The Special Senses

Special Senses
• Include smell, taste, vision, hearing, and equilibrium
• More complex sensory structure
• More complex integration both peripherally and centrally
• More complex experience

Olfaction
• This and taste are chemical senses
  – Molecules must be volatile, water or lipid soluble
  – Must dissolve in mucus produced by olfactory glands
  – Probably hundreds of primary odor sensations
• Olfactory information not only transmitted to cortex, but also to limbic system
  – Explains some elicited emotional responses
• Olfactory epithelium composed of receptors, supporting and basal stem cells located in small superior region of nasal cavity
  – Supporting cells support, nourish, electrically insulate receptors
  – Basal stem cells produce new receptors (which last about 1 month)
• Olfactory (Bowman’s) glands - mucus secretion
  – These and supporting cells innervated by facial (VII) nerve - in presence of certain odors, there is increased activity of lacrimal gland and nasal mucus glands

Site of Olfaction (graphic)
Olfactory Epithelium (graphic)
Olfactory Epithelium (graphic)

Olfactory Receptors
• 10-100 million receptors in a square inch space
• Bipolar first order neurons
• At distal end, olfactory hairs (cilia) extend from dendrites
• In presence of chemical molecule, generator potential created
  – Activated receptor integral proteins (G-proteins) \( \rightarrow \) activate adenylate cyclase \( \rightarrow \) ATP converted to cAMP \( \rightarrow \) changed Na\(^+\) permeability
• If AP produced, information carried to olfactory bulb
• Receptors adapt quickly (50% in 1 sec)
  – Complete adaptation can occur (after a minute) - partly related to central adaptation
• Sensitivity can be very high (low levels)
  – Methyl mercaptan added to natural gas because of high sensitivity \((1/25\times10^{-9}\text{ mg/ml})\)

Olfactory Pathways
• Olfactory receptors/olfactory nerves (1st order) → olfactory bulb/tract (2nd order) → primary (lateral) olfactory areas (medial side of temporal lobe) → orbitofrontal area (Brodmann’s area - 11) or other limbic regions and hypothalamus

• Primary olfactory area encompasses part of limbic system including amygdaloid body - awareness of odors

• Orbitofrontal area - odor discrimination
  – Some lateralization in right lobe

• Limbic and hypothalamic projections contribute emotional or experiential responses to odors

**Taste**

• Sense of taste enhanced by sense of smell
  – Only five specific taste sensations as opposed to hundreds for smell
  – Include sour, sweet, bitter, salty & umami

• Olfactory sensation more acute than taste

**Gustatory Receptors**

• Taste buds primarily on tongue within circumvallate or fungiform papillae
  – Circumvallate across posterior of tongue, fungiform across whole of surface

• 10,000 buds in youth, declining with age

• Taste buds composed of three types of epithelial cells organized in capsules with taste pore
  – Receptor cells - about 50 cells per capsule with gustatory hairs (microvilli)
  – Supporting cells
  – Basal cells - at base of capsule, produce supporting cells which then differentiate to receptor cells (which last about 10 days)

• In presence of dissolved chemical molecule, receptor potential created which leads to proportional release of neurotransmitter, stimulating 1st order neurons
  – 1st order neurons may innervate numerous receptors in more than one taste bud

• Five important taste sensations not necessarily specific to receptor cells
  – Some localization
    • Tip of tongue especially sensitive to sweet and salty
    • Back of tongue, bitter (toxic substances) - threshold lowest of four
    • Lateral portions of tongue, sour - threshold second lowest of four
    • Na⁺ (salty) and H⁺ (sour) enter through ion-specific channels, other tastants via G-protein effect
    • Umami not known to be regional

• Adaptation occurs in 1-5 minutes
  – Partly receptor and central adaptation

**Taste Bud (graphic)**

**Circumvallate Papillae (graphic)**

**Taste Buds (graphic)
Spacial Distribution of Taste (graphic)

Umami
- Sensation is meaty or savory
- Sensitivity to amino acid glutamate
  - Receptor is taste-mGluR4 (modified version of brain cell receptor for neurotransmitter glutamate)
  - Much less sensitive than neurotransmitter receptor
- Foods high in glutamate – steak, seafood, aged cheeses, mushrooms, tomatoes, broth, chocolate
- Enhancing effect of MSG

