Chapter 17

The Special Senses

PowerPoint® Lecture Slides
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An Introduction to the Special Senses

- Five Special Senses
  - Olfaction
  - Gustation
  - Vision
  - Equilibrium
  - Hearing
Smell (Olfaction)

- Olfactory Organs
  - Provide sense of smell
  - Located in nasal cavity on either side of nasal septum
  - Made up of two layers
    - Olfactory epithelium
    - Lamina propria
Smell (Olfaction)

- Layers of olfactory organs
  - Olfactory epithelium contains
    - Olfactory receptors
    - Supporting cells
    - Basal (stem) cells
  - Lamina propria contains
    - Areolar tissue
    - Blood vessels
    - Nerves
    - Olfactory glands
Smell (Olfaction)

Figure 17–1 The Olfactory Organs.
Figure 17–1a The Olfactory Organs.
Smell (Olfaction)

Figure 17–1b The Olfactory Organs.
Smell (Olfaction)

- **Olfactory Glands**
  - Secretions coat surfaces of olfactory organs

- **Olfactory Receptors**
  - Highly modified neurons
  - Olfactory reception
    - Involves detecting dissolved chemicals as they interact with odorant-binding proteins
Smell (Olfaction)

- Olfactory Pathways
  - Axons leaving olfactory epithelium
    - Collect into 20 or more bundles
    - Penetrate cribriform plate of ethmoid
    - Reach olfactory bulbs of cerebrum where first synapse occurs
  - Axons leaving olfactory bulb:
    - travel along olfactory tract to reach olfactory cortex, hypothalamus, and portions of limbic system
Olfactory Pathways

Arriving information reaches information centers without first synapsing in thalamus
Smell (Olfaction)

- **Olfactory Discrimination**
  - Can distinguish thousands of chemical stimuli
  - CNS interprets smells by the pattern of receptor activity

- **Olfactory Receptor Population**
  - Considerable turnover
  - Number of olfactory receptors declines with age
Taste (Gustation)

- **Gustation** provides information about the foods and liquids consumed
- **Taste receptors** (or gustatory receptors) are distributed on tongue and portions of pharynx and larynx
  - Clustered into **taste buds**
Taste (Gustation)

- Taste buds
  - Associated with epithelial projections (lingual papillae) on superior surface of tongue
  - Three types of lingual papillae
    - Filiform papillae:
      - provide friction
      - do not contain taste buds
    - Fungiform papillae:
      - contain five taste buds each
    - Circumvallate papillae:
      - contain 100 taste buds each
Taste (Gustation)

Figure 17–2 Gustatory Receptors.
Figure 17–2 Gustatory Receptors.
Taste (Gustation)

Figure 17–2 Gustatory Receptors.
Taste (Gustation)

- Taste buds contain
  - Basal (stem) cells
  - Gustatory cells
    - Extend *taste hairs* through taste pore
    - Survive only 10 days before replacement
  - Monitored by cranial nerves that synapse within *solitary nucleus* of medulla oblongata, then on to thalamus and primary sensory cortex
Taste (Gustation)

- Gustatory Discrimination
  - Primary taste sensations
    - Sweet
    - Salty
    - Sour
    - Bitter
Taste (Gustation)

- Additional human taste sensations
  - Umami
    - Characteristic of beef/chicken broths and Parmesan cheese
    - Receptors sensitive to amino acids, small peptides, and nucleotides
  - Water
    - Detected by water receptors in the pharynx
Taste (Gustation)

- Gustatory Discrimination
  - Dissolved chemicals contact taste hairs
  - Bind to receptor proteins of gustatory cell
  - Salt and sour receptors
    - Chemically gated ion channels
    - Stimulation produces depolarization of cell
  - Sweet, bitter, and umami stimuli
    - G proteins: gustducins
Taste (Gustation)

- **End Result of Taste Receptor Stimulation**
  - Release of neurotransmitters by receptor cell
    - Dendrites of sensory afferents wrapped by receptor membrane
    - Neurotransmitters generate action potentials in afferent fiber
Taste (Gustation)

