

Biology 210

Study Notes Exam 4

Chapter 12: The Central Nervous System

Embryonic Development: at 3 weeks, neural plate forms from ectoderm

- neural plate folds on itself to form neural tube
- the anterior end of the neural tube expands to form the 3 primary brain vesicles: the forebrain, the mesencephalon (midbrain) & the rhombencephalon (hindbrain)
- the remaining posterior end of the neural tube forms the spinal cord
- expansions of the lumen of the neural tube form the brain ventricles
- at week 5, further development of the primary vesicles gives rise to the secondary vesicles:
 - o the forebrain divides into the telencephalon & diencephalons
 - the telencephalon forms the cerebral hemispheres (cerebrum)
 - the diencephalons forms the hypothalamus, thalamus & epithalamus
 - o the hindbrain divides into the metencephalon & myelencephalon
 - the metencephalon forms the cerebellum & pons
 - the myelencephalon forms the medulla oblongata
 - o the midbrain remains undivided
- later in development, the brain outgrows the skull, causing the cerebral hemispheres to grow over & enclose the diencephalons & midbrain
- by week 26, continued growth of the cerebrum causes its surfaces to crease & fold into convolutions

Brain Regions:

- **cerebral hemispheres**
- **brain stem:** inferior portion; continuous with spinal cord
 - o *midbrain, pons & medulla oblongata*
- **diencephalon:** superior to brain stem
 - o *thalamus, hypothalamus, epithalamus & subthalamus*
- cerebellum: posterior to brain stem

Ventricles of Brain:

- ***lateral ventricles:*** deep within cerebral hemispheres, separated anteriorly by the *septum pellucidum*
- ***third ventricle:*** in diencephalon; communicates with lateral ventricles via the intraventricular foramen
- ***fourth ventricle:*** in hindbrain; continuous with third ventricle via the *cerebral aqueduct* (in midbrain)
- apertures (openings) in the walls of the fourth ventricle connect the ventricles with the subarachnoid space surrounding the brain
- the ventricles & subarachnoid space are filled with *cerebrospinal fluid*

Cerebral Hemispheres:

- superior part of brain; ~ 83% of total brain mass
- 3 regions: cerebral cortex (gray matter), white matter & basal nuclei
- **gyri:** elevated ridges of brain tissue, separated by shallow grooves called **sulci**
- **fissures:** deeper grooves separating larger regions of brain
 - o **longitudinal fissure:** separates cerebral hemispheres
 - o **transverse fissure:** separates cerebral hemispheres from cerebellum
- deep *sulci* divide cerebral hemisphere into **5 lobes:** *frontal, parietal, temporal, occipital & insula*
 - o **central sulcus:** separates frontal lobe from parietal lobe
 - bordered by anterior *precentral gyrus* & posterior *postcentral gyrus*
 - o **parieto-occipital sulcus:** medial surface of hemisphere; separates occipital & parietal lobes
 - o **lateral sulcus:** deep sulcus separating temporal lobe from parietal & frontal lobes
 - **insula:** cerebral lobe buried deep within lateral sulcus

Cerebral White Matter: deep to gray matter of cortex

- communication between cortical areas & between cortex & lower CNS centers
- commissures: connect gray areas of hemispheres (corpus callosum, anterior & posterior commissures)
- association fibers: connect parts of same hemisphere
- projection fibers: connect cortex to rest of nervous system

Basal Nuclei (basal ganglia): subcortical nuclei deep within cerebral white matter

- regulate motor control (muscle movements, & perhaps also attention & cognition)
- corpus striatum: composed of lentiform nucleus & caudate nucleus
 - o lentiform nucleus: composed of putamen & globus pallidus
- amygdala: on tail of caudate nucleus; part of limbic system

Cerebral Cortex: conscious mind; awareness, communication, memory & understanding & initiation of voluntary movements

- billions of neurons; ~ 40% of total brain mass
- *Brodman areas:* 52 structural regions of cortex
- cortex has 3 types of functional areas:
 - o **motor areas:** control voluntary motor functions
 - o **sensory areas:** conscious awareness of sensation
 - o **association areas:** integrate information for voluntary action
- each hemisphere controls sensory & motor functions of opposite side of body
- lateralization (specialization) of cortical functions within each hemisphere
- no functional region of cortex acts alone; conscious behavior involves entire cortex

Cerebral Cortex Areas & Functions:

- **Sensory Areas:**
 - o **primary somatosensory cortex:** in postcentral gyrus of parietal lobe
 - spatial discrimination: receive input from sensory receptors in skin & proprioceptors in skeletal muscles & identify region being stimulated

- **somatosensory association cortex:** posterior to primary somatosensory cortex
 - integrates sensory inputs (temp., pressure...) relayed to it by primary somatosensory cortex
 - **visual areas:**
 - *primary visual (striate) cortex:* posterior tip & medial aspect of occipital lobe
 - receives visual information from retinas
 - *visual association area:* surrounds primary visual area in occipital lobe
 - interprets visual stimuli using past visual experiences
 - **auditory areas:**
 - primary auditory cortex: temporal lobe next to lateral sulcus
 - determines pitch, rhythm, & loudness
 - *auditory association area:* posterior to primary auditory cortex
 - perception of sound & sound memory
 - **olfactory (smell) cortex:** frontal lobes just above orbits & medial aspects of temporal lobes
 - part of “rhinencephalon”; conscious awareness of odors
 - **gustatory (taste) cortex:** parietal lobe just deep to temporal lobe
 - perception of taste stimuli
 - **vestibular (equilibrium) cortex:** posterior region of insula deep to temporal lobe
 - conscious awareness of balance
- **Motor Areas:**
- ***primary (somatic) motor cortex:*** located in precentral gyrus of frontal lobe
 - pyramidal cells: large neurons allow precise control over voluntary skeletal muscle movement; form pyramidal (corticospinal) tracts
 - damage (from stroke...) paralyzes muscles on side of body opposite that of lesion (only voluntary movement lost)
 - ***premotor cortex:*** anterior to precentral gyrus in frontal lobe
 - controls learned repetitious or patterned motor skills (playing musical instrument, typing) & helps in planning movements
 - damage results in loss of learned skills, but movement of muscles is often still possible
 - ***Broca’s area:*** anterior to inferior region of premotor area
 - present in one hemisphere only (generally left)
 - special motor speech area – controls muscles of tongue, throat & lips during (& possibly in planning of) speech
- **Association Areas:**
- ***prefrontal cortex:*** anterior portion of frontal lobe; most complex cortical region
 - involved with intellect, cognition, recall & personality
 - necessary for production of abstract ideas, judgment, reasoning, planning, conscience, etc.
 - ***language areas***
 - Wernicke’s area: involved in speaking unfamiliar words
 - Broca’s area: primary area for speech production
 - lateral prefrontal cortex: language comprehension & word analysis

- lateral & ventral regions of temporal lobe: coordinate auditory & visual aspects of speech
- *general (common) interpretation area*: includes parts of temporal, parietal & occipital lobes; usually in left hemisphere
 - likely involved in processing spatial relationships; may be involved in integration of stimuli into single understanding
- *visceral association area*: cortex of insula

Lateralization: each hemisphere has unique abilities

- **cerebral dominance:** one hemisphere dominant for language (usually left)