Gustatory Pathways
- Receptors → any of three cranial nerves (1st order) → medulla/pons → some to limbic system and hypothalamus, others to thalamus → primary gustatory area (43 - parietal lobe)
- Cranial nerves included:
  - Facial - anterior 2/3 of tongue
  - Glossopharyngeal - posterior 1/3 of tongue
  - Vagus - throat and epiglottis
- Primary gustatory area - taste discrimination

Vision
- Perception of visible light (direct or reflected) that enables resolution of objects
- Integration important to develop image of 3D world
- More than 50% of body's sensory receptors associated with vision

Accessory Structures of Eye
- Eyelid (palpebrae) - protects eye from excessive light and foreign objects, lubricates surface of eyeball
- Integument
- Muscle - obicularis oculi
- Tarsal plate - connective tissue that provides lid form
- Tarsal glands (Meibomian) - modified sebaceous glands for lubrication
- Conjunctiva - continuous from posterior side of lid to anterior-lateral side of eyeball
  - Source of bloodshot eyes
- Eyelashes and eyebrow shade and protect
  - Sebaceous ciliary glands in lash follicles
    - Inflamed gland - sty
- Lacrimal apparatus - produce and circulate lacrimal fluid for eye lubrication and flushing
  - Lacrimal glands and ducts
  - Medially across eye to superior/inferior canals (entrance - lacrimal puncta)
– Lacrimal sac with connection to nasal cavity via nasolacrimal duct
– Lacrimal fluid (tears) - about 1 ml/day - largely saline solution with lysozyme (bactericidal)

**Accessory Structures of Eye (graphic)**

**Lacrimal Apparatus (graphic)**

**Anatomy of the Eye**

- Three layers - fibrous tunic, vascular tunic, retina
- Fibrous tunic - outermost layer
  - Cornea - transparent avascular anterior region
    - Three tissue layers - nonkeratinized stratified squamous epithelium, collagenous connective tissue, simple squamous epithelium
    - Transplants - avascular nature
  - Sclera - white of the eye, primarily dense connective tissue, gives eye shape

**Structures of the Eye (graphic)**

**Vascular Tunic (Uvea)**

- 2nd layer has three regions
- Iris - composed of circular and radial smooth muscle, forms pupil, suspended between cornea and lens by ciliary process
  - Parasympathetic innervation controls circular muscles - constriction
  - Sympathetic innervation controls radial muscles - dilation
- Ciliary body
  - Ciliary processes - vascular, secrete aqueous humor, attachment for suspensory ligaments
  - Ciliary muscle - controls shape of lens
  - Ciliary muscle and muscles of iris - intrinsic muscles
- Choroid - vascularized providing nutrient supply to retina, pigmented with melanin

**Adjustment of the Pupil (graphic)**

**Anterior Structures of the Eye (graphic)**

**Retina**

- Third layer is neural portion
- Optic disc - location of optic nerve and blood vessels, blind spot
- Remaining portion is sensory epithelium
  - Underlying pigmented epithelium - melanin (light absorbance)
  - Three neural layers - photoreceptive, bipolar cell, ganglion cell
    - 6 million cones
    - 120 million rods
  - Central fovea - highest visual acuity, only cones, no overlying bipolar or ganglion cell layer
  - Other cell types that connect laterally - horizontal and amacrine cells

**Ophthamoscopic View (graphic)**
Retinal Layers (graphic)
Retinal Layers (graphic)

Lens
- Avascular, transparent, layered, proteinaceous structure (crystallins)
- Suspended behind iris by suspensory ligaments
- Cataracts

Interior Chambers
- Anterior cavity
  - Filled with aqueous humor created by capillary filtration
    - Produced at ciliary process, flows forward through pupil and reabsorbed at scleral venous sinus
    - Replaced every 90 min - supports avascular lens and cornea
  - Interocular pressure largely dependent on volume of aqueous humor
    - When high, glaucoma - degeneration of retina results
- Posterior cavity - vitreous chamber
  - Contains vitreous body - produced embryonically and not replaced
  - Pushes retina against back of eye and maintains shape of eyeball