- **Taste Sensitivity**
  - Exhibits significant individual differences
  - Some conditions are inherited
    - For example, phenylthiocarbamide (PTC):
      - 70% of Caucasians taste it but 30% do not
  - Number of taste buds
    - Begins declining rapidly by age 50
Accessory Structures of the Eye

Provide protection, lubrication, and support

Includes

- The palpebrae (eyelids)
- The superficial epithelium of eye
- The lacrimal apparatus
Accessory Structures of the Eye

- Eyelids (Palpebrae)
  - Continuation of skin
  - Blinking keeps surface of eye lubricated, free of dust and debris
  - Palpebral fissure
    - Gap that separates free margins of upper and lower eyelids
Accessory Structures of the Eye

- Eyelids (Palpebrae)
  - Medial canthus and lateral canthus
    - Where two eyelids are connected
  - Eyelashes
    - Robust hairs that prevent foreign matter from reaching surface of eye
  - Tarsal glands
    - Secrete lipid-rich product that helps keep eyelids from sticking together
Accessory Structures of the Eye

- Superficial Epithelium of Eye
  - Lacrimal caruncle
    - Mass of soft tissue
    - Contains glands producing thick secretions
    - Contributes to gritty deposits that appear after good night’s sleep
  - Conjunctiva
    - Epithelium covering inner surfaces of eyelids (palpebral conjunctiva) and outer surface of eye (ocular conjunctiva)
Figure 17–3a Gross and Superficial Anatomies of the Accessory Structures.
Accessory Structures of the Eye

- **Lacrimal Apparatus**
  - Produces, distributes, and removes tears
  - **Fornix**
    - Pocket where palpebral conjunctiva joins ocular conjunctiva
  - **Lacrimal gland (tear gland)**
    - Secretions contain lysozyme, an antibacterial enzyme
Accessory Structures of the Eye

- Tears
  - Collect in the lacrimal lake
  - Pass through
    - Lacrimal puncta
    - Lacrimal canaliculi
    - Lacrimal sac
    - Nasolacrimal duct
  - To reach inferior meatus of nose
Figure 17–3b The Organization of the Lacrimal Apparatus.
The Eye

- Three Layers of the Eye
  - Outer fibrous tunic
  - Middle vascular tunic
  - Inner neural tunic

- Eyeball
  - Is hollow
  - Is divided into two cavities:
    - Large posterior cavity
    - Smaller anterior cavity
Figure 17–4a The Sectional Anatomy of the Eye.
Figure 17–4b The Sectional Anatomy of the Eye.
The Eye

Figure 17–4c The Sectional Anatomy of the Eye.
The Eye

- The Fibrous Tunic
  - Sclera (white of eye)
  - Cornea
  - Limbus (border between cornea and sclera)
The Eye

- **Vascular Tunic (Uvea) Functions**
  - Provides route for blood vessels and lymphatics that supply tissues of eye
  - Regulates amount of light entering eye
  - Secretes and reabsorbs aqueous humor that circulates within chambers of eye
  - Controls shape of lens, which is essential to focusing
Figure 17–4c The Sectional Anatomy of the Eye.
The Eye

The Vascular Tunic

■ Iris

■ Contains **papillary constrictor muscles:**
  – changes diameter of pupil
Figure 17–5 The Pupillary Muscles.
The Vascular Tunic

- Ciliary Body
  - Extends posteriorly to level of **ora serrata**:
    - serrated anterior edge of thick, inner portion of neural tunic
  - Contains ciliary processes, and ciliary muscle that attaches to suspensory ligaments of lens

The Eye: Ciliary Muscles
The Vascular Tunic

The choroid

- Vascular layer that separates fibrous and neural tunics posterior to ora serrata
- Delivers oxygen and nutrients to retina
The Eye

- The Neural Tunic (Retina)
  - Outer layer called pigmented part
  - Inner neural part
    - Contains visual receptors and associated neurons
    - Rods and cones are types of photoreceptors:
      - rods:
        » do not discriminate light colors
        » highly sensitive to light
      - cones:
        » provide color vision
        » densely clustered in fovea, at center of macula lutea
Figure 17–4c The Sectional Anatomy of the Eye.
The Eye

