of oxygen, glucose
  - Oxygen deprivation → death within minutes

Cell body/soma

- Contains endoplasmic reticulum (*ER:* chromatophilic substance, Nissl bodies), Golgi apparatus, mitochondria, neurofibrils, microtubules, pigments (e.g. melanin, lipofuscin); surrounds nucleus
- Site of protein synthesis, processing

Dendrite

- Short processes, project from cell body
- Receive information from adjacent neurons, contain receptors
- Brings information to cell body via graded potentials
- One neuron may have numerous dendrites

Axon

- Projection from specialized region of cell body, AKA axon hillock
  - *Axon hillock:* site of action potential generation
- Neuron's conducting region; forms synapses with dendrites
- Each neuron has only one axon
  - May be as long as 1m/3ft
  - *Nerve fiber:* one long axon
- *Axon collaterals:* axon branches
- Carries action potential from cell body to target cell (e.g. other neurons)
- Lacks rough ER, golgi apparatuses
- Cytoplasm contains numerous microtubules/microfilaments
  - Site of materials migration between cell body, axon terminus
- May be insulated with myelin sheath
- *Axolemma:* plasma membrane of axon
  - Responsible for maintaining neuron's membrane potential via ion channels
- *Axon terminals:* ends of axons, release neurotransmitters
- Clusters of axons
  - *In PNS:* nerves
  - *In CNS:* tracts

Myelin sheath

- Only axons are myelinated
- Functions
  - Protects fibers; ↑ transmission speed
- Produced by oligodendrocytes in CNS, by Schwann cells in PNS
- *Nodes of Ranvier:* gaps in myelin where action potential jumps from one node to next

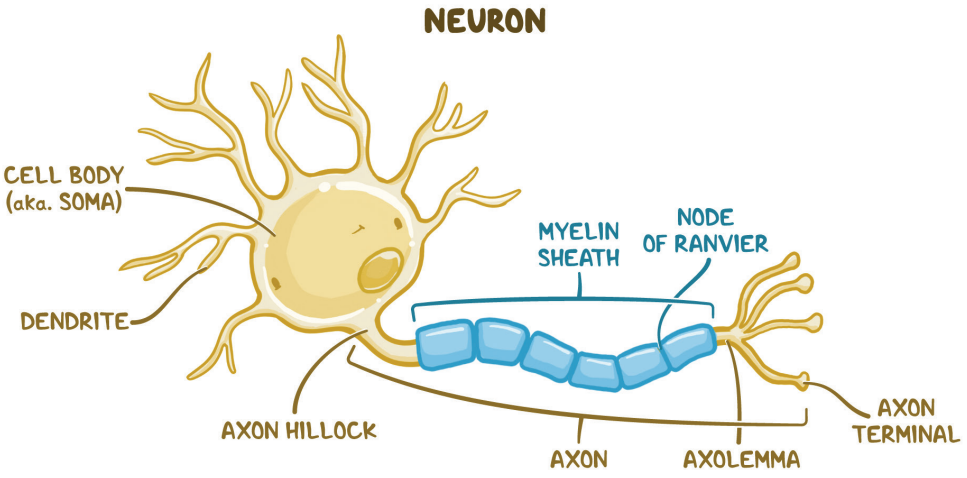

Figure 50.2 Structure of a neuron.

- Saltatory conduction → ↑ speed of propagation
- *Gray matter:* CNS regions containing nerve cell bodies, unmyelinated axons
- *White matter:* CNS regions containing myelinated axons

Structural and functional classification

- Unipolar neurons
  - One process, divides into two branches
  - Mostly function in PNS as first-order sensory neurons; conduct impulses along afferent pathways
- Bipolar neurons
  - Two processes (axon, dendrite) on opposite sides of cell body
  - Sensory neurons found in special sense organs (e.g. olfactory mucosa, retina)
- Multipolar neurons
  - ≥ *three processes:* one axon, rest are dendrites
  - *Primary functions:* interneurons within CNS; motor neurons (conduct impulses along efferent pathways)

CNS GLIAL CELLS (NEUROGLIA)

Astrocytes

- Most abundant; multiple functions
  - Provide structural, metabolic support for neurons
  - Determine capillary permeability (essential for blood-brain barrier via formation of tight junctions)
  - Control chemical environment (clean up spilled neurotransmitters, potassium ions)

Microglial cells

- Protective role
- Phagocytize microbes, debris

Oligodendrocytes

- Forms myelin sheath

Ependymal cells

- Line cavities of brain, spinal cord
- Form partially permeable barrier between cerebrospinal fluid (CSF), tissue
- Cilia assist in CSF circulation

PNS NEUROGLIA

Satellite cells

- Similar function as astrocytes

Schwann cells, AKA neurolemmocytes

- Form myelin sheath
- Involved in regeneration of damaged peripheral nerve fibers

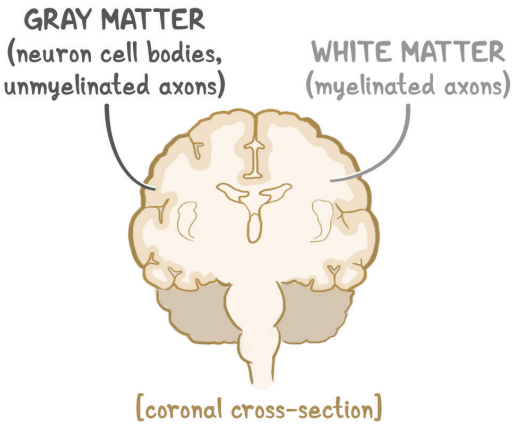

Figure 50.3 Coronal cross-section of the brain showing gray matter and white matter.

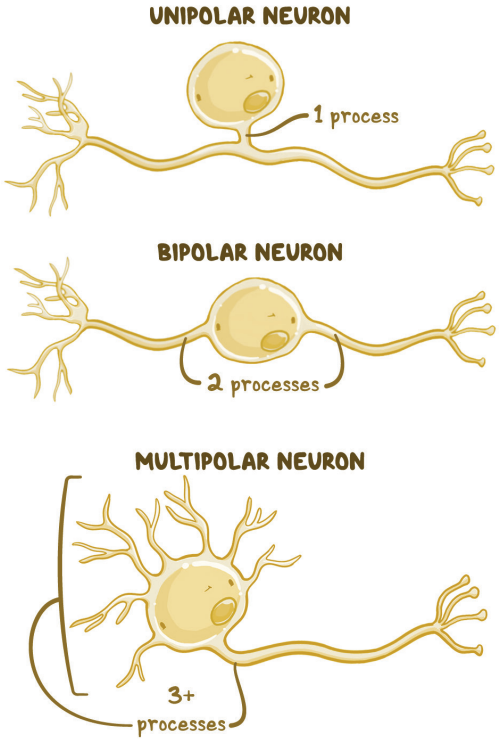

Figure 50.4 Structures of unipolar, bipolar, and multipolar neurons.

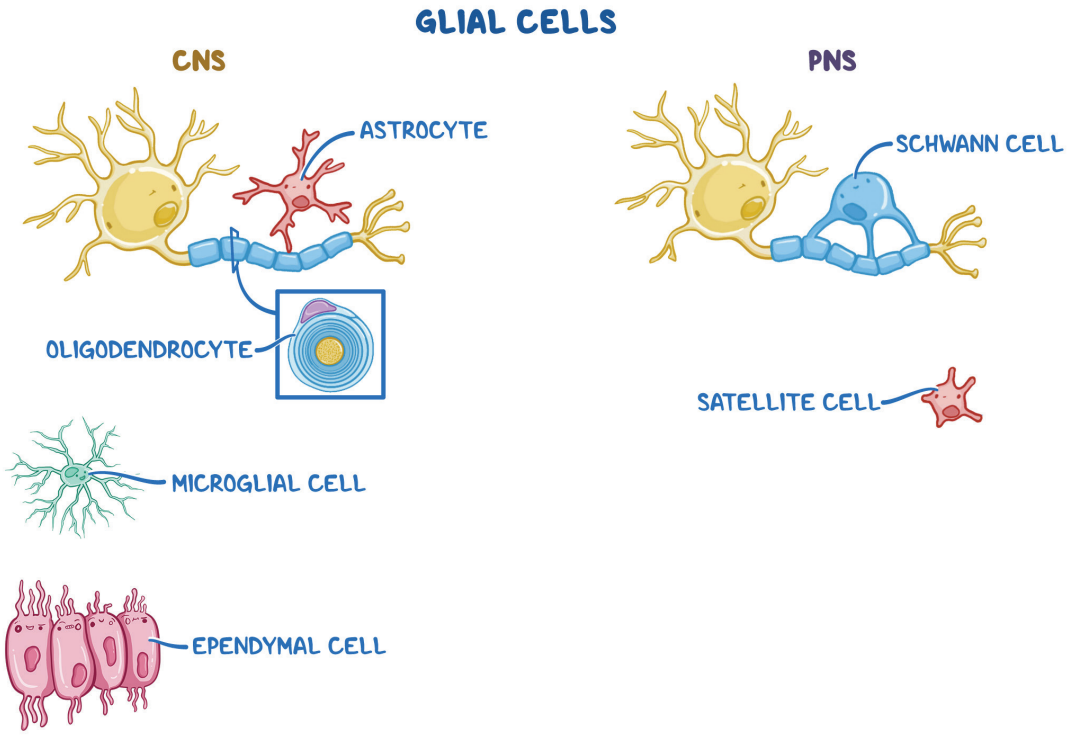

Figure 50.5 Glial cells of the CNS and PNS.