Diencephalon: central core of forebrain; surrounded by cerebral hemispheres

- **thalamus:** most (80%) of diencephalon & forms walls of third ventricle
 - *intermediate mass*: in some people, holds together bilateral masses of gray matter of thalamus
 - sorts & edits sensory information & relays to appropriate area of sensory cortex & association areas
 - most inputs to cerebral cortex travel through thalamic nuclei (emotion, visceral & motor activity...)
- **hypothalamus:** below thalamus; merges with midbrain inferiorly
 - extends from *optic chiasma* (point of optic nerve crossover) anteriorly to *mamillary bodies* (olfactory pathway relays) posteriorly
 - connected to *pituitary gland* by stalk called *infundibulum*
 - main visceral control center; controls **homeostasis**
 - **Roles:** *autonomic control center, center for emotional response, body temperature regulation, regulation of food intake, regulation of water balance & thirst, regulation of sleep-wake cycles, control of endocrine system function*
- **epithalamus:** dorsal area of diencephalon, forms roof of third ventricle
 - **pineal gland:** secretes hormone *melatonin* – helps in regulation of sleep-wake cycle
 - *choroid plexus:* secretes CSF

Brain Stem:

- **midbrain:** between diencephalon & pons
 - cerebral peduncles: connect midbrain to cerebrum
 - cerebellar peduncles: connect midbrain to cerebellum
 - cerebral aqueduct: connects third & fourth ventricles
 - corpora quadrigemina: midbrain nuclei
 - superior colliculi: visual reflex centers
 - inferior colliculi: auditory relay
 - substantia nigra: pigmented nucleus; contains melanin, a precursor of the neurotransmitter dopamine
 - red nucleus: pigmented nucleus; rich blood supply & iron pigment; motor relay for limb flexion
- **pons:** between midbrain & medulla oblongata

- conduction tracts (pons = bridge); complete pathways between higher brain centers & spinal cord; relays between motor cortex & cerebellum
- **medulla oblongata:** most inferior part of brain stem; blends with spinal cord
 - pyramids: large pyramidal tracts descending from motor cortex
 - tracts cross over to opposite side before entering spinal cord... cerebral hemispheres control voluntary movements of muscles on opposite side of body
 - sensory & visceral motor nuclei (control heart rate & blood vessel diameter, breathing rate, vomiting, coughing...)

Cerebellum: dorsal to pons & medulla; inferior to occipital lobes; ~ 11% of total brain mass

- bilaterally symmetrical with two hemispheres connected medially by vermis
- convoluted with gyri called folia
- fissures divide each hemisphere into lobes: anterior, posterior & flocculonodular
- **arbor vitae:** tree-like white matter formed by axons of Purkinje cells
- processes information from cerebral motor cortex & from sensory pathways and sends instructions to cerebral motor cortex & motor centers to regulate balance, posture & coordinated skeletal muscle movement

Limbic System: regions of the medial aspects of each cerebral hemisphere & diencephalons encircling brain stem (limbus = ring) & linked by the **fornix**

- **emotional brain**
 - **amygdala:** recognizes angry or fearful facial expressions, assesses danger & elicits fear response
 - **cingulate gyrus:** regulation of expression of emotions & feelings of frustration
 - hippocampus: plays a role in storing information in long-term memory

Reticular Formation: extends through core of brainstem

- *reticular activating system:* maintains cerebral cortical alertness
- filters out repetitive stimuli
- motor nuclei help regulate skeletal & visceral muscle activity

Brain Wave Patterns & EEG:

- an **electroencephalogram (EEG)** records electrical activity of neurons
- the patterns of electrical activity can be discriminated as 4 types of brain waves, with decreasing regularity:
 - **alpha waves** (8-13 Hz): indicate relaxed state of wakefulness
 - **beta waves** (14-25 Hz): indicate mental alertness (concentration)
 - **theta waves** (4-7 Hz): common in children; abnormal in adults
 - **delta waves** (< 4 Hz): seen during sleep & anesthesia; abnormal when awake (indicate brain damage)
- **epilepsy** involves epileptic seizures that reflect abnormal electrical activity of brain neurons that interferes with normal “communication” of neurons
 - can be controlled by anticonvulsive drugs (inhibitory neurotransmitters, sedatives)

Sleep & Sleep-Awake Cycles:

- **sleep** is defined as a state of changed consciousness, from which a person can be aroused by stimulation (distinguished from coma, where a person cannot be aroused)
- 2 major types of sleep:
 - **NREM (non-rapid eye movement) sleep:** 4 stages ending in slow-wave sleep
 - **REM (rapid eye movement) sleep:** appears after slow-wave sleep; normally occurs about every 90 minutes
 - Most dreams occur during REM sleep (nightmares most often occur during stage 3 & 4 NREM sleep)
- **Sleep disorders:** narcolepsy (abrupt lapses into sleep from wakefulness), insomnia (chronic inability to attain sufficient sleep), sleep apnea (temporary cessation of breathing during sleep)

Memory:

- **memory** involves the storage & retrieval of information
- memory storage occurs in stages & is continually changing
- the **hippocampus** of the limbic system & surrounding structures play roles in memory processing
- memory traces (chemical & structural changes that encode memory) are widely distributed in the brain
- memory storage involves 2 distinct stages:
 - **short-term memory (STM) or working memory:** fleeting memory limited to 7 or 8 chunks of information
 - **long-term memory (LTM):** appears to have limitless capacity
- transfer of information from STM to LTM is enhanced by:
 - emotion tied to an event
 - rehearsal
 - association of new information with old information in LTM
 - automatic (unconscious) memory
- categories of memory:
 - **fact (declarative) memory:** learning explicit information (names, faces, words, dates...); stored with context
 - **skill (procedural) memory:** less conscious memory; involves motor activity (riding a bike or playing a musical instrument); often stored without context
- Memory storage pathway: sensory perception in cerebral cortex -> hippocampus & amygdala -> diencephalon, basal forebrain & prefrontal cortex -> back to sensory cortex
- **Anterograde amnesia:** ability to associate new information with old is lost; person lives in here & now, but can still learn skills
- **Retrograde amnesia:** loss of memories formed in the distant past

Protective Coverings of the Brain: cranium & cranial meninges

- **meninges:** 3 connective tissue membranes just external to brain
 - **dura mater:** outer layer; 2-layered sheet of fibrous CT (periosteal layer & meningeal layer)
 - **dural sinuses:** collect venous blood from brain & send to jugular veins

- *dural septa*: inward extensions of dura mater that subdivide cranial cavity & limit excessive brain movement
 - *falx cerebri, falx cerebelli, & tentorium cerebelli*
 - *arachnoid*: middle layer; *subarachnoid space* contains large capillaries & CSF
 - *pia mater*: innermost layer; just superior to & clings to cerebrum; rich with tiny blood vessels serving brain tissue
- ***cerebrospinal fluid***: formed by choroid plexuses hanging from the roof of the ventricles
 - capillaries feed choroid plexus; *ependymal cells* lining ventricles regulate content of filtrate
 - *hydrocephalus*: excess CSF in ventricles (due to faulty drainage of CSF into subarachnoid space – caused by tumors, inflammation or developmental abnormalities, head injury or meningitis) causes increased pressure that can damage nerves; can be relieved by draining excess CSF into vena cava or abdominal cavity

Blood Flow to Brain:

- blood flows to brain via *internal carotid & vertebral arteries*
- *internal jugular veins* return blood to heart from head
- ***blood-brain barrier***: capillaries serving brain tissue have tighter junctions than most capillaries of body; let very little through
 - bloodborne substances within capillaries of brain separated from extracellular space & neurons by continuous endothelium of capillary walls, thick basal lamina & astrocytes contacting capillaries
 - selective barrier: allows diffusion of nutrients but not metabolic wastes to enter brain tissue
 - ineffective against fats, fat soluble molecules (some drugs) & alcohol
 - some beneficial drugs (for brain cancer or infections) also cannot pass
 - brain injury or infection/inflammation may result in localized breakdown of blood-brain barrier

Brain Disorders:

- ***concussion***: slight brain injury with mild short-lived symptoms
- ***contusion***: more severe brain tissue destruction; may produce coma
- ***subdural/subarachnoid hemorrhage***: bleeding into meningeal spaces
- ***cerebral edema***: swelling of brain due to trauma; treated with anti-inflammatories
- ***cerebrovascular accident (CVA or stroke)***: blocked blood circulation to brain; brain tissue dies
 - ***ischemia***: deprivation of blood supply to brain tissue; oxygen & nutrient deficit
 - ***transient ischemic attack (TIA)***: temporary neurological deficits (numbness, paralysis, impaired speech); warning flags for possible CVA
 - may be due to glutamate release by oxygen-deprived dying neurons exciting living neurons at NMDA receptors, leading to unregulated calcium uptake & causing healthy neurons to die due to free radicals & inflammation
- ***Alzheimer's disease (AD)***: progressive neurodegenerative disease that leads to dementia with memory loss, disorientation & eventually speech loss & hallucination

- AD is associated with an *acetylcholine* shortage & structural changes in memory centers of brain; some familial cases & genetic mutations involved
- accumulation of plaques with beta amyloid peptide & neurofibrillar tangles
- damage appears to be due to overstimulation of NMDA receptors with glutamate & calcium influx (as above)
- **Parkinson's disease:** characterized by wide-eyed, unblinking expression, muscular rigidity & involuntary tremors
 - results from degeneration of dopamine-producing cells of substantia nigra
 - treatment options: dopamine replacement (L-dopa), deep brain stimulation

Spinal Cord Anatomy

Protection of Spinal Cord: *vertebral column, meninges & cerebrospinal fluid (CSF)*

- **vertebral column:** spinal cord is located within the vertebral canal of the vertebral column
 - vertebral foramina form the canal, & vertebral ligaments, meninges & CSF provide additional protection
- **meninges:** 3 connective tissue membranes just external to spinal cord
 - *dura mater, arachnoid, & pia mater*
 - *epidural space:* between vertebrae & dura mater; filled with fat & veins
 - *denticulate ligaments:* extensions or thickenings of the pia mater that suspend the spinal cord within the meninges (protection against shock)
- **cerebrospinal fluid:** formed by choroid plexuses hanging from the roof of the ventricles in the brain & runs through central canal of spinal cord
 - *lumbar puncture (spinal tap):* removal of CSF for testing; larger space in meningeal sac in lumbar area since spinal cord ends at L1

Spinal Cord: enclosed within vertebral column; extends from foramen magnum of skull to level of first or second lumbar vertebrae

- two-way conduction path to & from brain
- major reflex center: spinal reflexes initiated & completed at spinal cord level

External Anatomy of Spinal Cord:

- 31 pairs of **spinal nerves** attach to spinal cord by paired roots
- 2 enlargements (thickenings of spinal cord)
 - *cervical enlargement:* from C4-T1: sends nerves to upper limbs
 - *lumbar enlargement:* from T9-T12: sends nerves to lower limbs
- **conus medullaris:** tapering of spinal cord between L1 & L2
- **filum terminale:** extension of pia mater that anchors spinal cord to coccyx
- **cauda equina** (horse's tail): roots of lumbar & sacral spinal nerves travel along spinal cord inferiorly before exit
- **spinal nerves:** communicate between spinal cord & body tissues served
 - **dorsal roots** carry sensory tracts to spinal cord
 - dorsal root *ganglia* contain cell bodies of sensory neurons
 - **ventral roots** send motor tracts away from spinal cord

Internal Anatomy of Spinal Cord:

- grooves: **anterior median fissure & posterior median sulcus**
- **inner gray matter & outer white matter**
- **gray matter:** butterfly-shaped region surrounded by outer white matter
 - **anterior, lateral & posterior horns** containing primarily cell bodies of neurons
 - **anterior horns:** cell bodies of somatic motor neurons
 - **posterior horns:** interneurons & cell bodies of 2nd order sensory neurons (sometimes also called interneurons)
 - **lateral horns:** cell bodies of autonomic motor neurons
 - **gray commissure:** across center of gray matter; contains **central canal** – an open space with CSF continuous with the ventricles of the brain (arises from 4th ventricle)
- **white matter:** nerve fibers allow communication between different parts of spinal cord & between spinal cord & brain
 - **anterior, posterior & lateral columns (funiculi)** containing axons carrying information to & from the brain
 - **ascending (sensory) tracts:** axons carrying nerve impulses up spinal cord toward brain
 - **lateral & anterior spinothalamic tracts:** convey nerve impulses for sensing pain, temperature, deep pressure & crude sense of touch
 - **posterior columns:** carry nerve impulses for proprioception (muscles & joints), light pressure, vibration & discriminative touch
 - **descending (motor) tracts:** axons carrying nerve impulses down spinal cord from brain
 - **direct pathways:** cause precise voluntary skeletal muscle movement
 - **lateral & anterior corticospinal tracts:** from cerebral cortex
 - **corticobulbar tracts:** from brainstem (“bulb” of brain)
 - **indirect pathways:** maintain muscle tone, posture & balance
 - **rubrospinal, tectospinal & vestibulospinal tracts** (from red nucleus & superior colliculus of midbrain, & vestibular nucleus of medulla, respectively)

Chapter 13: The Peripheral Nervous System & Reflex Activity

Sensory Receptors: specialized to respond to changes (stimuli) in environment

Classification by Stimulus Type:

- **mechanoreceptors:** respond to touch, pressure (including blood pressure), vibration, stretch & itch
- **thermoreceptors:** respond to temperature changes
- **photoreceptors:** respond to light energy
- **chemoreceptors:** respond to chemicals in solution (molecules smelled, tasted; changes in blood pH, solutes)
- **nociceptors:** respond to pain from potentially damaging stimulus

Classification by Location:

- **exteroceptors:** sensitive to stimuli arising outside body (touch, pressure, pain receptors)
- **interoceptors:** sensitive to stimuli arising inside body (internal viscera, blood vessels...)
- **proprioceptors:** respond to internal stimuli in skeletal muscle, tendons, joints, ligaments & connective tissue surrounding muscles & bones

Classification by Structural Complexity:

- **simple receptors:** modified dendritic endings of sensory neurons (most receptors in the body)
- **complex receptors:** sense organs associated with special senses (vision, hearing, smell & taste)
- **general sensory receptors (simple receptors):** respond to tactile sensation, temperature, pain & muscle sense
 - **free dendritic endings:** everywhere; most abundant in epithelial & connective tissues
 - most are unmyelinated with small diameter (slow)
 - respond chiefly to pain & temperature
 - examples: Merkel discs in deep skin epidermis & root hair plexuses that surround hair follicles
 - **encapsulated nerve endings:** one or more sensory neuron terminals in connective tissue capsule; most are mechanoreceptors
 - **Meissner's corpuscles:** touch receptors in dermal papillae
 - **Pacinian corpuscles:** deep pressure receptors in hypodermis
 - **Ruffini's corpuscles:** deep, continuous pressure receptors in the dermis, hypodermis & joint capsules
 - **muscle spindles:** proprioceptors in skeletal muscle perimysium; cause muscle contraction to counteract stretch
 - **Golgi tendon organs:** proprioceptors in tendons (close to muscle insertion); cause muscle relaxation (inhibitory to prevent damage due to overstretching)
 - **joint kinesthetic receptors:** proprioceptors within articular capsules in synovial joints; several receptor types that monitor joint function

Sensory Integration

- **Organization of Somatosensory System:**
 - **Receptor level:** sensory receptors
 - **Circuit level:** ascending pathways
 - **Perceptual level:** neuronal circuits in cerebral cortex

- **Processing at Receptor Level:**
 - **Transduction by sensory receptors:** a stimulus alters permeability of membrane receptors, leading to a local graded potential or **receptor potential** (like EPSP)... if the receptor is a separate cell (nonneuron), depolarization is called a **generator potential**
 - If the receptor potential is at or above the threshold, an action potential will be generated & propagated to the CNS
 - **Adaptation by sensory receptors:** some receptors (pressure, touch, smell) become insensitive to the same stimuli over time (don't notice feel of clothing after some time) while others do not adapt (nociceptors & proprioceptors need to continually react to stimuli)

- **Processing at Circuit Level:**
 - ascending pathways conduct sensory impulses upward
 - **first-order neurons:** conduct impulses from sensory receptors to brain stem or spinal cord
 - **second-order neurons:** conduct impulses from spinal cord or medullary nuclei to the thalamus or cerebellum
 - **third-order neurons:** conduct impulses from the thalamus to the somatosensory cortex
 - **posterior column-medial lemniscus pathway:** impulses conveyed to cerebral cortex via posterior column of spinal cord & medial lemniscus of brain stem (relayed by thalamus)
 - transmit discriminative touch, pressure, vibration, & conscious proprioception impulses, & also arousal (to RAS)
 - **anterolateral (spinothalamic) pathway:** : impulses conveyed to cerebral cortex via anterior & lateral spinothalamic tracts within anterior & lateral columns of spinal cord (also relayed by thalamus)
 - transmit pain, temperature (lateral) & itch, tickle, pressure & coarse touch (anterior) impulses
 - involved with emotional aspects of perception & some higher level motor reflexes (orienting to stimulus)
 - **spinocerebellar tracts:** convey information from proprioceptors on one side of the body to the same side of the cerebellum to coordinate skeletal muscle activity (unconscious sensation) & maintain posture & balance

- **Processing at the Perceptual Level:**
 - **Perception** involves awareness of stimuli, their origin & discrimination of their characteristics

- Localization & modality of sensory inputs are begun as tracts reach the thalamus, but most processing occurs in the *somatosensory cortex*
- *Main aspects of sensory detection:*
 - *perceptual detection:* detection of stimulus
 - *magnitude estimation:* how much of the stimulus
 - *spatial discrimination:* site or pattern of stimulus
 - *feature abstraction:* neuron or circuit is tuned to one feature over others
 - *quality discrimination:* differentiation of submodalities (parts) of sensation
 - *pattern recognition:* find patterns in complex stimuli

Nerves & Associated Ganglia:

Nerve: cordlike organ of PNS consisting of bundles of axons enclosed in layers of connective tissue

- each axon enclosed in *endoneurium*
- bundles of fibers (fascicles) enclosed in *perineurium*
- bundles of fascicles enclosed in *epineurium*
- **sensory (afferent) nerves:** carry impulses toward CNS
- **motor (efferent) nerves:** carry impulses away from CNS
- **mixed nerves:** contain both sensory & motor fibers (can be somatic &/or autonomic)
- peripheral nerves classified as *spinal nerves* or *cranial nerves*
- **ganglia:** collections of neuron cell bodies associated with nerves in PNS

Regeneration of Nerve Fibers:

- in general, mature neurons are amitotic (do not divide)
- if cell body remains intact, regeneration is possible
- following injury, the two ends of neuron surrounding site of injury seal off & swell from accumulation of materials
- *Wallerian degeneration:* the axon distal to the site of injury & its myelin sheath begins to disintegrate (debris cleaned up by macrophages & Schwann cells)
- **Schwann cells** proliferate in response to macrophage signals, & express cell adhesion molecules & release growth factors to stimulate axonal growth... then, they guide axon extensions across the gap (form *regeneration tube* to bridge gap) & remyelinate the axon
- The greater the distance between broken axon ends, the less the chance of regeneration

Cranial Nerves: 12 pairs

- I. **Olfactory Nerve (cranial nerve I):** *sensory* for smell
- II. **Optic Nerve (cranial nerve II):** *sensory* for vision
- III. **Oculomotor Nerve (cranial nerve III):** *motor* for eyeball movement (4 of the 6 extrinsic eye muscles) & upper eyelid movement (*sensory* for proprioception in extrinsic eye muscles)
- IV. **Trochlear Nerve (cranial nerve IV):** *motor* for eyeball movement (superior oblique muscle) (*sensory* for proprioception in superior oblique muscle)
- V. **Trigeminal Nerve (cranial nerve V):** *sensory* for touch, pain & thermal sensation in face; *motor* for chewing

- VI. **Abducens Nerve (cranial nerve VI):** *motor* for eyeball abduction (lateral rectus muscle) (sensory for proprioception in lateral rectus muscle)
- VII. **Facial Nerve (cranial nerve VII):** *sensory* for taste (anterior 2/3 of tongue); *motor* for contraction of facial muscles and activity of lacrimal, nasal, palatine & salivary glands
- VIII. **Vestibulocochlear Nerve (cranial nerve VIII):** *sensory* for hearing (cochlear nerve) & equilibrium (vestibular nerve)
- IX. **Glossopharyngeal Nerve (cranial nerve IX):** *sensory* for taste (posterior 1/3 of tongue); *motor* for swallowing (elevation of larynx & pharynx)
- X. **Vagus Nerve (cranial nerve X):** *sensory* for taste (epiglottis), baroreception & chemoreception in blood vessels, and sensation from thoracic & abdominal organs; *motor* for regulation of heart rate, breathing, swallowing/speech & digestive system activity
- XI. **Accessory Nerve (cranial nerve XI):** *motor* for head & neck movement and swallowing (sensory for proprioception in sternocleidomastoid & trapezius muscles)
- XII. **Hypoglossal Nerve (cranial nerve XII):** *motor* for speech & swallowing (sensory for proprioception in tongue muscles)

Spinal Nerves: 31 pairs

- 8 pairs of cervical
- 12 pairs of thoracic
- 5 pairs of lumbar
- 5 pairs of sacral
- 1 pair of coccygeal
- **ventral roots:** contain motor (efferent) fibers arising from the anterior horn & extending to skeletal muscle fibers
- **dorsal roots:** contain sensory (afferent) fibers arising from sensory neurons in the dorsal root ganglia; conduct impulses from sensory receptors to spinal cord
- spinal nerves are short (1-2 cm); branch into smaller **dorsal ramus**, larger **ventral ramus** & tiny **meningeal branch** to meninges & blood vessels
 - o thoracic spinal nerves have **rami communicantes** with autonomic (visceral) fibers
- **dermatomes:** areas of skin innervated by individual spinal nerves
- **Hilton's Law:** any nerve serving a muscle that produces movement at a joint also innervates the joint & the skin over the joint