Figure 17–6a The Cellular Organization of the Retina.
Figure 17–6b The Optic Disc of the Retina in Diagrammatic Sagittal Section.
Figure 17–6c Photograph of the Retina as Seen through the Pupil.
The Eye

- The Neural Tunic (Retina)
  - Inner neural part
    - Bipolar cells:
      - neurons of rods and cones synapse with ganglion cells
    - Horizontal cells:
      - extend across outer portion of retina
  - Amacrine cells:
    - comparable to horizontal cell layer
    - where bipolar cells synapse with ganglion cells
Inner Neural Part of Retina (cont’d)

- Horizontal and amacrine cells
  - Facilitate or inhibit communication between photoreceptors and ganglion cells
  - Alter sensitivity of retina

- Optic disc
  - Circular region just medial to fovea
  - Origin of optic nerve:
    - blind spot
The Eye

Figure 17–7 A Demonstration of the Presence of a Blind Spot.
The Eye

- The Chambers of the Eye
  - Ciliary body and lens divide eye into
    - Large **posterior cavity** (vitreous chamber)
    - Smaller **anterior cavity**:  
      - anterior chamber:  
        » extends from cornea to iris  
      - posterior chamber:  
        » between iris, ciliary body, and lens
The Eye

- Smaller anterior cavity
  - Aqueous humor
    - Fluid circulates within eye
    - Diffuses through walls of anterior chamber into canal of Schlemm
    - Re-enters circulation
  - Intraocular pressure
    - Fluid pressure in aqueous humor
    - Helps retain eye shape
Figure 17–8 The Circulation of Aqueous Humor.
The Eye

- Large posterior cavity (vitreous chamber)
  - Vitreous body
    - Gelatinous mass
    - Helps stabilize eye shape and supports retina
The Eye

- The Lens
  - Lens fibers
    - Cells in interior of lens
    - No nuclei or organelles
    - Filled with **crystallins**, which provide clarity and focusing power to lens
  - Cataract
    - Condition in which lens has lost its transparency
The Eye

- The Lens
  - Light refraction
    - Bending of light by cornea and lens
    - Focal point:
      - specific point of intersection on retina
  - Focal distance:
    - distance between center of lens and focal point
Figure 17–9 Factors Affecting Focal Distance.
The Eye

- Light Refraction of Lens
  - Accommodation
    - Shape of lens changes to focus image on retina
  - Astigmatism
    - Condition where light passing through cornea and lens is not refracted properly
    - Visual image is distorted
- Visual acuity
  - Clarity of vision
  - “Normal” rating is 20/20
Figure 17–10 Accommodation.
Figure 17-11a Visual Abnormalities.
Figure 17–11b Visual Abnormalities.
Figure 17–11c Visual Abnormalities.
The Eye

Figure 17–11d Visual Abnormalities.
The Eye

Converging lens

(e) Hyperopia (corrected)

Figure 17–11e Visual Abnormalities.
The Eye

Figure 17–12 Image Formation.
Visual Physiology

- **Rods**
  - Respond to almost any photon, regardless of energy content

- **Cones**
  - Have characteristic ranges of sensitivity
Visual Physiology

- **Anatomy of Rods and Cones**
  - Outer segment with membranous discs
  - Inner segment
    - Narrow stalk connects outer segment to inner segment
- **Visual pigments**
  - Is where light absorption occurs
  - Derivatives of rhodopsin (opsin plus retinal)
  - Retinal: synthesized from vitamin A
Figure 17–13 Structure of Rods and Cones.
Visual Physiology

- Photoreception
  - Photon strikes retinal portion of rhodopsin molecule embedded in membrane of disc
    - Opsin is activated
    - Bound retinal molecule has two possible configurations:
      - 11-\textit{cis} form
      - 11-\textit{trans} form
Figure 17–14 Photoreception.
Visual Physiology

Figure 17–14 Photoreception.
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Figure 17–14 Photoreception.
Figure 17–14 Photoreception.
Visual Physiology