SYNAPSES

- Junction point from one neuron to next
- *Presynaptic neuron:* conducts impulse toward synapse
- *Postsynaptic neuron:* conducts impulse away from synapse

Chemical synapse

- Most common type of synapse
- Information exchanged unidirectionally via neurotransmitters (e.g. serotonin, glutamate, glycine, epinephrine, GABA, histamine)
- Action potential spreads along presynaptic neuron → depolarizes presynaptic neuron → voltage-gated calcium channels open → trigger release of neurotransmitter in vesicles via exocytosis → neurotransmitter binds to postsynaptic membrane receptor → generation of action potential → excitation/inhibition (depending on neurotransmitter)
- Neurotransmitter removed from synaptic cleft by diffusion, degradation, cellular uptake

Electrical synapse

- Open channels conduct electricity via gap junctions composed of connexons (protein channels); connecting cytoplasm of adjacent neurons
- Rapid, unidirectional or bidirectional transmission
- Examples
  - Cardiac muscles (promote synchronized activity)
  - Hypothalamic hormone-secreting neurons (creates burst of hormone release)

SPINAL CORD

- Long, tubular bundle of nervous tissue; protected by bony vertebral column, meninges, CSF
- Central canal continuous with fourth ventricle; carries CSF through spinal cord
- Extends from brainstem to lumbar region
  - Information travels up spinal cord via afferent (sensory) fibers, down via efferent (motor) fibers

- *White matter:* afferent, efferent fibers
- *Gray matter:* cell bodies
- Cell bodies arranged in three columns, AKA horns
  - *Anterior (ventral) horns:* receive information from brain's motor cortex → send it to skeletal muscles → trigger voluntary movement
  - *Posterior (dorsal) horns:* take sensory information → send it to brain's sensory cortex
  - *Lateral horns:* help regulate processes like urination, digestion, heart rate (mostly sympathetic activity)
- 31 pairs of nerves
  - *Nerve pairs:* 8 cervical, 12 thoracic, 5 lumbar, 5 sacral, 1 coccygeal
  - *Cauda equina:* nerve roots at end of vertebral canal
- Nerves arising from spinal column innervate specific bodily regions
  - Each spinal nerve (except C1) provides cutaneous sensory perception
  - *Dermatome:* section of skin supplied by pair of spinal nerves

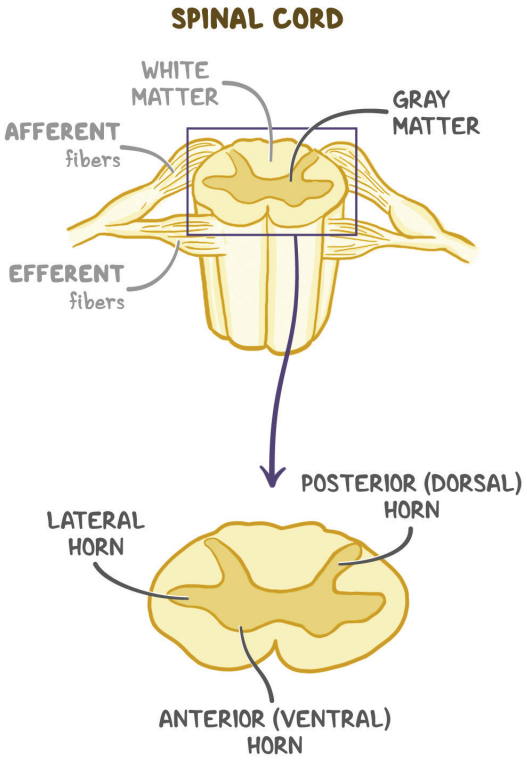

Figure 50.6 Cross-section of the spinal cord showing its structure.

STRUCTURES OF THE BRAIN

Brainstem: medulla, pons, midbrain

- Posterior part of brain continuous with spinal cord
- Responsible for basic life-sustaining body functions; e.g. breathing, blood pressure, consciousness, swallowing
- 10/12 cranial nerves (cranial nerves III-XII) arise in brainstem
- Medulla
  - Vasomotor (cardiovascular) center, respiratory center, swallowing/coughing/vomiting centers
  - All ascending sensory, descending motor tracts connecting spinal cord with other parts of brain
  - Pyramids on anterior surface of medulla: descending corticospinal tracts cross (decussate) to opposite side
- Pons
  - Controls facial expressions, sensations
  - Controls body equilibrium, posture
  - Works with medulla to regulate breathing (pneumotaxic center), relay information between cerebellum, cerebral hemispheres
- Midbrain (mesencephalon)
  - Participates in vision, hearing, motor control, sleep-wake cycle, consciousness
- Reticular formation (RF) scattered throughout brainstem
  - Responsible for consciousness; maintaining posture, general muscle tone, major visceral functions; interpretation, processing of noxious stimuli

Cerebellum

- AKA "little brain"
- Responsible for coordinating, planning, executing movements; balance, posture, spatial perception
- Integrates sensory information; fine-tunes motor activity (e.g. learned motor skills), stores it as muscle memory

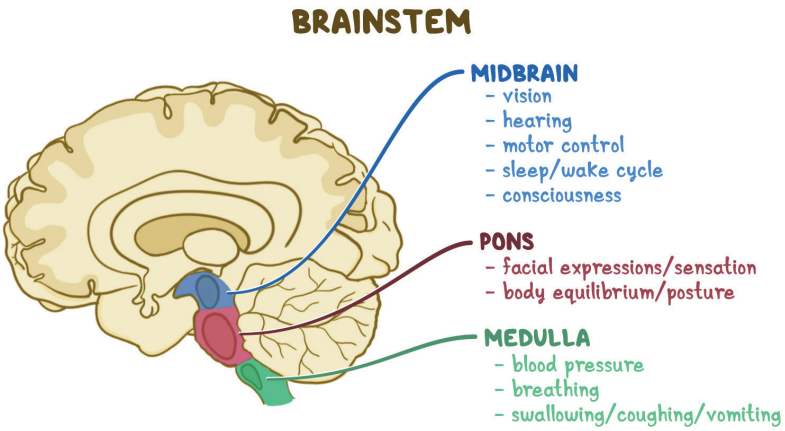

Figure 50.7 Sagittal section of the brain showing the brainstem, which includes the midbrain, pons, and medulla.

Diencephalon

- Thalamus
  - Relay station for sensory, motor information going to/from cerebral cortex, brainstem, spinal cord; screens insignificant information
- Hypothalamus
  - Major homeostatic control system
  - Links nervous system to endocrine system via pituitary gland
  - Thermostatic control of body temperature
  - Along with limbic system, participates in emotions such as anger, emotional response to pain, sexual arousal-related behaviors
  - Regulates circadian rhythms
  - Plays role in regulating eating, drinking; contains thirst center, which senses osmotic pressure of extracellular fluid
- Pineal gland
  - Produces melatonin

Cerebrum

- Divided into right, left hemispheres
- Separated by *corpus callosum:* connects left side to right side
- Contain folds *(gyri):* increase surface area
- *Sulci:* grooves between gyri
- *Four lobes:* frontal, parietal, temporal, occipital
- Frontal
  - *Primary motor cortex:* voluntary movement (motor homunculus)
  - *Premotor cortex:* orientation of body
  - *Supplementary motor area:* planning sequence of movement
- Parietal
  - Somatosensory processing
  - Has homunculus pattern similar to motor cortex
- Temporal
  - Functions in hearing, olfaction, visual recognition
- Occipital
  - Responsible for analyzing, interpreting visual information

Cerebral cortex

- Gray matter (cell bodies, dendrites) on outer surface of cerebrum: information processing
  - *Motor association area:* determines appropriate movements for specific tasks
  - *Primary somatosensory:* receives sensory input; somatosensory association area provides discrete interpretation
- Language processing
  - *Broca's area:* generation of spoken word (moving muscles to speak)
  - *Wernicke's area:* comprehension of speech
- *White matter:* axons; carry information to other parts of brain

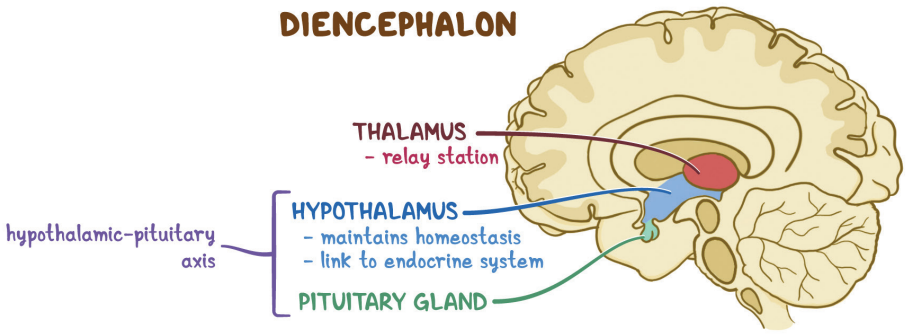

Figure 50.8 Sagittal section of the brain showing the diencephalon, which includes the thalamus, hypothalamus, and pituitary gland.

