The Special Senses
Introduction
Vision

Receptors
- Specialized structures designed to respond to specific stimuli
- Variable complexity

General Properties of Receptors
- Transducers
  - Stimulus energy is converted to an AP
- 2 types of graded potentials generated by receptors
  - Receptor potential
    - Occurs in a separate receptor cell (not the neuron)
    - Example: Rods and cones use phototransduction
  - Generator potential
    - Occurs when either:
      - The neuron is the receptor
        - Example: neurons in olfactory epithelium
      - The receptor releases NT and stimulates the sensory neuron

General Properties of Receptors
Stimulus causing receptor potentials
↓
Generator potential in afferent neuron
↓
Nerve impulse

Sensation and Perception
Stimulatory input
↓
Detection of stimulus = sensation
Conscious level = perception

General properties of receptors
- Information conveyed by receptors
  - Modality
    - Type of stimulus or sensation – hearing, vision, taste, etc.
  - Location
    - Brain refers pain to its point of origin
  - Intensity
    - Determined by impulse transmission rate, variations in sensory thresholds in a group of sensory neurons
  - Duration
    - Encoded by changes in the pattern of impulse transmission over time
Sensory Adaptation

- Reduction in rate of impulse transmission when stimulus is prolonged
- Occurs in all receptors except those for pain
- Let’s try it...

Classification of Receptors

- **Stimulus Modality**
  - Chemoreceptors
  - Thermoreceptors
  - Nociceptors
  - Mechanoreceptors
  - Photoreceptors

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Classification of Receptors

- Stimulus Modality
  - Chemoreceptors
  - Thermoreceptors
  - Nociceptors
  - Mechanoreceptors
  - Photoreceptors
    - Respond to light
    - Rods, cones, certain retinal ganglion cells

Classification of Receptors

- Origin of stimuli
  - Exteroceptors
  - Interoceptors
  - Proprioceptors

Classification of Receptors

- Origin of stimuli
  - Exteroceptors
  - Interoceptors
    - Respond to stimuli that originate inside the body
    - Examples: pressure, hunger, thirst
  - Proprioceptors

Classification of Receptors

- Origin of stimuli
  - Exteroceptors
  - Interoceptors
  - Proprioceptors
    - Respond to stimuli that originate due to the positions and tensions of joints and muscles

Special senses

- Vision
- Hearing
- Olfaction
- Gustation
Vision Introduction

- 70% of all sensory receptors are in the eye
- Nearly half of the cerebral cortex is involved in processing visual information
- Optic nerve is one of body's largest nerve tracts

Vision Introduction

- The eye is a photoreceptor organ
- Refraction
  - Light bends when it passes from one medium to another
- Conversion (transduction) of light into AP's
- Information is interpreted in cerebral cortex

Accessory Structures

- Lacrimal apparatus
  - Series of structures that produce tears, direct their flow, and drain them
    - Lacrimal gland and ducts
      - Connect to nasal cavity
    - Lacrimal secretion (tears)
      - Dilute saline solution
      - Mucus, antibodies, and lysozyme
      - Blinking spreads the tears toward medial commissure
      - Drain into the nasolacrimal duct
Accessory Structures

- Six extrinsic eye muscles

![Diagram of eye muscles](image1)

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Action</th>
<th>Controlling cranial nerve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral rectus</td>
<td>Moves eye laterally</td>
<td>VI (abducens)</td>
</tr>
<tr>
<td>Medial rectus</td>
<td>Moves eye medially</td>
<td>III (oculomotor)</td>
</tr>
<tr>
<td>Superior rectus</td>
<td>Elevates eye and turns it medially</td>
<td>III (oculomotor)</td>
</tr>
<tr>
<td>Inferior rectus</td>
<td>Depresses eye and turns it medially</td>
<td>III (oculomotor)</td>
</tr>
<tr>
<td>Superior oblique</td>
<td>Elevates eye and turns it laterally</td>
<td>III (oculomotor)</td>
</tr>
<tr>
<td>Inferior oblique</td>
<td>Depresses eye and turns it laterally</td>
<td>IV (trochlear)</td>
</tr>
</tbody>
</table>

