Nervous System: Special Senses  
(Chapter 17)  
Lecture Materials  

for  
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Primary Sources for figures and content:  
Special Senses
Five special senses: smell, taste, sight, hearing, equilibrium
All involve special sensory receptors
- distinct receptor cells
- housed in complex sensory organs or unique epithelial structures

Olfaction (smell)
olfactory organs = olfactory epithelium
-housed in nasal cavity, inferior surface of cribiform plate and superior nasal conchae
Olfactory Epithelium Components
1. olfactory receptor cells
   - bipolar neurons
   - chemoreceptors
   - bind and respond to odorants (smell chemicals)
2. supporting cells
   - simple columnar epithelium
3. basal cells
   - stem cells
   - replace olfactory receptor cells every 60 days
4. lamina propria
   - areolar CT
   - supports epithelium and neurons
   - contains olfactory glands for mucus production: mucus covers surface of olfactory epithelium
Olfactory receptor cells
- single dendrite at apical surface of epithelium
- dendrite ends in knob covered in olfactory cilia
- cilia extend into mucus
- odorant binding proteins on cilia bind chemical odorant molecules that have diffused into mucus
- each receptor cell has only one type of odorant binding protein but each protein binds several odorants
- humans: ~1000 different odorant binding proteins, distinguish ~10,000 different odors
- axon from each cell passes through olfactory foramina of cribriform plate to synapse on olfactory bulbs (axons = olfactory nerves)
Signaling

1. Odorant binds odorant binding protein on olfactory receptor cell cilia in mucus

2. G-protein is activated which activates adenylate cyclase

3. ATP is converted into cAMP

4. cAMP causes sodium channels to open resulting in depolarization

5. If threshold is reached and action potential is transmitted to the CNS olfactory bulbs

6. The nervous impulse from the olfactory bulbs travels down the olfactory tracts to be routed to:
   a. olfactory cortex of the cerebrum for interpretation (*smell is the only type of sensory info that reaches the cerebral cortex without first synapsing in the thalamus: no sensory dampening!*)
   b. hypothalamus and limbic systems to elicit emotional response to odors

-the signaling can also stimulate reflexes for salivation, digestive secretion, sneezing and coughing

-olfactory pathways converge and are subject to rapid central adaptation
Olfactory disorders:

*Uncinate fits* = olfactory hallucinations
-distorted sense of smell due to damage of olfactory pathways, epilepsy, or migraines

*Anosmias* = “without smells”
-loss of sense of smell
-due to head injury, inflammation, age, or zinc deficiency
(zinc necessary for growth of basal cells to replace receptor cells)

**Gustation** (taste)
gustation organs = taste buds
~10,000 total
-most located on tongue associated with lingual papillae (friction bumps)
-small number on oral surfaces: soft palate, inner cheeks, pharynx, epiglottis
Taste Bud Components
50-100 epithelial cells of two types:
1. gustatory cells
   - taste receptor cells
   - in various stages of maturity
   - mature have long microvilli = gustatory hairs that function as chemoreceptors
   - gustatory hairs bind tastants (taste chemicals)
   - each gustatory cell is wrapped in sensory dendrites
2. basal cells
   - stem cells
   - replace gustatory cells every 7-10 days
   - taste buds located deep in tongue epithelium with taste hairs protruding into taste pore
5 Primary Taste Sensations
1. sweet: sugars, alcohols, some amino acids
2. sour: acids
3. salty: metal ions
4. bitter: alkaloids
5. umami “delicious”: amino acid glutamate (beef taste) (MSG binds this)

Tastes and cravings drive dietary needs:
- umami → proteins
- sugar & salty → carbs and minerals
- sour → vitamin C
Tastes also protect:
- most toxins are bitter
Gustatory Signaling (on handout)
Vision (sight)
vision organs = eyes
-70% of total body receptors
-50% of cerebral cortex involved in vision processing
Accessory structures (on handout)
**diplopia** = “double vision”
- failure to coordinate movement of eyes resulting in two different visual fields
- due to paralysis, weak muscles, intoxication

**strabismus** = “cross eyed”
- congenital weakness of external eye muscles
- treated with exercises or surgery
The Eye
-fluid filled sphere
-wall consists of three layers:
  1. outer fibrous tunic
  2. intermediate vascular tunic
  3. inner neural tunic
-interior divided into two cavities (anterior, posterior) by the lens
-cavities contain fluids called humors:
  maintain shape of eye
1. Fibrous tunic
-dense fibrous CT
-avascular
A. Sclera (“white of eye”)
  -posterior 5/6ths
  -functions to maintain eye shape and as attachment for eye muscles
-continuous with epineurium of optic nerve and dura mater of brain

B. Cornea
  - anterior 1/6th
  - clear, allows light to enter eye
  - high concentration of pain receptors
  - damage = scaring = inhibit vision
Corneal transplant: due to lack of blood supply there are no immune cells, no need to tissue type match