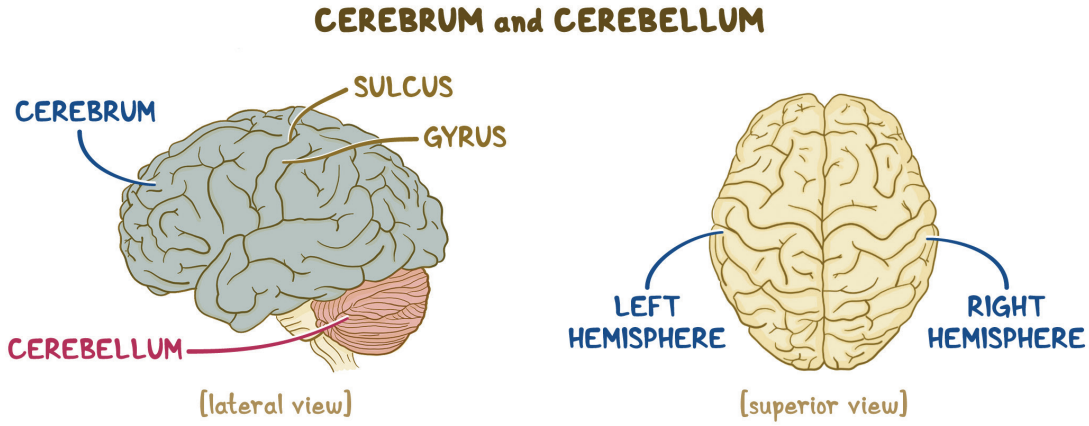

Figure 50.9 The structure of the cerebrum and cerebellum. The cerebrum contains gyri (which are the folds) and sulci (which are the grooves between the folds).

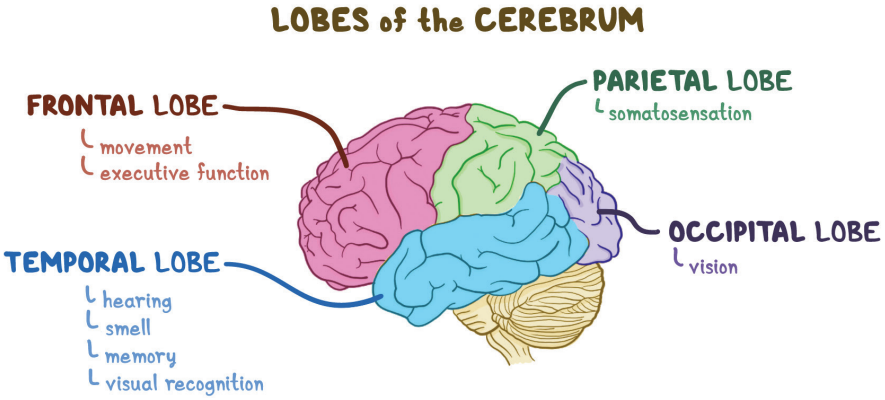

Figure 50.10 The four lobes of the cerebrum and some of their functions.

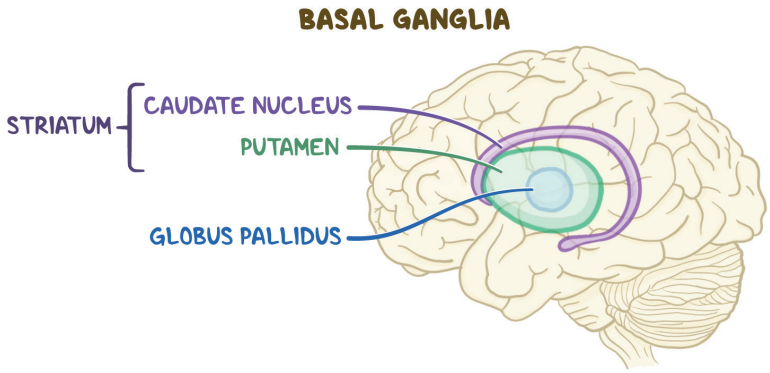

Figure 50.11 The structures of the basal ganglia.

Basal nuclei (ganglia)

- Gray matter deep within brain; deep nuclei of cerebral hemispheres
- Contains caudate nucleus, globus pallidus, putamen nucleus
- Mainly responsible for regulating movement, tone, motor control

VENTRICLES & CSF

Ventricles

- Four interconnected spaces filled with CSF
- *Two lateral ventricles:* located in frontal lobes, extend posteriorly into parietal lobes
- *Interventricular foramen (foramen of Munro):* connects lateral ventricles to each other, to third ventricle
- *Third ventricle:* lies between thalamic bodies, surrounded by hypothalamus
- *Cerebral aqueduct (aqueduct of Sylvius):* connects third, fourth ventricles
- *Fourth ventricle:* located between cerebellum, pons
- *Two lateral apertures (foramina of Luschka), one medial aperture (foramen of Magendie):* connect fourth ventricle to subarachnoid space

CSF

- CSF similar in composition to blood with most proteins removed
- Made by ependymal cells of choroid plexuses
- Circulates throughout ventricles, central canal; also covers brain, meninges
- Protects brain (brain "floats" in cushioning fluid), provides nutrients to tissues in CNS

Flow of CSF through ventricles

- CSF produced by choroid plexus in lateral, third, fourth ventricles → lateral ventricle → through interventricular foramen to third ventricle → through cerebral aqueduct to fourth ventricle → through lateral, median apertures to subarachnoid space (some CSF enters central canal of spinal cord) → superior sagittal sinus, venous circulation

MENINGES

Anatomy

- Made up of three layers
- *From superficial to deep:* dura mater, arachnoid mater, pia mater
- *Dura mater:* tough, inflexible layer
  - Separates brain into compartments, forms sinuses for major veins of brain
  - *Falx cerebri:* separates right, left major veins of brain
  - *Falx cerebelli:* separates right, left lobes of cerebellum
  - *Tentorium cerebelli:* separates right, left lobes
- *Arachnoid mater:* middle layer that projects into sinuses (arachnoid villi)
  - *Subarachnoid space:* lies between arachnoid, pia mater
  - Contains CSF
  - Contains all blood vessels, cranial nerve of brain
- *Pia mater:* innermost layer
  - Adheres to brain
  - Fuses with empyema, forming choroid plexus, which produce CSF

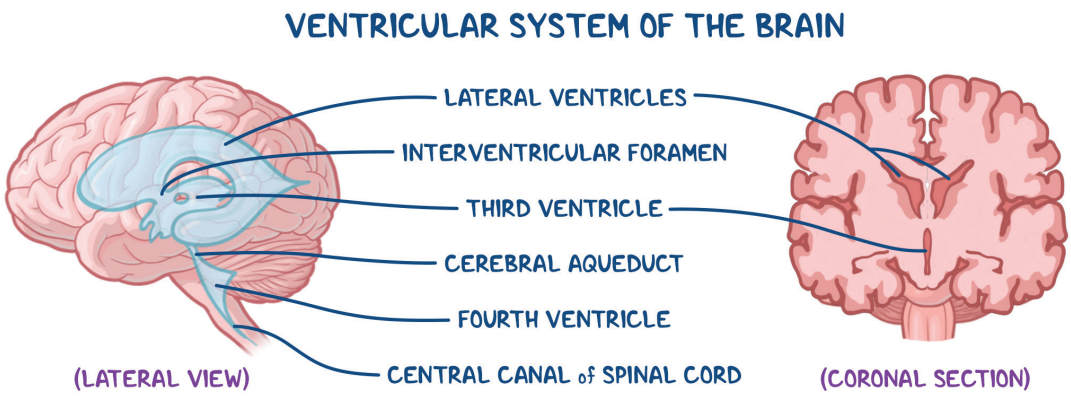

Figure 50.12 Ventricular system of the brain.