Nerve Plexuses: interlacing nerve networks (lateral to spinal cord) from ventral rami of groups of spinal nerves serving similar body regions

- muscles of the anterolateral thorax & abdominal wall served by spinal nerves T1-T12 as intercostal nerves, with cutaneous branches to skin
- **cervical plexus:** spinal nerves C1-C5; supplies skin & muscles of head, neck & superior part of shoulders & chest
 - o **phrenic nerve:** serves diaphragm for breathing
- **brachial plexus:** spinal nerves C5-T1; supplies shoulders & upper limbs
 - o **branches:** roots (ventral rami of C5-T1), trunks (upper, middle, lower), divisions (anterior & posterior) & cords (lateral, medial & posterior)
 - o **nerves:** **musculocutaneous, median, ulnar, radial & axillary**

- **lumbosacral plexus:** lower limb; branches to pelvis, abdomen & buttocks
 - **lumbar plexus:** spinal nerves L1-L4; supplies anterior abdominal wall, external genitals & part of lower limbs
 - **femoral nerve:** serves muscles of anterior upper leg (quadriceps) & skin of anterior & medial lower leg
 - **obturator nerve:** serves adductor muscles of medial thigh
 - **sacral plexus:** spinal nerves L4-S4; supplies buttocks, perineum & lower limbs
 - **sciatic nerve:** serves entire leg except anteromedial thigh (longest & thickest nerve in body); branches to *tibial & common fibular nerves* just above knee
 - **coccygeal plexus:** spinal nerves S4-Co; supplies small area of skin in coccygeal region

Somatic Motor Pathways:

Levels of Motor Control:

- some lower-level motor control is mediated by reflex arcs, but complex motor activities appear to be regulated by fixed-action patterns (stereotyped sequential motor actions triggered internally or by environmental stimuli)
- **Segmental level:** segmental circuits of *spinal cord*
 - Segmental circuits activate anterior horn segments of the spinal cord to stimulate a specific group of muscle fibers
 - Circuits controlling locomotion & common motor activity are called central pattern generators (CPGs)
- **Projection level:** *cortical* motor areas that produce the *direct (pyramidal) system & indirect (extrapyramidal or multineuronal) system*.
 - axons of the neurons at this level project to the *spinal cord* & help control both reflex & fixed-action pattern activities, and produce voluntary movement
- **Programs & Instructions Level:** neurons in the basal nuclei of the cerebrum and of the cerebellum (*precommand areas*) that regulate motor activity
 - Involved in starting & stopping movements, coordinating movements with posture, blocking unwanted movements & maintaining muscle tone
 - **Cerebellum:** center for sensorimotor integration & control, correcting errors in muscle activity, & fine-tuning motor activity
 - damage to the cerebellum results in disorders of synergy & muscle tone, disturbances of equilibrium & speech disorders
 - **Basal nuclei:** receive inputs from all cortical areas & send output to the premotor & prefrontal cortex to coordinate more complex motor activities
- **Organization of Upper Motor Neuron Pathways:**
 - *cortical* motor areas that produce the *direct (pyramidal) system & indirect (extrapyramidal or multineuronal) system*
 - **Direct Motor Pathways**
 - lateral corticospinal tracts: conveys nerve impulses from motor cortex to skeletal muscles on opposite side of the body for precise, voluntary movements of hands & limbs
 - anterior corticospinal tracts: conveys nerve impulses from motor cortex to skeletal muscles on opposite side of the body for movements of axial skeleton

- corticobulbar tracts: conveys nerve impulses from motor cortex to skeletal muscles of the head & neck for precise, voluntary movements
- **Indirect (extrapyramidal) tracts**
 - all somatic motor tracts other than direct motor pathways
 - axons of UMN that carry impulses from indirect pathways descend from various nuclei of the brain stem into 5 major tracts of spinal cord & terminate on local circuit neurons or LMNs
 - rubrospinal, tectospinal, vestibulospinal, lateral & medial reticulospinal tracts

Reflexes:

- **somatic reflexes:** lead to contraction of skeletal muscles
- **autonomic (visceral) reflexes:** lead to responses from smooth muscle, cardiac muscle & glands

Reflex arc:

- **sensory receptor:** distal end of sensory neuron; responds to *stimulus*
- **sensory neuron:** carries impulse from receptor to axon terminals in gray matter of spinal cord (or brain stem)
- **integration center:** within CNS gray matter, signal travels across synapse or through interneuron, generating a response
- **motor neuron:** response impulse is sent from sensory neuron or interneuron through motor neuron to effector
- **effector:** muscle or gland that carries out response (reflex)
- **general reflex types:**
 - *monosynaptic reflex:* involves only 2 neurons (sensory & motor) & one synapse
 - *polysynaptic reflex:* involves more than 2 neurons (sensory, motor & interneurons) & more than one synapse
 - *ipsilateral reflex:* sensory neurons enter & motor neurons exit spinal cord on same side
 - *contralateral reflex:* sensory neurons enter & motor neurons exit spinal cord on opposite sides
- **somatic spinal reflexes:**
 - **stretch reflex:** causes contraction of skeletal muscle in response to muscle stretching
 - sensory receptors are *muscle spindles*
 - **tendon reflex:** causes muscle relaxation in response to increasing muscle tension (to prevent tendons from tearing)
 - sensory receptors are (*Golgi*) *tendon organs*
 - **flexor (withdrawal) reflex:** causes muscle contraction to move body region away from painful stimulus
 - *plantar flexion reflex:* curling under of toes in response to stimulation of lateral outer margin of toe
 - damage to descending motor pathways causes great toe extension (Babinski sign), although a normal response in infants
 - **crossed extensor reflex:** works with withdrawal reflex to maintain balance

- contraction of extensors on opposite side of body to compensate for withdrawal (*contralateral reflex*)

Chapter 14: The Autonomic Nervous System

Autonomic Nervous System – system of motor neurons within the *motor division* of the *peripheral nervous system* that innervates smooth muscle, cardiac muscle & glands.