2. Vascular tunic = uvea
  - contains blood and lymphatic vessels for all three tunics
-consists of three regions
A. Choroid
  -lines posterior 5/6ths
  -pigmented dark brown by melanocytes to prevent light scatter
B. Ciliary body
  -circular smooth muscles that function to focus lens and center it posterior to pupil
  -attached to lens by suspensory ligaments
  -secretes fluid that fills anterior chamber of eye
C. Iris

- anterior portion of uvea
- has central opening called pupil
- smooth muscle + elastic fibers
- regulate pupil size to control light level entering eye:

- parasympathetic stimulation = circular muscles contract → pupil size decreases
- sympathetic stimulation = radial muscles contract → pupil size increases
- color variations depend on amount and location of melanin:
  - more on both sides = brown
  - less on posterior only = blue
3. Neural tunic = retina
   - two parts
   A. Pigmented layer
      - melanin-rich simple cuboidal epithelium in contact with choroid
      - absorbs light to prevent scatter
      - stores Vitamin A
      - capable of phagocytosis
   B. Neural layer
      - five types of neurons
      1. photoreceptors:
         - detect light photons
           a. rods = dim light, no color, peripheral vision
           b. cones = color, sharp vision
2. horizontal cells: visual processing
3. bipolar cells: transmit info from photoreceptors
4. amacrine cells: visual processing
5. ganglion cells: transmit visual info to brain, axons exit eye as optic nerve

-optic disc = “blind spot”: where axons bundle to form optic nerve, no photoreceptors
-macula lutea: focal point directly behind center of lens, contains all the cones of the retina (also has rods)
-fovea centralis: center of macula, contains cones only, point of sharpest vision
-majority of retina contains rods only

**macular degeneration:**
- photoreceptors in macula die due to poor blood supply
- patient has only grainy peripheral vision

**detached retina:**
- portion of retina separates from choroid
- due to sudden head jerk
- photoreceptors without blood supply die
4. Cavities / Segments
A. Posterior cavity
   - posterior to lens
   - filled with vitreous humor: clear gel formed in embryo, maintained throughout life
   - functions:
     - support retina in contact with choroid while allowing light to pass through
     - provide intraocular pressure to counteract extrinsic eye muscles

_floaters_ = small moving spots caused by cell debris in vitreous humor
B. Anterior cavity
- anterior to lens
- filled with aqueous humor, constantly produced by ciliary body
- aqueous humor diffuses through both cavities, reabsorbed at the scleral venous sinus at base of iris
-aqueous humor functions:
  - maintain consistent intraocular pressure
  - diffusion medium for lens and cornea

*glaucoma* = failure to drain aqueous humor, pressure compresses retina and optic nerve resulting in vision loss

5. Lens
- transparent, flexible, avascular disc
- cells with no organelles, contain crystallin proteins only
- allows precise focusing of light on retina
- held in place directly behind pupil by suspensory ligaments which attach lens to ciliary body
cataract = clouding of the lens due to clumping of crystallins
-due to age, diabetes, smoking, sun
-corrected by lens replacement or laser removal of crystallins

Visual Physiology
-visible light = electromagnetic radiation, 380-750nm, composed of photons
-can be separated by wavelength into visible spectrum of colors from violet (380nm) to red (750nm)

-eye detects photons reflecting off objects: color = wavelengths being reflected
- at constant speed light travels in straight line
- when it passes through new object, speed changes, and the light bends/refracts
- more curved the surface the greater the refraction

-a lens has a curve that functions to refract all light to a single focal point
- focal distance = distance between lens and its focal point, depends on:
  1. distance from object to lens (increases as object gets closer)
  2. shape of lens (rounder = shorter)
Focusing light on the retina
-light entering eye is refracted by cornea, lens and humors
-refraction by cornea & humors constant
-refraction by lens can be altered by changing its shape = accommodation

-at rest lens focuses on macula lutea from objects 6m (20ft) away
-to focus on closer objects, ciliary body compresses lens to shorten focal distance
-flexibility of lens only allows focus up to 10cm (4in) from eye

*Presbyopia* = loss of accommodation with age

*Myopia* (near sighted): lens refracts light to focal point in front of retina
-cannot focus on distant objects
-accommodation allows focus of near
Hyperopia (far sighted): lens refracts light to focal point behind retina
- accommodation maxed out to focus on distant objects preventing focus of near

Astigmatism = unequal curvature of cornea or lens (part out of focus, part in)

Radial Keratotomy (Lasik): reshape cornea

Visual Acuity (you@20ft / normal@ X ft)
20/20: normal
20/15: better
20/200: <= legally blind
Photoreception
-process by which eye detects light
-requires visual pigments in photoreceptors

1. Photoreceptors (rods & cones)
   -neurons with two parts:
     A. inner segment: soma and processes that synapse on a bipolar cell
     B. outer segment:
        -contacts pigmented layer
        -composed of discs of membrane containing visual pigments

rods: long, slender
cones: short, tapered
-discs constantly replaced: new added at bottom, old shed at tip, phagocytosed by pigmented layer