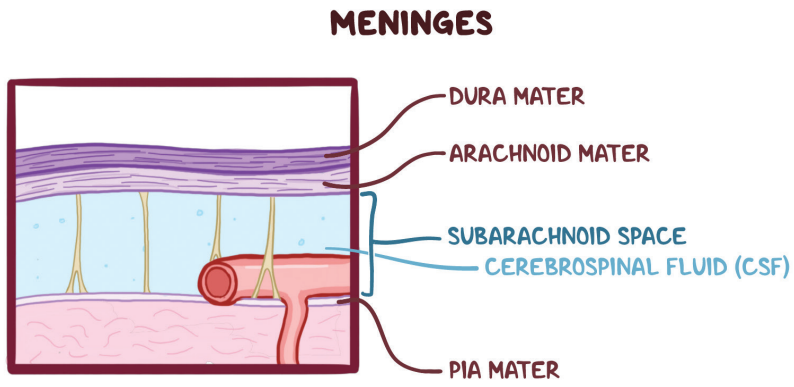

Figure 50.13 The meninges: three tissue layers which protect the brain and spinal cord.

AUTONOMIC NERVOUS SYSTEM

- Involuntary branch of PNS
- Extends from CNS to target organ via two-neuron chain; interact at autonomic ganglion
  - *Preganglionic fiber:* synapses with cell body of second neuron
  - *Postganglionic fiber:* innervates effector organ
- Both systems are active; one dominates other depending on situation
- Dual innervation of organs by both sympathetic and parasympathetic divisions
  - *Exceptions:* most arterioles, veins, sweat glands only innervated by sympathetic nerve fibers

Sympathetic

- *"Fight or flight" functions:* activated when individual exposed to stressful situation
- Originates in thoracic, lumbar region of spinal cord (T1-L2)
- *Preganglionic axon length:* short
- *Postganglionic axon length:* long
- Neurotransmitters, receptors
  - Preganglionic fibers release acetylcholine → binds to nicotinic receptor in postganglionic neuron → releases norepinephrine → binds to alpha/beta receptors on effector organs → releases acetylcholine → binds to muscarinic receptors on sweat glands
  - Preganglionic fibers release acetylcholine → binds to nicotinic receptor on adrenal medulla → epinephrine released → binds to alpha/beta receptors on effector organs

Parasympathetic

- *"Rest and digest" functions:* conserves, stores energy; maintains "housekeeping" functions
- Originates in craniosacral areas of spinal cord (CN III, VII, IX, X; S2-S4)
- *Preganglionic axon length:* long
- *Postganglionic axon length:* short
- Neurotransmitters, receptors
  - Preganglionic fiber releases acetylcholine → binds to nicotinic receptor in postganglionic neuron → releases acetylcholine → binds to muscarinic receptor on effector organ

Enteric nervous system (GI)

- *"Second brain:"* autonomous function independently from autonomic nervous system
- Neurons collected into two ganglia
  - Myenteric (Auerbach's), Meissner's plexus
- Coordinates peristalsis, GI tract secretions

Sympathetic vs. parasympathetic effects on organs

- Some organs only innervated by sympathetic division, but many innervated by both sympathetic, parasympathetic divisions → work cooperatively to regulate normal function
- Heart
  - *Sympathetic:* beta-1 receptors → ↑ heart rate, contractility → ↑ cardiac output
  - *Parasympathetic:* muscarinic (M) receptors → ↓ heart rate, contractility (atria only) → ↓ cardiac output
- Vascular smooth muscle
  - *Sympathetic:* skin/splanchnic alpha-1 receptors → constriction; skeletal muscle vascular beta-2 receptors → dilation; skeletal muscle vascular alpha-1 receptors → constriction
  - *Parasympathetic:* no direct effect
- Bronchial tree
  - *Sympathetic:* beta-2 receptors → dilation
  - *Parasympathetic:* M receptors → constriction
- Eye
  - *Sympathetic:* beta-2 receptors → ciliary muscle relaxation for far vision; alpha-1 → radial muscle contraction → pupil dilation
  - *Parasympathetic:* M receptors → ciliary muscle contraction for near vision + sphincter muscle constriction → pupil constriction
- GI tract
  - *Sympathetic:* alpha-2, beta-2 receptors → GI tract smooth muscle wall relaxation, ↓ GI motility; alpha-1 → ↑ sphincter tone
  - *Parasympathetic:* M receptors → ↑ GI smooth muscle wall contraction and motility, ↓ sphincter tone; ↑ gastric secretion
- Bladder
  - *Sympathetic:* beta-2 receptors → detrusor muscle relaxation, urinary sphincter contraction
  - *Parasympathetic:* M receptors → detrusor muscle contraction, urinary sphincter relaxation
- Liver
  - *Sympathetic:* beta-2, alpha-1 receptors → gluconeogenesis, glycogenolysis
  - *Parasympathetic:* no direct effect
- Adrenals
  - *Sympathetic:* nicotinic receptors → release of epinephrine, norepinephrine
  - *Parasympathetic:* no direct effect

NEURON ACTION POTENTIAL

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- Electric signals sent down axons
- Generated by rapid rising, falling of membrane potential
- Resting membrane potential (approx. -65mV) determined by intra, extracellular ion concentrations
  - Ion channels open → depolarization of neuron (net influx of positive charge/ excitatory postsynaptic potential)
  - Depolarization to approx. -55mV → voltage-gated sodium channels open at axon hillock → sodium rushes into cell → action potential (neuron is positively charged to approx. +40mV)
  - Sodium channel becomes inactivated (absolute refractory period)
  - Voltage-gated potassium channels then act → potassium flows out
  - Sodium/potassium pump moves sodium out of cell, potassium in → hyperpolarization
  - Sodium channels remain closed but can be activated (relative refractory period); hyperpolarization → stronger stimulus needed
- In myelinated areas, electrical force of moving ions pushes subsequent ions along (saltatory conduction)

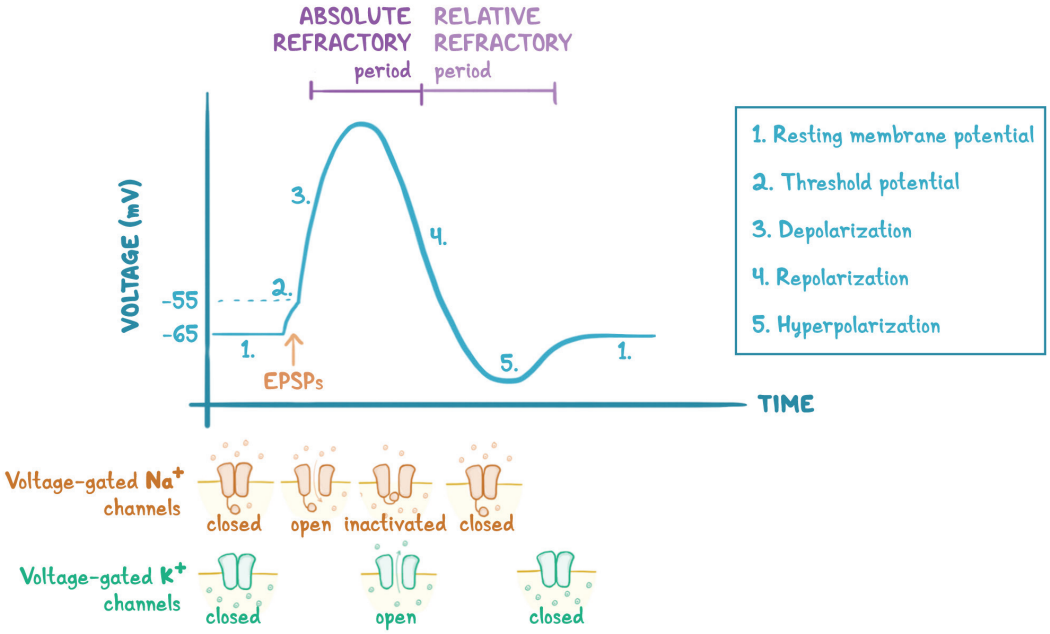

Figure 50.14 Graphical summary of the voltage changes that occur during a neuron action potential and the accompanying states of voltage-gated sodium and potassium channels. The action potential is initiated by a net influx of excitatory postsynaptic potentials (EPSPs). Not shown above are sodium/potassium pumps, which help to maintain the resting membrane potential, as well as help to return to that resting potential through repolarization.

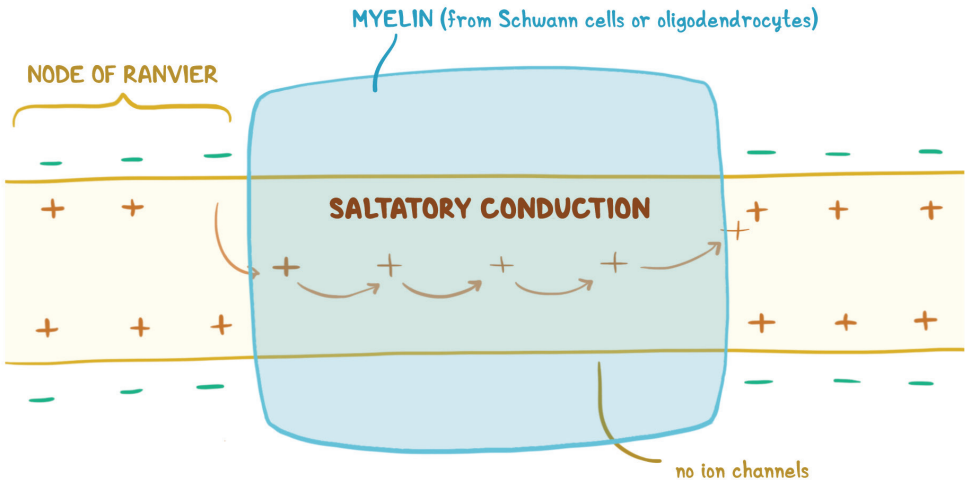

Figure 50.15 Saltatory conduction through myelinated areas of an axon increases the speed of signal conduction down the axon.