- Recovery after Stimulation
  - Bleaching
    - Rhodopsin molecule breaks down into retinal and opsin
  - Night blindness
    - Results from deficiency of vitamin A
Figure 17–15 Bleaching and Regeneration of Visual Pigments.
Figure 17–16 Cone Types and Sensitivity to Color.
Visual Physiology

- Color Vision
  - Integration of information from red, green, and blue cones
- Color blindness
  - Inability to detect certain colors
Light and Dark Adaptation

Dark
- Most visual pigments are fully receptive to stimulation

Light
- Pupil constricts
- Bleaching of visual pigments occurs
Visual Physiology

- The Visual Pathways
  - Begin at photoreceptors
  - End at visual cortex of cerebral hemispheres
  - Message crosses two synapses before it heads toward brain
    - Photoreceptor to bipolar cell
    - Bipolar cell to ganglion cell
Visual Physiology

- **Photoreceptors**
  - Monitor a specific receptive field in retina

- **Ganglion Cells**
  - Monitor a specific portion of a field of vision

- **M Cells**
  - Are ganglion cells that monitor rods
  - Are relatively large
  - Provide information about:
    - general form of object
    - motion
    - shadows in dim lighting
Ganglion Cells

P cells

- Are ganglion cells that monitor cones
- Are smaller, more numerous
- Provide information about edges, fine detail, and color
Figure 17–17 A Standard Test for Color Vision.
Ganglion Cells

- **On-center neurons**
  - Are excited by light arriving in center of their sensory field
  - Are inhibited when light strikes edges of their receptive field

- **Off-center neurons**
  - Inhibited by light in central zone
  - Stimulated by illumination at edges
Figure 17–18 Convergence and Ganglion Cell Function.
Central Processing of Visual Information

- Axons from ganglion cells converge on optic disc
- Penetrate wall of eye
- Proceed toward diencephalon as optic nerve (II)
- Two optic nerves (one for each eye) reach diencephalon at optic chiasm
Visual Data

- From combined field of vision arrive at visual cortex of opposite occipital lobe
  - Left half arrive at right occipital lobe
  - Right half arrive at left occipital lobe

Optic radiation

- Bundle of projection fibers linking lateral geniculate with visual cortex
The Field of Vision

Depth perception

By comparing relative positions of objects between left-eye and right-eye images
The Brain Stem and Visual Processing

- Circadian rhythm
  - Is tied to day-night cycle
  - Affects other metabolic processes
Figure 17–19 The Visual Pathways.
The Ear

- The External Ear
  - Auricle
    - Surrounds entrance to **external acoustic meatus**
    - Protects opening of canal
    - Provides directional sensitivity
  - **External acoustic meatus**
    - Ends at tympanic membrane (eardrum)
  - **Tympanic membrane**
    - Is a thin, semitransparent sheet
    - Separates external ear from middle ear
The Ear

Figure 17–20 The Anatomy of the Ear.
The Ear

The External Ear

Ceruminous glands

- Integumentary glands along external acoustic meatus

- Secrete waxy material (cerumen):
  - keeps foreign objects out of tympanic membrane
  - slows growth of microorganisms in external acoustic meatus
The Middle Ear

- Also called tympanic cavity
- Communicates with nasopharynx via auditory tube
  - Permits equalization of pressures on either side of tympanic membrane
- Encloses and protects three auditory ossicles
  - Malleus (hammer)
  - Incus (anvil)
  - Stapes (stirrup)
Figure 17–21a The Structures of the Middle Ear.
Figure 17–21b The Tympanic Membrane and Auditory Ossicles of the Middle Ear.
The Ear

- **Vibration of Tympanic Membrane**
  - Converts arriving sound waves into mechanical movements
  - Auditory ossicles conduct vibrations to inner ear
  - **Tensor tympani muscle**
    - Stiffens tympanic membrane
  - **Stapedius muscle**
    - Reduces movement of stapes at oval window
The Ear