- also known as the *involuntary nervous system* (subconscious control) & the *general visceral motor system*

* see chart below for comparisons of the branches of the motor division of the PNS & the divisions of the autonomic nervous system

Parasympathetic division: “resting & digesting” system... low energy use (low blood pressure, heart rate & respiratory rate), active digestion of food & elimination of waste; pupils of eyes are constricted & lenses accommodated for close vision

Sympathetic division: “fight or flight” system... activated during emergency or threatening/stressful situations; rapid heart & breathing rate, greatly decreased gastrointestinal & urinary tract activity, pupils dilated. Visceral blood vessels are constricted & blood is shunted to active skeletal muscles

Anatomy of the autonomic nervous system:

Parasympathetic (Craniosacral) division:

Cranial Outflow:

- **Cranial nerve III (Oculomotor nerves) → Ciliary Ganglia:**
 - innervate smooth muscle in eyes to constrict pupils & bulge lenses (for close vision)
- **Cranial nerve VII (Facial nerves) → Pterygopalatine Ganglia:**
 - travel to nasal mucosa, palate & pharynx; stimulate secretion from nasal and lacrimal glands
- **Cranial nerve VII (Facial nerves) → Submandibular Ganglia:**
 - stimulate submandibular & sublingual salivary glands
- **Cranial nerve IX (Glossopharyngeal nerves) → Otic Ganglia:**
 - stimulate parotid salivary glands
- * Preganglionic fibers from cranial nerves III, VII & IX join branches of the trigeminal nerve as postganglionic fibers to their targets
- **Cranial nerve X (Vagus nerves):** most (~90%) of preganglionic parasympathetic fibers; branches to:
 - *cardiac plexuses:* to slow heart rate
 - *pulmonary plexuses:* to slow breathing rate
 - *esophageal plexuses:* branches to the liver, gallbladder, stomach, small intestine, kidneys, pancreas, & and half of large intestine to stimulate digestion

Sacral Outflow: arises from sacral spinal nerves S₂-S₄; branch to form pelvic splanchnic nerves & synapse in distal half of large intestine, the urinary bladder, ureters & reproductive organs

Sympathetic (Thoracolumbar) division:

- innervates more organs than the parasympathetic division... in addition to supplying the visceral organs, it also supplies smooth muscle of visceral structures of the skin (sweat glands, arrector pili muscles) as well as smooth muscle of all arteries and veins
- clusters of sympathetic preganglionic neurons (from spinal nerves T₁-L₂) produce the ***lateral horns*** of the gray matter of the spinal cord (lateral horns are absent in the sacral region of the spinal cord (fewer parasympathetic preganglionic neurons))
- all *preganglionic* neurons enter a **paravertebral (chain) ganglion**... once there, they can:
 - synapse with a postganglionic neuron in the same chain ganglion or ascend to synapse in a ***cervical chain ganglion (trunk ganglion)***
 - spinal nerves T₁-T₄ synapse in a *superior cervical ganglion* & serve the head (skin, blood vessels, stimulate dilator muscles of eyes & inhibit nasal & salivary glands) & send branches to heart
 - spinal nerves T₁-T₆ synapse in a *middle & inferior cervical ganglion* (serve the heart, thyroid gland & skin) or a *chain ganglion* (serve the heart, aorta, lungs & esophagus)
 - pass through the chain ganglion & synapse in a ***prevertebral (collateral) ganglion*** (such as the celiac, mesenteric & hypogastric ganglia)
 - thoracic spinal nerves T₅-L₂ take this route & travel in the thoracic splanchnic nerves to synapse at the *celiac & superior mesenteric ganglia* (serve the stomach, small intestine, proximal half of large intestine, liver, spleen & kidneys);
 - thoracic spinal nerves T₁₀-L₂ descend to the lumbar & sacral chain ganglia... some synapse there, but most travel in the lumbar & sacral splanchnic nerves to synapse in the *inferior mesenteric & hypogastric ganglia* (serve the distal half of large intestine, urinary bladder & reproductive organs)
 - some fibers in the thoracic splanchnic nerves pass through the celiac ganglion & synapse with cells in the adrenal medulla (stimulates secretion of epinephrine & norepinephrine into blood)

Motor Division of the Peripheral Nervous System:

| | Effectors | Efferent Pathways | Neurotransmitter Effects |
|---------------------------------|--|--|--|
| Somatic Nervous System | Skeletal muscle | 1 motor neuron (cell body in CNS & axon in spinal nerve) extends to skeletal muscle | acetylcholine released from somatic motor neuron to skeletal muscle; effect is always stimulatory |
| Autonomic Nervous System | Smooth muscle, Cardiac muscle & glands | preganglionic neuron from CNS to ganglion; postganglionic neuron extends to effector organ | postganglionic neuron may release acetylcholine or norepinephrine; effect may be stimulatory or inhibitory |

Autonomic Nervous System:

| | Origin | Ganglia | Fiber Length | Neurotransmitters |
|------------------------|--|---|--|---|
| Parasympathetic | Craniosacral outflow Cranial nerves III, VII, IX, X Sacral spinal nerves S ₂ -S ₄ | close to organ(s) served | long preganglionic short postganglionic | ACh (acetylcholine) released by pre- & postganglionic fibers |
| Sympathetic | Thoracolumbar outflow Thoracic spinal nerves T ₁ -T ₁₂ Lumbar spinal nerves L ₁ -L ₂ | close to CNS (spinal cord) – paravertebral & prevertebral ganglia | short preganglionic long postganglionic | preganglionic fibers - ACh; postganglionic fibers – most release norepinephrine, some release ACh |

Physiology of the Autonomic Nervous System

Neurotransmitters & Receptors

- **acetyl choline & norepinephrine** (noradrenaline) are the major neurotransmitters released by ANS neurons
- **cholinergic fibers:** release *acetyl choline* (all parasympathetic postganglionic axons & sympathetic postganglionic axons innervating sweat glands & some blood vessels)
 - **cholinergic receptors:**
 - **nicotinic receptors:** found on all ganglionic neurons (both sympathetic & parasympathetic) & adrenal medulla; response is **always stimulatory**
 - **muscarinic receptors:** found on all parasympathetic target organs & some sympathetic targets (eccrine sweat glands & some blood vessels); response may be *stimulatory* or *inhibitory*
 - acetyl choline is quickly inactivated in a synapse by acetylcholinesterase (AChE)
- **adrenergic fibers:** release *norepinephrine* (most sympathetic postganglionic axons)
 - **adrenergic receptors:** **alpha** receptors & **beta** receptors
 - α -1 & β -1 receptors (response is generally stimulatory)
 - α -2 & β -2 receptors (response is generally inhibitory)
 - β -3 receptors: only in brown adipose tissue: activation causes thermogenesis
 - cells of most effectors contain either alpha or beta receptors; some visceral effectors contain both
 - norepinephrine stimulates alpha receptors more strongly; epinephrine is a potent stimulator of alpha & beta receptors
 - activity of norepinephrine at a synapse is terminated when it is taken up by the axon that released it or it is inactivated by enzymes (catechol-O-methyltransferase (COMT) or monoamine oxidase (MAO))

Effects of Drugs: drugs can be administered to block the effects of a neurotransmitter (inhibit receptor) or enhance its effects (block enzyme that degrades neurotransmitter (cholinesterase))

- agonists: bind to & activate receptors
- antagonists: bind to & block receptors

Interactions of Autonomic Divisions:

- **antagonistic interactions:** in most cases, where each division innervates the same organ, the effects are opposite
- **sympathetic tone** (low level of smooth muscle constriction of blood vessels) & **parasympathetic tone** (helps regulate activity of digestive organs)
- cooperative effects
- **unique roles of the sympathetic division:**
 - thermoregulatory responses to heat (through control of blood vessel diameter)
 - release of renin from the kidneys (increases blood pressure)
 - metabolic effects (increases metabolism, raises blood glucose, mobilizes fats for energy, increases alertness through reticular activating system)
- parasympathetic effects are more localized, whereas sympathetic effects are more systemic (widespread)

Control of Autonomic Function:

Visceral (autonomic) reflex

- similar to somatic reflex arc, except *2-neuron motor chain*
- a visceral sensory neuron sends information about chemical changes, stretch & irritation of viscera to the spinal cord for integration, & the response is carried by a preganglionic & then postganglionic neuron to the visceral effector
- **referred pain:** since *visceral* pain afferents travel the same pathways as *somatic* pain afferents, pain stimuli arising in the viscera may be perceived as somatic in origin (felt in skin of the face, neck, chest or arm)

Autonomic Control by Higher Centers:

- **Brain stem & spinal cord:** reticular formation of brain stem, pons & medulla regulate heart rate & breathing rate, spinal cord reflexes
- **Hypothalamus:** main integration center (regulates heart activity, blood pressure, body temperature, water balance & endocrine system activity)
- **Cerebral Cortex:** although most autonomic functioning is involuntary, in some cases voluntary control appears possible

Homeostatic Imbalance: Hypertension (high blood pressure) may result from increased vasoconstriction by sympathetic fibers (could be stress-induced)

Chapter 15: The Special Senses

The Chemical Senses: Taste & Smell

The Olfactory Epithelium & Sense of Smell

Olfactory receptors:

- **olfactory epithelium:** small, yellowish patch of pseudostratified epithelium in the roof of the nasal cavity
 - the olfactory epithelium covers the superior nasal concha & contains 3 cell types:
 - millions of bowling pin-shaped **olfactory receptor cells**
 - columnar *supporting cells*; contain yellow-brown pigment lipofuscin
 - *basal cells*
 - olfactory receptor cells are bipolar neurons that have **olfactory cilia** covered by a coat of **mucus** (produced by supporting cells & nasal glands)
 - the mucus dissolves airborne chemicals (odors), & is continually renewed to prepare for new stimuli
 - olfactory receptor cells are *replaced* about every 90 days (atypical of neurons that are generally amitotic)
 - each receptor cell appears to contain one type of perhaps more than 1000 types of odorant binding proteins on their membrane to detect a specific form of odor
 - olfactory epithelium also contains *nociceptors*, & as with taste, some of the perception of smell is really pain
 - odor molecules must be in the gaseous state & water soluble to be detected by the olfactory receptor cells
 - **pathway to brain:** stimulation of receptor cells leads to depolarization & an action potential sent to the **olfactory bulb**, where the receptor synapses with a **mitral cell** within a specific *glomerulus*
 - mitral cells send impulses from the olfactory bulbs to one of 2 destinations:
 - via the *thalamus* to the **olfactory cortex** (interpretation of smell)
 - via the subcortical route to the *hypothalamus*, *amygdala* (**limbic system**) which elicits emotional responses to odors (can trigger ANS activity)

Taste Buds & the Sense of Taste

- **Taste buds:** about 10,000 in adult human; most on the tongue
 - Most taste buds are located within papillae (projections of the tongue mucosa)
 - 4 types of papillae:
 - **fungiform papillae:** most numerous type; found scattered over the surface of the tongue, but most at the tip & along sides
 - **foliate papillae:** along both sides of tongue towards posterior
 - **circumvallate (vallate) papillae:** form an inverted V at the back of the tongue; 7-12 with ~250 taste buds each
 - **filiform papillae:** in center of tongue; no taste buds
 - each taste bud has 40-100 epithelial cells of 3 types:
 - **gustatory (taste) cells:** receptor cells with membranes with gustatory hairs that sense stimuli; contacted by dendrites of sensory neurons; replaced every 7-10 days

- *supporting cells*: most cells within taste bud; insulate receptor cells
- *basal cells*: stem cells; divide & differentiate into supporting cells
- pure taste sensations are grouped into 4 types:
 - *sweet*: sensed at anterior tip of tongue
 - *salty*: sensed at anterior sides of tongue
 - *sour*: sensed at middle sides of tongue
 - *bitter*: sensed at posterior of tongue
- taste receptor activation: chemical dissolved in saliva contacts gustatory hairs, causing depolarization & release of neurotransmitter from the gustatory cells... the neurotransmitter binds sensory dendrites which respond with an action potential that delivers an impulse to the CNS
- afferent fibers carrying taste information from the tongue:
 - ***chorda tympani branch of the facial nerve (cranial nerve VII)*** transmits impulses from taste buds at the anterior 2/3 of tongue
 - ***glossopharyngeal nerve (cranial nerve IX)*** transmits impulses from taste buds on the posterior 1/3 of tongue
 - ***vagus nerve (cranial nerve X)*** transmits impulses from a few taste buds on the epiglottis & pharynx
- ***trigeminal nerve (cranial nerve V)*** does not innervate taste buds, but transmits impulses from nociceptors that discriminate texture in foods, as well as hot/cold & spicy foods
- **pathway to brain**: taste afferents travel to the *medulla*, the *thalamus*, & then on to the ***gustatory cortex*** in the parietal lobes
- taste is about 80% smell... when olfactory receptors are blocked (nasal congestion), taste of food is partially to mostly blocked

The Eye & Vision

- vision is the dominant sense (~ 70% of sensory receptors in the body are in the eyes)
- **accessory structures of eye**:
 - **eyebrows**: short coarse hairs at supraorbital margins; movement of this region is possible through contraction of orbicularis oculi & corrugator muscles
 - **eyelids (palpebrae)**: thin skin covered folds of epithelium supported by connective tissue; contraction of the ***orbicularis oculi*** muscle closes eyelids & contraction of the ***levator palpebrae superioris*** opens eyelids
 - reflex blinking occurs about every 3-7 seconds to protect the eye & prevent desiccation (drying) with secretions
 - **conjunctiva**: transparent mucus membrane that lines the eyelids (***palpebral conjunctiva***) & reflects back over the anterior surface of the eyeballs (***bulbar conjunctiva***)
 - bulbar conjunctiva only covers sclera (white of eye), not cornea
 - **lacrimal apparatus**: consists of lacrimal gland & ducts that drain lacrimal secretions into the nasal cavity
 - ***lacrimal gland***: lies within the orbit above the eye; releases a lacrimal secretion (tears) containing mucus, antibodies & the enzyme lysozyme (kills bacteria)

- secretions travel through the lacrimal canals to the lacrimal sac, & then into the nasolacrimal duct into the nasal cavity
- **extrinsic eye muscles:**
 - lateral rectus: moves eye laterally (control by CN VI)
 - medial rectus: moves eye medially (control by CN III)
 - superior rectus: elevates eye (control by CN III)
 - inferior rectus: depresses eye (control by CN III)
 - inferior oblique: elevates eye & turns it laterally (control by CN III)
 - superior oblique: depresses eye & turns it laterally (control by CN IV)
- **structure of the eyeball**
 - **fibrous tunic:** dense, avascular CT; 2 regions:
 - **sclera:** white of eye
 - **cornea:** anterior 1/6 of fibrous tunic; transparent CT
 - corneal epithelium: 2 layers... stratified squamous epithelium on outside with deep simple squamous epithelial tissue
 - **vascular tunic (uvea):** 3 regions:
 - **choroid:** highly vascular dark brown membrane; blood vessels supply nutrients to all tunics
 - melanin from melanocytes absorb light & prevent scattering
 - **ciliary body:** contains smooth muscle bundles (ciliary muscles) that control lens shape
 - **iris:** lies between cornea & lens; has round central opening called *pupil*
 - pupil opens & closes to control light entry into eye; controlled by smooth muscle in iris
 - **sensory tunic (retina):** consists of 2 layers:
 - outer **pigmented layer:** a single cell layer thick; contains *phagocytic* pigmented epithelial cells that absorb light & prevent scattering
 - inner neural layer: outpocketing of brain; 3 main types of neurons:
 - **photoreceptors: rods & cones**
 - rods: respond to dim light; blurry shades of gray
 - cones: respond to bright light; sharp, color vision
 - **bipolar cells:** link between photoreceptors & ganglion cells
 - **ganglion cells:** receive input from bipolar cells & their axons leave eye as optic nerve
 - **blind spot (optic disc):** location on retina where the optic nerve exits eye
 - **fovea centralis:** only cones present; region of greatest visual acuity
 - **Internal Chambers & Fluids:**
 - Posterior segment: posterior to lens; contains vitreous humor
 - Anterior segment: anterior to lens; composed of anterior chamber (in front of iris) & posterior chamber (between iris & lens) – both contain aqueous humor
 - Aqueous humor drains into venous blood through the scleral canal of Schlemm; blocked drainage can cause *glaucoma* (compression of retina & optic nerve) & eventually *blindness*