ANATOMY & PHYSIOLOGY OF THE EYE

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ANATOMY OF THE EYE

Conjunctiva

- Mucous membrane rich with lymphatic channels
- Portions
  - *Palpebral conjunctiva:* lines interior of eyelid adhered to tarsus
  - *Bulbar conjunctiva:* lines surface of the eye; nonkeratinized stratified squamous epithelium
- Functions
  - Protects cornea from friction via mucus production
  - Contributes to immune surveillance by preventing microbes from entering eye

Lacrimal apparatus

- Consists of lacrimal gland, draining ducts

Lacrimal gland

- Paired, almond-shaped exocrine glands located at upper lateral portion of each orbit
- Compound tubuloacinar structure, contains serous cells producing watery serous secretions, AKA tears
- Innervated by parasympathetic fibers from facial nerve (CN VII)
- Lacrimal secretions contain lysosomes, antibodies, mucus to moisten, protect eye surface
- Pathway of tears
  - Produced in lacrimal gland → blinking causes spread of tears across eyeball → lacrimal canaliculi via lacrimal puncta → lacrimal sac → nasolacrimal duct → empties into inferior nasal meatus inside nasal cavity

CHAMBERS & FLUIDS

- Anterior, posterior segments separated by lens

Posterior segment

- Largest segment
- Filled with gel-like vitreous humor

- Transmits light
- Holds neural layer of retina against retinal pigmented layer
- Maintains shape of eyeball
- Contributes to intraocular pressure

Anterior segment

- Divided into anterior and posterior chambers
- Filled with aqueous humor

Anterior chamber

- Larger chamber
- Bounded by cornea anteriorly, trabecular meshwork laterally, iris posteriorly

Posterior chamber

- Smaller chamber; irregularly shaped; size changes during accommodation
- Bounded by iris anteriorly, lens posteriorly
- Base formed by the ciliary processes

Aqueous humor

- Continually produced by ciliary processes
- Composed of filtered plasma
- Transports needed metabolites to avascular cornea, lens; removes metabolic wastes
- Pathway of flow: enters posterior chamber → passes through pupil → anterior chamber → trabecular network → scleral venous sinus (canal of Schlemm) → venous blood
  - Small amount diffuses into vitreous humor
  - Intraocular pressure primarily depends on balance between production and drainage

LAYERS OF EYE WALL

- Divided into fibrous layer, vascular layer, innermost layer (retina)
  - Superficial → deep

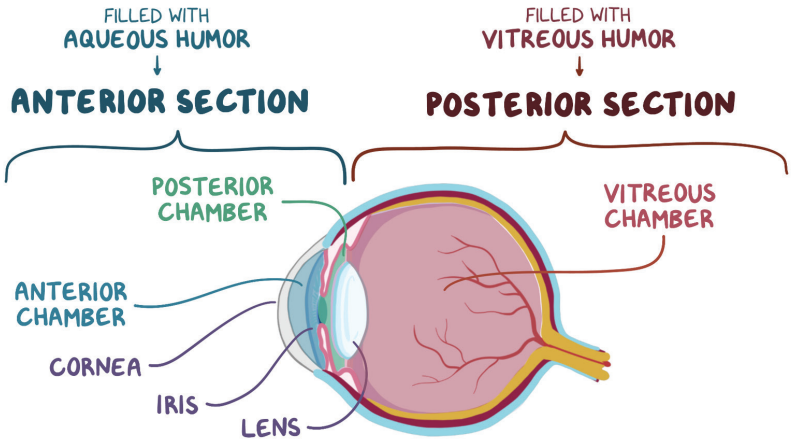

Figure 50.16 Three eye chambers. Anterior and posterior chambers are filled with aqueous humor. Vitreous chamber is filled with vitreous humor.

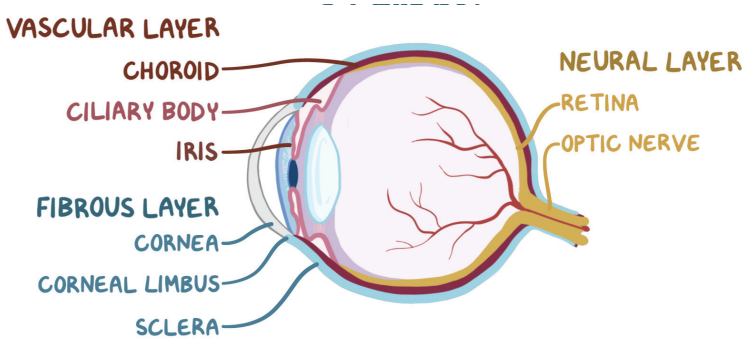

Figure 50.17 The three layers of the eye.

Fibrous layer

- Sclera
  - "White" of eye
  - Composed mainly of collagen, elastic fibers
  - Attachment point for extrinsic eye muscles
  - Continuous with cornea, dura mater of brain
- Limbus
  - Intersection between sclera, cornea
- Cornea
  - Anterior, transparent avascular portion of fibrous layer
  - Makes up major refractive surface of eye
  - *Layers:* anterior → posterior
- Corneal (sub) layers
  - *Stratified squamous epithelium:* derived from neural crest cells
  - *Bowman layer:* acellular; serves as barrier, protecting underlying stroma from malignant cells in epithelium
  - *Stroma:* transparent due to lack of blood vessels, lymphatics
  - *Descemet membrane:* basement layer separating epithelium from Bowman layer; protective function; epithelial stem cells located in this layer
- *Simple squamous epithelium:* AKA corneal endothelium; contains sodium pumps to pump water out of cornea, preserving its clarity

Vascular layer

- AKA uvea
- Choroid, iris, ciliary body
- Pigmented middle layer
- Choroid
  - Richly vascularized
  - Contains melanocytes to absorb light
  - Discontinued by optic nerve posteriorly
- Iris
  - Visible colored portion surrounding pupil (central opening in iris; allows light to enter eye)
  - *Composed of two smooth muscle layers:* sphincter pupillae (contracts during close vision, bright light, parasympathetic activation to constrict pupil), dilator pupillae (contracts during distance vision, dim light, sympathetic activation to dilate pupil)
- Ciliary body
  - *Ciliary muscles:* smooth muscles that control shape of lens
  - *Ciliary processes:* secrete aqueous humor
  - *Ciliary zonule/suspensory ligament:* fibers extending from ciliary processes to lens (secures lens in place)

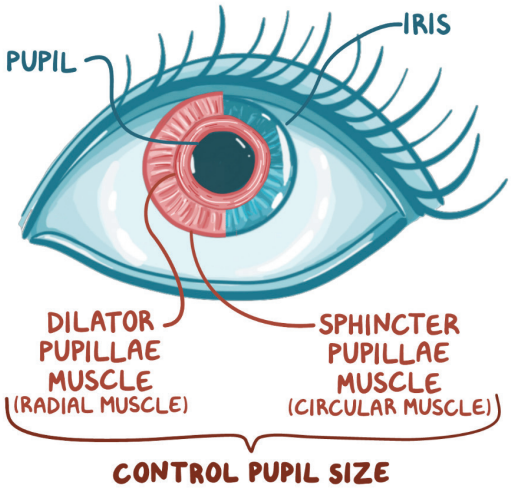

Figure 50.18 The iris is composed of two smooth muscle layers, the dilator pupillae and the sphincter pupillae.

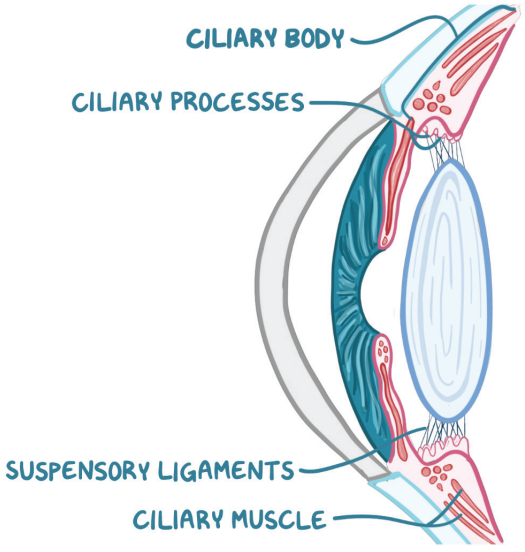

Figure 50.19 Components of the ciliary body.