Image Formation
- Refraction of light by cornea and lens
  - 75% by cornea
  - Resulting image upside-down and backwards
- Lens responsible for accommodation to adjust for angle of incoming light
  - When viewing something close, the ciliary muscle contracts pulling ciliary process and choroid forward releasing tension of suspensory ligaments, lens thickens due to its elasticity
  - Presbyopia - lens loses elasticity over time (age 40) and can’t focus on close objects
- Iris adjusts with accommodation to keep light from penetrating periphery of lens (close focus - closes pupil)
- Convergence – medial movement of two eyeballs
  - required by binocular vision and dependent on distance of object

Refraction of Light and Accommodation (graphic)

Sight Correction
- Emmetropic - normal vision
- Myopic - nearsighted (elongated eyeball or thick lens)
  - Corrected by concave lens
- Hypermetropic (hyperopia) - farsighted (shortened eyeball or thin lens)
  - Corrected by convex lens
- Astigmatism - abnormal shape
  - Corrected by uneven grind of lens

Sight Abnormalities (graphic)
Physiology of Vision

- Structure of rods and cones
  - Transduction occurs in outer segment
  - Nucleus, mitochondria, other organelles & synapse in inner segment

- Photopigment in outer segment - pigmented proteins
  - Outer segment is convolution of plasma membrane (folds or discs), photopigments are integral proteins in this region, new discs continually replaced
  - Rods - rhodopsin - blue to green light
  - Cones - one of three kinds sensitive to blue, green or yellow-orange light
    - Color blindness – absence or low level of one or more
    - Composed of glycoprotein (opsin) and Vit A derivative (retinal)
      - Amino acid sequence of opsin determines light sensitivity - four types
    - Light converts retinal from cis to trans form - isomerization
      - Retinal then separates from opsin - bleaching
    - In darkness (or absence of a certain color of light), retinal isomerase converts retinal back to cis form, which then rebinds to opsin - regeneration

- Isomerization changes permeability of membrane to Na⁺
  - Ligand-gated Na⁺ channels normally open (dark current) - open position maintained by cyclic GMP
  - Continual release of neurotransmitter - glutamate which inhibits bipolar cells
  - Light (isomerization) activates an enzyme (transducin) which in turn activates phosphodiesterase breaking down cyclic GMP, and closing Na⁺ channels
  - Reduced dark current → hyperpolarization → reduced glutamate release → removes inhibition of bipolar cells
  - In darkness, no active transducin and guanylate cyclase stimulating factor → guanylate cyclase → synthesis of cyclic GMP

Rods and Cones (graphic)
Discs of Outer Segment (graphic)
Isomerization (graphic)
Photoreceptor Action (graphic)

Light & Dark Adaptation

- Dependent on the rate and level of bleaching or regeneration of the photopigments
- Regeneration of rhodopsin is slower than color photopigments (5 mins for half to regenerate (30-40 for complete regeneration) vs. 1.5 min)

Retinal Integration

- General convergence (fewer ganglion cells than photoreceptors, average-1:126), more for rods
  - Increased sensitivity, but decrease acuity
  - Rods excite bipolar cells
  - Cones may excite or inhibit (through horizontal cells) bipolar cells
• Horizontal cells transmit inhibitory signals to adjacent regions - lateral inhibition
  – Enhances contrast
• Ganglion cells excited by bipolar cells or via amacrine cells and produce APs

Visual Pathway
• Optic nerve → optic chiasm (only some fibers cross) → lateral geniculate nucleus of thalamus → primary visual areas of occipital lobe of cortex (area 17)
• Visual field of each eye divided into central and peripheral halves
  – Only fibers responsible for the lateral halves of visual field cross at optic chiasm

Bilateral Integration of Sight (graphic)

Hearing Structures
• Structurally divided into three regions - external, middle and inner ear
• External Ear
  – Auricle (elastic cartilage) - helix and lobule
  – External auditory meatus (temporal bone) - contains ceruminous glands and hair
  – Tympanic membrane (connective tissue overlaid by simple cuboidal epithelium)
• Middle Ear
  – Air filled and lined with epithelium
  – Eustachian tube - connection with nasopharynx
  – Auditory ossicles - malleus (against tympanic membrane), incus, stapes (against oval window of cochlea)
    • Tensor tympani and stapedius muscles - decrease ossicle vibration
• Inner Ear (labyrinth)
  – Bony labyrinth contains perilymph (similar to CSF) surrounding membranous labyrinth
  – Posterior portion - vestibule containing utricle & saccule, and semicircular canals and associated ampullae
  – Anterior portion - cochlea (bony spiral shape and central modiolus)