The Inner Ear

- Contains fluid called endolymph
- Bony labyrinth surrounds and protects membranous labyrinth
- Subdivided into
  - Vestibule
  - Semicircular canals
  - Cochlea
Figure 17–22 The Inner Ear.
The Ear

- **The Inner Ear**
  - **Vestibule**
    - Encloses saccule and utricle
    - Receptors provide sensations of gravity and linear acceleration
  - **Semicircular canals**
    - Contain semicircular ducts
    - Receptors stimulated by rotation of head
  - **Cochlea**
    - Contains *cochlear duct* (elongated portion of membranous labyrinth)
    - Receptors provide sense of hearing
The Ear

- The Inner Ear
  - Round window
    - Thin, membranous partition
    - Separates perilymph from air spaces of middle ear
  - Oval window
    - Formed of collagen fibers
    - Connected to base of stapes
The Ear

- **Stimuli and Location**
  - Sense of gravity and acceleration
    - From hair cells in vestibule
  - Sense of rotation
    - From semicircular canals
  - Sense of sound
    - From cochlea
The Ear

- Equilibrium
  - Sensations provided by receptors of vestibular complex
  - Hair cells
    - Basic receptors of inner ear
    - Provide information about direction and strength of mechanical stimuli
The Ear

- The Semicircular Ducts
  - Are continuous with **utricle**
  - Each duct contains
    - Ampulla with gelatinous **cupula**
    - Associated sensory receptors
    - Stereocilia – resemble long microvilli:
      - Are on surface of hair cell
    - Kinocilium – single, large cilium
Figure 17–23a The Semicircular Ducts.
Figure 17–23b-d The Semicircular Ducts.
Figure 17–23b-d The Semicircular Ducts.
Figure 17–23b-d The Semicircular Ducts.
The Utricle and Saccule
- Provide equilibrium sensations
- Are connected with the endolymphatic duct, which ends in endolymphatic sac

Maculae
- Oval structures where hair cells cluster

Statoconia
- Densely packed calcium carbonate crystals on surface of gelatinous mass
- **Otolith** (ear stone) = gel and statoconia
Figure 17–24a–b The Saccule and Utricle.
Figure 17–24c A Diagrammatic View of Macular Function.
The Ear

Pathways for Equilibrium Sensations

Vestibular receptors

- Activate sensory neurons of vestibular ganglia
- Axons form vestibular branch of vestibulocochlear nerve (VIII)
- Synapse within vestibular nuclei
The Ear

- Four Functions of Vestibular Nuclei
  - Integrate sensory information about balance and equilibrium from both sides of head
  - Relay information from vestibular complex to cerebellum
  - Relay information from vestibular complex to cerebral cortex
    - Provide conscious sense of head position and movement
  - Send commands to motor nuclei in brain stem and spinal cord
Figure 17–25 Pathways for Equilibrium Sensations.
The Ear

- **Eye, Head, and Neck Movements**
  - Reflexive motor commands
    - From vestibular nuclei
    - Distributed to motor nuclei for cranial nerves

- **Peripheral Muscle Tone, Head, and Neck Movements**
  - Instructions descend in vestibulospinal tracts of spinal cord
Eye Movements

- Sensations of motion directed by superior colliculi of mesencephalon
- Attempt to keep focus on specific point
- If spinning rapidly, eye jumps from point to point
  - Nystagmus:
    - have trouble controlling eye movements
    - caused by damage to brain stem or inner ear
Hearing

- Cochlear duct receptors
  - Provide sense of hearing
Figure 17–26a The Structure of the Cochlea.
Figure 17–26b Diagrammatic and Sectional Views of the Cochlear Spiral.
The Ear

Hearing

Auditory ossicles

- Convert pressure fluctuation in air into much greater pressure fluctuations in perilymph of cochlea

- Frequency of sound:
  - determined by which part of cochlear duct is stimulated

- Intensity (volume):
  - determined by number of hair cells stimulated
The Ear

- Hearing
  - Cochlear duct receptors
    - Basilar membrane:
      - separates cochlear duct from tympanic duct
      - hair cells lack kinocilia
      - stereocilia in contact with overlying tectorial membrane
        » is attached to inner wall of cochlear duct
Figure 17–27 The Organ of Corti.
Figure 17–27 The Organ of Corti.
Figure 17–27 The Organ of Corti.
The Ear