2. visual pigment
   = rhodopsin, 2 parts:
   A. retinal
   -light absorbing
   -from Vitamin A
   -binds photons and changes shape
   B. opsin
   -protein
   -inactive when bound to retinal
   -photons $\rightarrow$ retinal isomerizes cis $\rightarrow$ trans,
   retinal releases opsin
   -used rhodopsin recycled and replaced
   -bleaching: trans retinal not bound to opsin, cannot respond to photons
   -leaves lingering image until rhodopsin is replaced
-retinal responds to different wavelengths and thresholds of photons depending on the opsin bound:

A. rods: absorb all (380-750nm)
   -activated by dim light
   -info perceived as shades of gray

B. cones: specific, 3 types
   -require bright light for activation
   1. blue: peak response @ 420nm
   2. green: peak @ 530nm
   3. red: peak @ 560nm

-absorption spectra of all three overlap allowing perception of intermediate hues from differential activation of more than one type of cone
**color blindness**
-congenital, X-linked
-lack one or more type of cone
-red-green most common
-8% of all men have some degree

Visual signaling
(on handout)
Hearing and Equilibrium

hearing and equilibrium organs = ears
-involve mechanoreceptors: hair cells with stereocilia, housed in inner ear

The ear: 3 major regions

1. External ear

A. Auricle/Pinna
- projection of skin-covered elastic cartilage
- functions to funnel sound into external auditory canal

B. External auditory canal
- from auricle to tympanic membrane
- lined with hairs and ceruminous glands: secrete cerumen
- both prevent entry of foreign material
C. Tympanic membrane
-boundary between external and middle ear
-composed of CT and epithelium
-transmits sound energy from air to auditory ossicles

2. Middle ear
-air-filled mucosa-lined chamber between tympanic membrane and oval window
-houses auditory ossicles: maleus, incus, stapes
-ossicles amplify and transmit sound energy from tympanic membrane (external ear) to oval window (inner ear)
-connected to nasopharynx by auditory tube: allows equalization of pressure

**otitis media** = middle ear infection
- usually caused by migration of throat infection
- inflammation can rupture tympanic membrane
- middle ear contains two muscles to protect ear from loud sounds:
muscles:

1. tensor tympani
   - inserts on malleus
   - contraction inhibits vibrations of tympanic membrane to dampen sound

2. stapedius
   - inserts on stapes
   - contraction inhibits vibration of oval window reducing sound conduction to inner ear

3. Inner ear
   - located in temporal bone, posterior to eye
   - consists of network of fluid filled chambers
   - fluid functions to transmit sound or movement energy to mechanoreceptor cells
A. Semicircular canals
- 3 total, one in each plane, connected to vestibule
- contains vestibular complex: houses equilibrium receptor cells
- filled with endolymph

B. Cochlea
- spiral conical chamber
- begins at oval window, ends at round window
- contains organ of Corti: houses hearing receptor cells
- filled with perilymph
Hearing

Sound = pressure disturbance that moves as a wave with two properties:

1. Frequency = wavelength
   - measured as waves /sec: Hertz (Hz)
   - perceived as pitch
   - humans: 20-20,000 Hz
   - ↑ frequency = ↑ pitch

2. Intensity = amplitude
   - measured in decibels (dB)
   - perceived as volume
   - humans: 0-120dB without pain
   - frequent/long term exposure to sounds >90dB can result in hearing loss (shear stereocilia off hair cells)
Organ of Corti
-spirals around inside of cochlea
-consists of: hair cells sandwiched between a superior tectorial membrane and an inferior basilar membrane

-hair cells held in place by supporting cells and surrounded by perilymph
-hair cells covered in apical projections: stereocilia
-stereocilia detect pressure or distortion, hair cell = mechanoreceptor
-each hair cell synapses with a sensory neuron
Sound transmission and auditory signaling (on handout)
Motor output to cranial nerve nuclei

Motor output to spinal cord through the tectospinal tracts

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Deafness = loss of hearing
Conduction deafness = reduced ability to conduct sound to perilymph (e.g. perforated tympanic membrane, otitis media, otosclerosis)
Sensorineural deafness = loss of function of hair cells or neurons in auditory pathway
Tinnitus = phantom cochlear noise
- ringing caused by inappropriate stimulation of auditory pathway due to inflammation, nerve damage, medications

Equilibrium and Orientation
-equilibrium receptors = the vestibular apparatus
-housed in the semicircular canals and vestibule
equilibrium receptors are designed to detect only changes in linear and angular movements, will adapt quickly
-the sense of equilibrium depends on information from the equilibrium receptors + vision + proprioception
-equilibrium receptors divided into two functional categories:
1. static equilibrium (linear)
2. dynamic equilibrium (angular)
(on handouts)
**Nystagmus** = rotational eye movements that occur following a spin
- eyes search for a focal point until endolymph comes to rest

**Vertigo** = perception of motion due to inappropriate stimulation along the equilibrium pathway

**Motion sickness:**
- results when the mesencephalon receives conflicting information about equilibrium:
  - visual cues indicate body is stationary but inner ear indicates movement