Retina

- Innermost layer
  - Further divided into outer pigmented layer, inner neural layer
- *Sub-layers:* superficial → deep
  - Pigment cell → photoreceptor → outer nuclear → outer plexiform → inner nuclear → inner plexiform → ganglion cell → optic nerve layer

Retina: outer pigmented layer

- Pigmented epithelial cells absorb light, store vitamin A for photoreceptor cells to use
- *Function:* photoreceptor maintenance

Retina: inner neural layer

- Extends anteriorly to ciliary body
- *Three types of neurons:* photoreceptors, bipolar cells, ganglion cells
  - *Night-vision photoreceptors (rods):* dim-light, non-color vision; more numerous, more sensitive to light than cones; not present on fovea; do not create sharp, clear images/low acuity
  - *Day-vision photoreceptors (cones):* bright-light, color vision; present on fovea; high resolution/high acuity
  - *Bipolar cells:* synapse with ganglion cells
  - *Ganglion cells:* where action potentials are generated; leave eye as optic nerve
- Optic disc
  - Spot where optic nerve (CN II) exits eye
  - AKA "blind spot"
  - Not noticeable since each blind spot is compensated by other eye
- Macula lutea
  - Area of greatest visual acuity
  - Contains mainly cones
  - Only portion of eye with enough cone density to allow detailed color vision, hard focus
  - Lateral to blind spots
- Fovea centralis
  - Center of macula lutea
  - Contains only cones
  - Region of greatest visual acuity in macula
- Optic nerve
  - Composed of retinal ganglion cell axons
  - Exits retina via optic disc
- Optic chiasm
  - X-shaped structure where optic nerves meet
  - Axons from nasal retina cross over to opposite sides → optic tracts
- Optic tract
  - Synapses with cells in lateral geniculate nucleus in both sides of thalamus

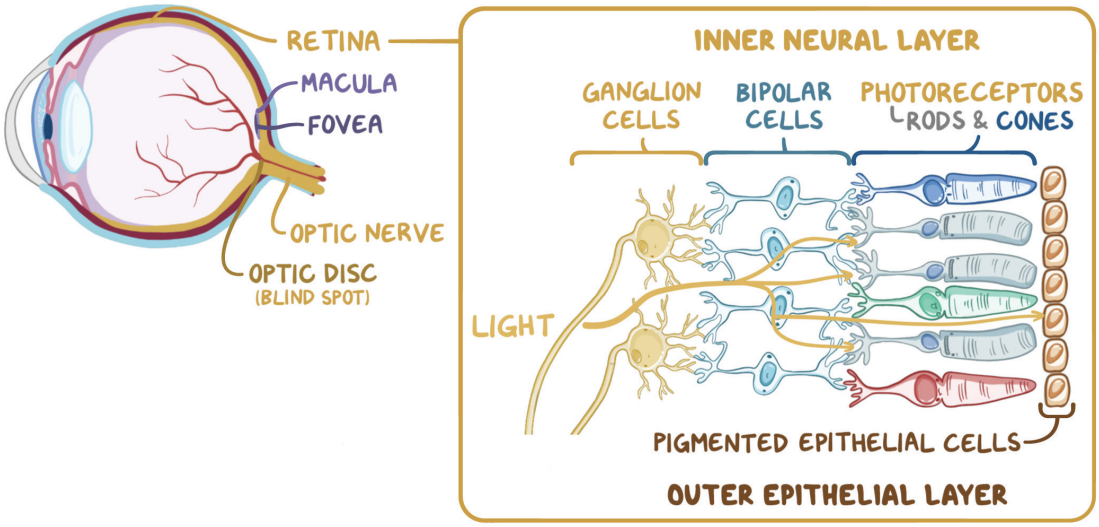

Figure 50.20 Components of the neural layer of the eye.

- Sharpens contrasts, enhances depth perception
- Optic radiations sent to primary visual cortex, AKA occipital lobe

VASCULAR SUPPLY

- Choroidal vessels supply external ⅓ of eye
- Retinal central artery and central vein supply internal ⅔ of the eye

EXTRAOCULAR MUSCLES

- Orbicularis oculi
  - Circular muscle that encircles eye
  - Closes eyelid when contracted
- Levator palpebrae superioris
  - Located inside eyelid
  - Raises eyelid
- Extrinsic eye muscles
  - Control eye movement
  - Originate from walls of orbit (common tendinous/annular ring), insert onto surface of eye

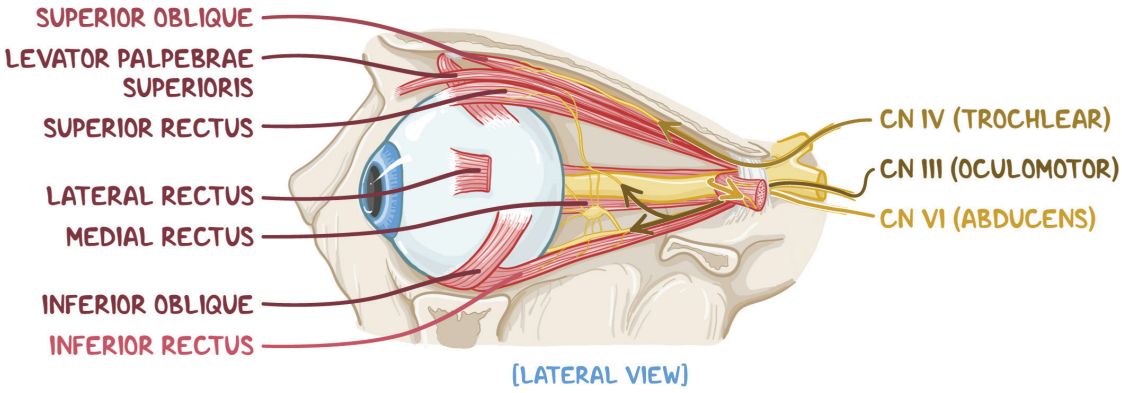

Figure 50.21 Lateral view of the left eye showing the extraocular muscles. Not shown: orbicularis oculi.

EXTRINSIC EYE MUSCLES

	FUNCTION	INNERVATION
SUPERIOR RECTUS	Elevation, intorsion	Oculomotor nerve (CN III)
INFERIOR RECTUS	Depression, extorsion	Oculomotor nerve (CN III)
LATERAL RECTUS	Abduction	Abducens nerve (CN VI)
MEDIAL RECTUS	Adduction	Oculomotor nerve (CN III)
SUPERIOR OBLIQUE	Depression, intorsion	Trochlear nerve (CN IV)
INFERIOR OBLIQUE	Elevation, extorsion	Oculomotor nerve (CN III)

PHYSIOLOGY OF VISION: PHOTORECEPTION & PHOTOTRANSDUCTION

- Photoreceptors, ganglion cells, bipolar cells generate excitatory (EPSPs), inhibitory postsynaptic potentials (IPSPs) instead of action potentials
- Light hits retina, 11-*cis* retinal converted to all-*trans* retinal → production of metarhodopsin II → activation of transducin → activation of phosphodiesterase, converting cGMP to 5-GMP → ↓ cGMP → closure of sodium channels → hyperpolarization of photoreceptor membrane → ↓ glutamate release (excitatory neurotransmitter) from photoreceptors → either inhibition or excitation
  - Depends on which type of glutamate receptor activated

Glutamate receptors

- *Ionotropic receptor:* excitatory/depolarizing
  - ↓ excitatory glutamate response → hyperpolarization of bipolar, horizontal cells → inhibition
- *Metabotropic receptor:* inhibitory/hyperpolarizing
  - ↓ inhibitory glutamate response → depolarization of bipolar, horizontal cells → excitation
- Establish on-off patterns of visual fields

LIGHT VS. DARKNESS

Light

- Photoreceptors hyperpolarize → ↓ glutamate release
  - *Glutamate:* inhibitory
- → Lack of IPSPs causes bipolar cells to depolarize, release neurotransmitter onto ganglion cells → ganglion cells propagates EPSPs → action potential transmitted to brain via optic nerve

Darkness

- Photoreceptors depolarize → increased glutamate release → glutamate causes IPSPs → IPSPs cause bipolar cells to hyperpolarize, inhibits release of neurotransmitters onto ganglion cells → ganglion cells do not propagate EPSPs → no action potentials carried along optic nerve to brain

Focusing light on retina

- Light → cornea → aqueous humor → lens → vitreous humor → neural layer of retina
  - Excites photoreceptors of pigmented layer → photoreception, AKA conversion of light into electrical impulses
- Light bent three times:
  - Entering cornea, AKA major refractive step; entering lens; exiting lens
  - Refractive power of cornea is constant, whereas lens' refractive power can be changed

Distant vision

- Normal resting status of human eye: preset for distant vision
- Ciliary muscles relaxed → ciliary zonule fibers taut → lens is flat (lowest refractive power) → parallel rays focus on retina
- Sympathetic activation causes ciliary muscle relaxation, pupillary dilation
- *Far point of vision:* distance beyond which no accommodation/change in lens shape required for focusing