- **Lens:** biconvex, transparent structure consisting of lens epithelium (cuboidal cells) & lens fibers (transparent crystalline protein fibers)
 - **cataract:** clouding of lens due to inadequate nutrient supply to lens fibers
- **physiology of vision:**
 - light is *reflected* by objects in the environment before reaching eyes
 - light entering the eyes is **refracted** (bent) 3 times before reaching the photoreceptors (by cornea & by anterior & posterior surface of lens)... the result is focused light reaching the retina
 - *path of light to photoreceptors: cornea, aqueous humor, lens, vitreous humor, neural layer to photoreceptors*
 - *focusing for distant vision* requires no accommodation of visual apparatus
 - *focusing for close vision requires:*
 - accommodation (bulging) of lens
 - constriction of pupils
 - convergence of eyeballs
 - **photoreception:**
 - visual pigments of rods & cones are a combination of retinal (a vitamin A derivative) & opsins (pigmented proteins)
 - **rods** use rhodopsin (deep purple pigment)
 - **cones** use 3 different types of opsins to yield:
 - red cones
 - green cones
 - blue cones
 - **excitation** of *photoreceptors* occurs following a chain of reactions initiated by the isomerization (structural change) of retinal & detachment of retinal from opsin (bleaching of the pigment) after being struck by light
 - *color blindness:* a congenital lack of one or more cone types
 - *light adaptation:* sensitivity of retina decreases & photoreceptors adapt & switch from rod to cone system
 - *dark adaptation:* reverse of light adaptation
 - *stereoscopic vision:* 3D image of objects due to separate but overlapping input from both eyes
- **pathway to brain:** impulses sent from the photoreceptors to the bipolar cells to the ganglion cells (all in retina), then via the optic nerve to the optic chiasma... there, tracts cross over to the opposite side & continue via the optic tracts to the thalamus, which projects the fibers to the primary visual cortex in the occipital lobe
 - some fibers in the optic tracts are sent to the midbrain to control eye movement, while others are sent to the hypothalamus to regulate daily biorhythms according to daylight

The Ear: Hearing & Balance

Structure of the Ear:

- **outer (external) ear:** consists of the *auricle (pinna)* & the *external auditory canal* (travels from auricle to eardrum; ceruminous glands secrete earwax)

- **tympanic membrane (eardrum):** boundary between outer & middle ear
 - vibrates with frequency of sound waves entering through external ear; transfers vibration to ossicles of middle ear
- **middle ear (tympanic cavity):** small air-filled cavity within temporal bone lined with mucosa & flanked by the eardrum & 2 openings (*oval (vestibular) window* & *round (cochlear) window*)
 - the anterior wall of the middle ear contains an opening to the **auditory tube** (leads to nasopharynx)
 - contains 3 **ossicles** (small bones) suspended by ligaments:
 - **malleus (hammer)** – attaches to eardrum
 - **incus (anvil)**
 - **stapes (stirrup)** – attaches to oval window of vestibule
- **inner ear (labyrinth):** consists of bony labyrinth & membranous labyrinth
 - **bony labyrinth:** cavity within the temporal bone filled with perilymph & containing the membranous labyrinth
 - **membranous labyrinth:** floats in perilymph within bony labyrinth; filled with fluid called endolymph
 - **vestibule:** central region composed of 2 sacs – the **sacculae & utricle**
 - contains equilibrium receptors for balance called **maculae**
 - **semicircular canals:** 3 rounded tubes projecting from utricle through swellings called **ampullae**
 - ampullae contain equilibrium receptors called **crista ampullaris**
- **cochlea:** snail-shaped chamber extending from the sacculae
 - contains **cochlear duct** housing the **organ of Corti**, which contains receptors for hearing
 - 3 chambers (scala vestibuli, scala media & scala tympani)

Mechanisms of Hearing:

- transmission of sound to inner ear: airborne sound entering external auditory canal strikes the tympanic membrane & sets it vibrating at the same frequency
- vibration is passed on to ossicles of middle ear (malleus, incus, stapes) & through oval window to scala vestibuli of cochlea
- perilymph vibration & movement causes the membrane of the round window to bulge due to pressure... this creates a pressure wave that is transferred to the basilar membrane around the organ of Corti
- stereocilia of **hair cells** within the organ of Corti sense the vibration, & depolarize & release neurotransmitter to stimulate afferent fibers of the cochlear nerve
- **pathway to brain:** impulses sent along the cochlear nerve fibers travel to the medulla & the midbrain, and sent to the *thalamus*, which relays inputs to the **auditory cortex** in the temporal lobe
- auditory reflexes to sound are initiated in the midbrain
- **homeostatic imbalance: deafness** (loss of hearing) – *conduction deafness* results from impaired sound conduction of inner ear fluids; *sensorineural deafness* results from damage to neurons in pathway from cochlea receptors to brain
 - **tinnitus:** ringing in ears; can be caused by nerve damage or illness

- *meniere's syndrome*: labyrinth disorder affecting semicircular canals & cochlea; may be caused by excessive endolymph; treatment involves antimotion drugs for mild cases; drainage/surgery for more severe cases

Mechanisms of Equilibrium & Orientation:

- **static equilibrium:** *maculae* in the vestibule are sensory receptors for static equilibrium
 - *maculae* respond to **vertical & side-to-side head movements**
 - maculae are composed of receptor cells called *hair cells* that sense inertial movements (gliding due to movement) in an overlying otolithic membrane
 - bending of hair cell cilia results in depolarization & stimulation of the vestibular nerve
- **dynamic equilibrium:** the *crista ampullaris* in the *ampullae* of the *semicircular canals* is the receptor for dynamic equilibrium
 - *hair cells* (receptor cells) with each crista have cilia that project into a gel-like mass called a cupula
 - **rotational movement** of the head causes endolymph movement in the semicircular ducts that bends the cilia of hair cells of the crista
 - bending of hair cell cilia results in depolarization & stimulation of the vestibular nerve
- **path to brain:** although not fully worked out, it appears that fibers from the vestibular nerve travel to either the *vestibular nuclei in the brain stem* or the *cerebellum*
 - since balance response needs to be fast/reflexive, input is to the reflex centers of brain stem rather than cerebral cortex as with other senses