Structures of the Ear (graphic)

Structures of the Middle Ear
Cochlea
• Three parallel chambers
  – Scala vestibuli (ends at oval window) and connecting scala tympani (ends at round window), filled with perilymph
  – Cochlear duct (scala media) between and separated from others by vestibular membrane and basilar membrane - filled with endolymph (high K+)
• Organ of Corti (spiral organ) - attached to basilar membrane
  – Consists of epithelial supporting cells and 16K hair cells
Hair cells have apical microvilli (stereocilia), synapse with 1st order neurons. Gelatinous tectoral membrane overlays hair cells. One row of inner hair cells (synapse with >90% of sensory neurons) and three rows of outer hair cells (synapse with 90% of motor neurons).

**Spiral Organization of Channels (graphic)**

**X-section of Channels (graphic)**

**X-section of Channels (graphic)**

**Organ of Corti (graphic)**

**Physiology of Hearing**

- Auricles aid in directing sound, particularly higher frequencies
- Sound vibrates tympanic membrane, vibrations transmitted to ossicles
- Ossicles amplify vibration (20X) to oval window
- Pressure waves in perilymph move up scala vestibuli, around helicotrema, down scala tympani, to round window
- Both vestibular and basilar membrane vibrate, the basilar membrane moves hair cells relative to tectorial membrane
- Spatial stimulation of hair cells dependent on frequency
  - Basilar membrane narrower and stiffer at base, and vibrates in response to higher frequencies (up to 20,000 Hz)
  - Basilar membrane broader at apex, and vibrates in response to lower frequencies (down to 20 Hz)
  - Greatest frequency sensitivity 500-5000 Hz
- Number of hair cells stimulated dependent on intensity
- Transduction of signal at hair cell - mechanical bending of stereocilia in one direction (toward tallest) cause mechanically-gated K⁺ channels (primarily) to open, causing depolarizing receptor potential (high K⁺ in endolymph)
- Leads to voltage-gated Ca⁺ channels in base of hair cell to open causing release of neurotransmitter (glutamate?)
- Bending of stereocilia in opposite direction closes channels

**Auditory Stimulation (graphic)**

**Hearing Pathways**

- Cochlear branch of vestibulocochlear nerve (VIII) → cochlear nuclei of medulla → partial crossing to superior olivary nuclei (also medulla) → inferior colliculus of midbrain from both cochlear nuclei & olivary nuclei → medial geniculate of thalamus → primary auditory area (areas 41 & 42 in temporal lobe)

**Vestibulocochlear Nerve (graphic)**

**Physiol. of Static Equilibrium**

- Measure relative to force of gravity (and linear acceleration)
- Primarily utricle and saccule
- Maculae (sensory epithelia) composed of hair cells and supporting cells
  - Utricular and saccular maculae are perpendicular to one another
- Hair cells have stereocilia (microvilli) and one kinocilium (true cilia)
• Overlying otolithic membrane - secreted by supporting cells with otoliths on top of membrane (calcium carbonate crystals) Density difference of otoliths cause differential movement
• Bending of stereocilia towards kinocilium creates depolarizing receptor potential, and release of neurotransmitter affecting first order neuron (vestibular branch of VIII)

**Macula of Utricle & Saccule (graphic)**

**Perception of Position (graphic)**

**Physiology of Dynamic Equilibrium**

• Measure angular acceleration
• Utricle and sacule contribute
• Three semicircular ducts in each of three planes filled with endolymph
• Ampullae contain sensory epithelium (crista - hair cells and supporting cells covered by gelatinous cupula)
• Movement of head causes differential movement of fluid in ducts vs. sensory apparatus - hair cells stimulated

**Semicircular Canals (graphic)**

**Ampulla Structure (graphic)**

**Stimulation of Ampullae (graphic)**

**Equilibrium Pathways**

• Vestibular branch of vestibulocochlear nerve (VIII) → vestibular nuclei of medulla or pons ←→ cerebellum OR
• Vestibular branch of vestibulocochlear nerve (VIII) → cerebellum via inferior cerebellar peduncle

**ALSO**

• Vestibular nuclei → nuclei of cranial nerves that control eye muscles (oculomotor, trochlear, abducens) and head movements (accessory)