Near vision

- Involves accommodation, pupillary constriction, convergence
- Lens accommodation
  - Ciliary muscles contract → ciliary zonule fibers relaxed → lens becomes spherical (increases refractory power of lens)
  - Parasympathetic activation → ciliary muscle contraction
- Pupil constriction
  - Mediated by sphincter pupillae muscles of iris
  - Parasympathetic activation
  - ↑ depth of focus
- Convergence of eyes
  - Eyes rotate medially as object moves closer
  - Mediated by extrinsic eye muscles via oculomotor nerve (CN III)

Visual field

- Everything seen by single eye
  - Overlap → central "binocular" visual field

- Split into two parts
  - *Nasal visual field:* projected onto temporal retina, axons stay 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 travel to right half of brain, vice versa
  - *Cause:* axons from nasal retina crossing over
- Some nerve fibers synapse at superior colliculi instead of lateral geniculate body, ascend to midbrain

ANATOMY & PHYSIOLOGY OF THE EAR

osms.it/ear-anatomy-physiology

EXTERNAL EAR ANATOMY

Pinna/auricle

- Composed of elastic cartilage covered with thick skin
- Function
  - Captures sound waves, guides them into auditory canal

External auditory meatus

- AKA auditory canal
- Contains ceruminous glands
  - Secretes cerumen (ear wax); with small hairs, traps foreign objects
- Function
  - Guides sound waves to tympanic membrane

Tympanic membrane

- AKA eardrum
- Thin, connective tissue membrane covered by skin (external), mucous membrane (internal)
- Separates external, middle ear
- Vibrates when hit by sound waves → vibrates ossicles

MIDDLE EAR ANATOMY

Auditory ossicles

- Linked by synovial joints in chain; transmit vibration of tympanic membrane to oval window
- *Malleus/"hammer":* connected to tympanic membrane, incus
- *Incus/"anvil":* connects malleus, stapes
- *Stapes/"stirrup":* footplate inserts onto oval window; connects middle, inner ear
- *Stapedius, tensor tympani:* two skeletal muscles attached to auditory ossicles; protect ears from prolonged, loud noises; not brief explosive, noise (e.g. gunshot)

Oval window

- Membrane-covered opening connecting middle, inner ear; transforms vibrations into fluid waves

Round window

- Membrane-covered opening relieves pressure created by fluid waves

Mastoid antrum

- Canal in posterior wall of tympanic cavity, communicates with mastoid air cells

Pharyngotympanic/eustachian tube

- Canal links middle ear, nasopharynx
- Swallowing/yawning opens tube to equalize middle ear cavity, atmospheric air pressure
- Pathogens may travel through tube → otitis media

INNER EAR ANATOMY

- *Bony labyrinth:* system of channels/cavities, houses membranous labyrinth, fluid filled
- *Three semicircular canals:* rotational acceleration in three planes of movement (lateral, superior, posterior)

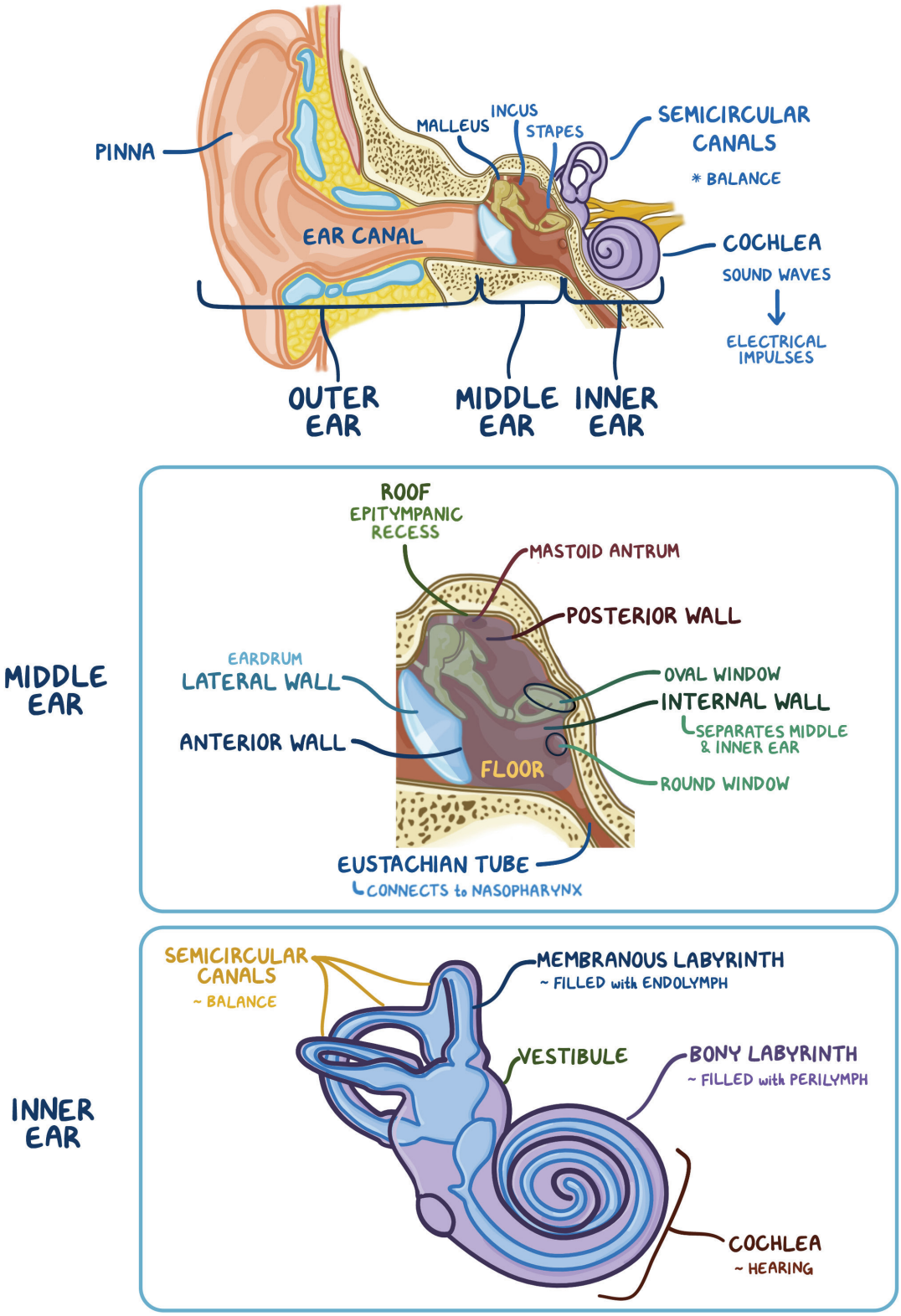

Figure 50.22 Parts of the ear with parts of the middle, inner ear.

Cochlea

- Spiral bony chamber, coils around central axis
- Contains *organ of Corti:* site of auditory transduction
- Two receptors
  - *Inner hair cells:* mechanoreceptors with protruding cilia; arranged in single rows embedded in basilar membrane
  - *Outer hair cells:* mechanoreceptors with protruding cilia; arranged in parallel rows; more numerous; body embedded in basilar membrane
- All hair cell cilia attached to tectorial membrane above

Basilar membrane

- Narrow, thick near oval window/base; wide, thin near cochlea (apex)
- Function
  - Sound reception
- Cochlear nerve (part of cranial nerve VIII) carries information from basilar membrane to brain; cell bodies in spiral ganglia

Three chambers (scalae)

- Scala vestibuli
  - Superior chamber superior to cochlea; with vestibule next to oval window
  - Filled with *perilymph:* similar to cerebrospinal fluid (CSF), extracellular fluid
  - Conducts sound vibrations for hearing, proprioception
- Scala media
  - Middle chamber
  - Cochlear duct
  - Filled with endolymph
- Scala tympani
  - Inferior chamber in cochlea
  - Attaches to round window
  - Filled with perilymph