- Pressure Waves
  - Consist of regions where air molecules are crowded together
  - Adjacent zone where molecules are farther apart
- Sine waves
  - S-shaped curves
The Ear

- **Pressure Wave**
  - **Wavelength**
    - Distance between two adjacent wave troughs
  - **Frequency**
    - Number of waves that pass fixed reference point at given time
    - Physicists use term *cycles* instead of *waves*:
      - Hertz (Hz): number of cycles per second (cps)
The Ear

- Pressure Wave
  - Pitch
    - Our sensory response to frequency
  - Amplitude
    - Intensity of sound wave
    - Sound energy is reported in **decibels**
Figure 17–28 The Nature of Sound.
Figure 17–30 Frequency Discrimination.
The Ear

Figure 17–29 Sound and Hearing.

STEP 1
Sound waves arrive at tympanic membrane.

STEP 2
Movement of the tympanic membrane causes displacement of the auditory ossicles.

STEP 3
Movement of the stapes at the oval window establishes pressure waves in the perilymph of the vestibular duct.
Figure 17–29 Sound and Hearing.
Auditory Pathways

Cochlear branch

- Formed by afferent fibers of spiral ganglion neurons:
  - enters medulla oblongata
  - synapses at dorsal and ventral cochlear nuclei
  - information crosses to opposite side of brain:
    - ascends to inferior colliculus of mesencephalon
The Ear

- **Auditory Pathways**
  - Ascending auditory sensations
    - Synapse in medial geniculate nucleus of thalamus
    - Projection fibers deliver information to auditory cortex of temporal lobe
Figure 17–31 Pathways for Auditory Sensations.
The Ear

- Hearing Range
  - From softest to loudest represents trillion-fold increase in power
  - Never use full potential
  - Young children have greatest range
## The Ear

<table>
<thead>
<tr>
<th>TABLE 17-1</th>
<th>The Power Content of Representative Sounds</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Typical Decibel Level</strong></td>
<td><strong>Example</strong></td>
</tr>
<tr>
<td>0</td>
<td>Lowest audible sound</td>
</tr>
<tr>
<td>30</td>
<td>Quiet library; soft whisper</td>
</tr>
<tr>
<td>40</td>
<td>Quiet office; living room; bedroom away from traffic</td>
</tr>
<tr>
<td>50</td>
<td>Light traffic at a distance; refrigerator; gentle breeze</td>
</tr>
<tr>
<td>60</td>
<td>Air conditioner at 20 feet; conversation; sewing machine in operation</td>
</tr>
<tr>
<td>70</td>
<td>Busy traffic; noisy restaurant</td>
</tr>
<tr>
<td>80</td>
<td>Subway; heavy city traffic; alarm clock at 2 feet; factory noise</td>
</tr>
</tbody>
</table>
### TABLE 17–1 The Power Content of Representative Sounds

<table>
<thead>
<tr>
<th>Typical Decibel Level</th>
<th>Example</th>
<th>Dangerous Time Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>Truck traffic; noisy home appliances; shop tools; gas lawn mower</td>
<td>Less than 8 hours</td>
</tr>
<tr>
<td>100</td>
<td>Chain saw; boiler shop; pneumatic drill</td>
<td>2 hours</td>
</tr>
<tr>
<td>120</td>
<td>“Heavy metal” rock concert; sandblasting; thunderclap nearby</td>
<td>Immediate danger</td>
</tr>
<tr>
<td>140</td>
<td>Gunshot; jet plane</td>
<td>Immediate danger</td>
</tr>
<tr>
<td>160</td>
<td>Rocket launching pad</td>
<td>Hearing loss inevitable</td>
</tr>
</tbody>
</table>
The Ear

- With age, damage accumulates
  - Tympanic membrane gets less flexible
  - Articulations between ossicles stiffen
  - Round window may begin to ossify