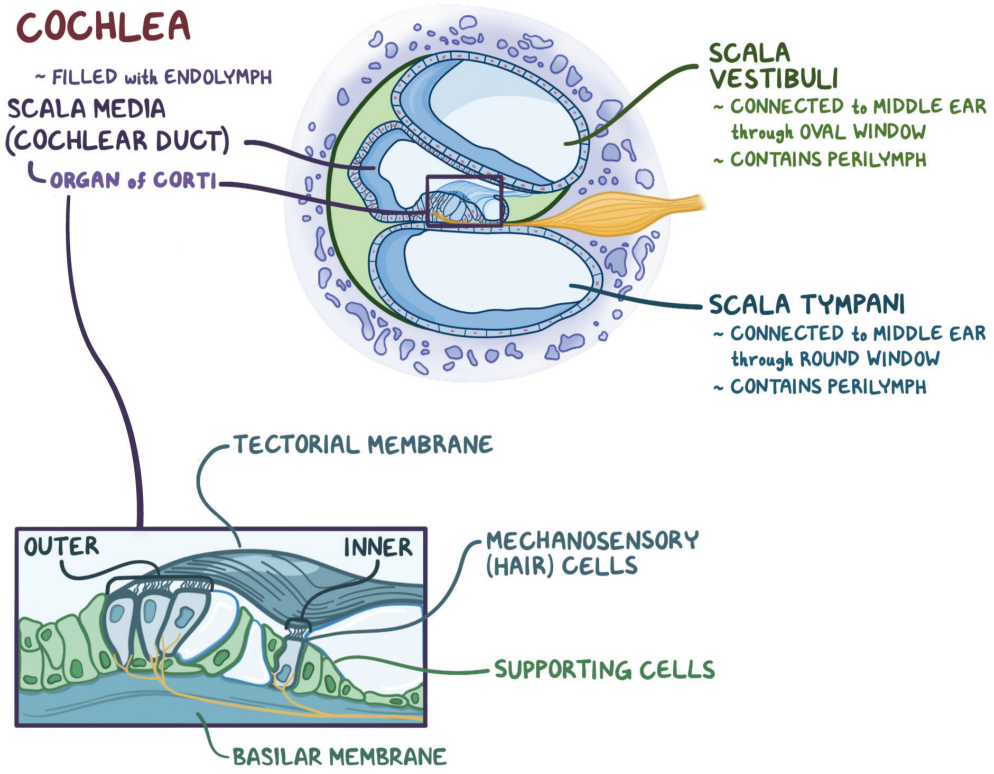

Figure 50.23 Anatomy of the cochlea and organ of Corti.

AUDITORY SYSTEM

Pathway of sound waves

- Sound waves travel through external ear → vibrate tympanic membrane
- Tympanic membrane vibrates ossicles → ossicles amplify sound → stapes vibrates oval window
- Perilymph in scala vestibuli moves → pressure waves travel through perilymph towards helicotrema → cochlear duct → vibrates basilar membrane
- Hair cells bend by shearing force, cilia pushes against tectorial membrane → cilia bend in one direction → ↑ potassium conduction → depolarization (cilia bends in other direction → ↓ potassium → hyperpolarization) → action potential generated in cochlear nerve → sends signals to brain
- Sounds waves > 20Hz
  - Pressure waves → cochlear duct → perilymph of scala tympani → cochlear duct → vibrates basilar membrane → sound waves converted to electrical signal → hearing sensation
- ↑ intensity of sound = ↑ distal membrane displaced in vibratory motion

Amplification of sound waves

- Pressure exerted on oval window > pressure exerted on tympanic membrane (due to smaller size of oval window)
- Ossicles

Frequency mapping (tonotopic map)

- Sound frequencies displace basilar membrane at different locations
- Base *(short, stiff fibers)*: 20,000Hz; nearest to stapes, responds best to high frequencies
- Apex *(long, floppy fibers)*: 20Hz; responds best to low frequencies

Central connections

- Hair cell receptors in organ of Corti → primary cell bodies located in spiral/auditory ganglion (bipolar cells in spiral of cochlea) → axon carries signal → dorsal, ventral cochlear nuclei in pons → secondary axons project via lateral lemniscus → inferior colliculus in midbrain → medial geniculate nucleus in thalamus → projects to primary auditory cortex located at transverse gyrus of Heschl in temporal lobe
- Accessory auditory nuclei
- Superior olivary nucleus: sound localization; integration, interpretation of sound received in both ears at slightly different times

VESTIBULAR SYSTEM

- Sensory information from vestibular system → generates visual images for retina → posture adjustments to maintain balance
- Vestibular organ located within temporal bone adjacent to cochlea; three semicircular canals, otolith organs (utricle, saccule)

Semicircular ducts

- Function
  - Rotational/angular acceleration to maintain balance
- Three canals at right angles to one another in each plane of space (anterior, posterior, lateral)
- Filled with *endolymph:* similar to intracellular fluid (↑ potassium; ↓ sodium)
- *Ampulla:* dilated portion at one end; contains hair cells, protrudes into gelatinous substance, cupula
- *Hair cells:* tonic rate of electrical firing
  - Fire constantly when head not moving
- Head rotation → endolymph deflects hair cells in certain direction in semicircular canals → change in baseline electrical firing rate → propagation down vestibular nerve → brainstem

Otolith organs: utricle, saccule

- Function
  - Linear acceleration
- Contain
  - Hair cells with calcium carbonate crystals
  - Maculae (balance receptor, responds to changes in head position)
- Moving head in any direction → gravity deflects calcium carbonate crystals, attached hair cells → stereocilia bends toward/away from kinocilium → depolarization/hyperpolarization respectively → excitation/inhibition respectively
- *Head upright*: macula horizontal, saccule vertical

- *Tilting head forward/laterally:* ipsilateral utricle excited
- *Tilting head backward/medially:* ipsilateral utricle inhibited
- *Forward movement of head:* saccule excited
- *Lateral, medial movement of head:* saccule excited

Pathway of signal centrally

- Hair cells receptor → propagation of signal → vestibular/Scarpa's ganglion (primary sensory cell bodies of vestibular system; bipolar cell type) → vestibular nuclei in pons (superior, inferior, lateral) → secondary sensory axons project to five areas in central nervous system (CNS)
- Spinal cord via medial, lateral vestibulospinal tracts
- Cerebellum via vermis, flocculonodular lobe
- Extraocular muscles via medial longitudinal fasciculus (MLF), CN nuclei III, IV, VI
- Reticular formation in medulla (vomiting center)
- *Medial geniculate body/cortex:* provides orientation of body in space

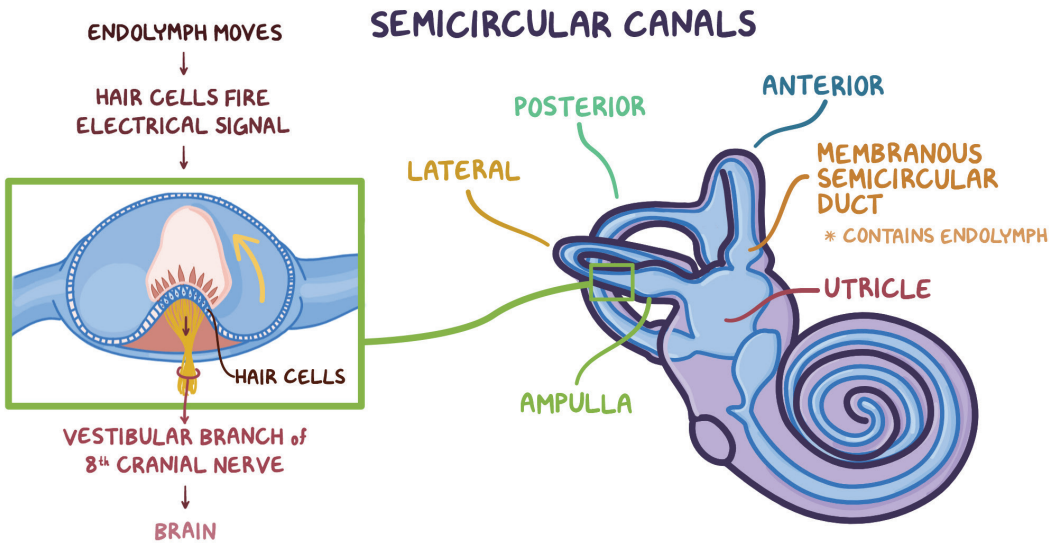

Figure 50.24 The semicircular canals measure rotational/angular acceleration to maintain balance. Movement of endolymph displaces hair cells in the ampulla. Hair cells then transmit this information as an electrical signal along the vestibular branch of CN VIII to the brain.

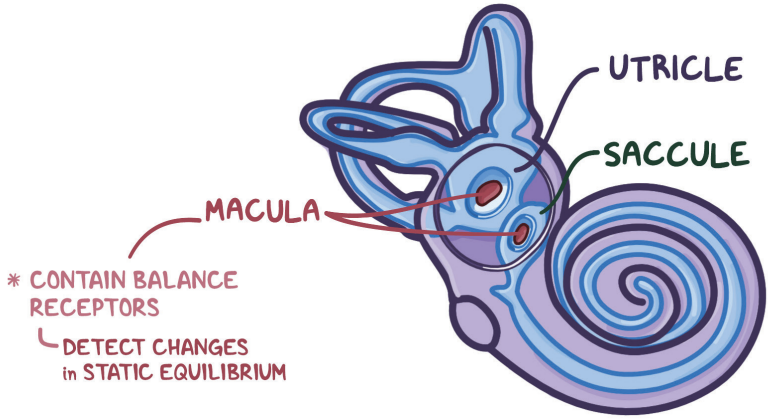

Figure 50.25 The otolith organs, the utricle and saccule, measure linear acceleration using balance receptors in the macula.