(c) Summary of muscle actions and innervating cranial nerves

![Diagram of eyeball layers](image2)

the Eyeball

- Wall of eyeball contains three layers (tunics)
  - Fibrous
  - Vascular
  - Sensory (retinal)

![Diagram of eyeball layers](image3)

the eyeball

- Three layers
  1) Fibrous tunic
     - Sclera – “white” of the eye
     - Cornea – clear continuation over the iris and pupil

![Diagram of eyeball layers](image4)
• Cornea must be actively dehydrated to remain transparent
• Sodium pumps remove sodium from the endothelium – water follows

Corneal Edema

• Three layers
  2) Vascular tunic (uvea) – 3 components
  – Choroid
  – Ciliary body
  – Iris

Three layers
2) Vascular tunic (uvea) – 3 components
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– Iris

Three layers
2) Vascular tunic (uvea)
– Choroid
– Ciliary body
  – Ciliary processes
  – Arranged in a ring around the lens
  – Ciliary muscle
  – Used to focus the eye
  – Iris

Three layers
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Three layers
2) Vascular tunic (uvea) – 3 components
  – Choroid
  – Ciliary body
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the eyeball

• Three layers
  3) Retina (innermost layer)
  • Photoreceptor neurons
    – Rods and Cones
  • Bipolar neurons
  • Ganglion neurons
    – Axons form the optic nerve
    – Exit eyeball at optic disc

the eyeball

• Rods and cones
  – Specialized photoreceptors
  – Rods = black and white vision
  – Cones = daylight color vision
  – Fovea centralis
    • Cones most concentrated here
    • Point of highest visual acuity
    • Other retinal layers are displaced (forms a depression)

Retinal Blood Supply

• Outer 1/3 of retina
  – Choroid
• Inner 2/3 of retina
  – Central artery and vein
The Eyeball

- Photoreceptors
  - Rods
    - More numerous at peripheral region
    - Dim light
      - Indistinct, fuzzy, non-color peripheral vision
    - About 100 million per eye

The eyeball

- Photoreceptors
  - Cones
    - Red, blue, and green
      - Highest density in macula lutea
    - Concentrated in fovea centralis
    - Operate in bright light
    - High-acuity color vision

The eyeball

- Lens
  - Biconvex, transparent, flexible
  - Attached to ciliary body by suspensory ligaments
  - Allows precise focusing of light on the retina
  - Forms a partition
    - Creates an anterior and posterior cavity
The eyeball

- Two Cavities
  - Anterior cavity
    - Filled with aqueous humor
    - Modified plasma
    - Constantly produced, in constant circulation
    - Accumulation may lead to glaucoma

- Posterior cavity
  - Filled with vitreous humor
  - Gelatinous mass
  - Avascular
  - Very few cells
  - A few phagocytes that remove debris from the field of vision
  - Responsible for eye holding its spherical shape

The Physiology of Vision

- Visual acuity – ability to discern detail
  - Ratio of distances
    - 20/20
    - 20/40
      - Less visual acuity
    - 20/15
      - More visual acuity

The Physiology of vision

- 5 processes produce a visual image
  1. Refraction
  2. Accommodation
  3. Pupil constriction
  4. Convergence
  5. Photoreception
Refraction

- The bending of light rays

Refraction

- Most of the light we see is reflected off of objects

Refraction

- This light begins as a single point, but spreads as distance from the object increases

Fig. 3.2 Specular, diffuse, and spread reflection from a surface.

Refraction

- The eye must collect and re-bend the light to a single point in order to construct an image
- Since focal length is fixed, the eye changes the shape of the lens to accomplish this

Refraction

- Light passing through a convex lens (as in the eye) is bent so that the rays converge at a focal point
- The image formed at the focal point is upside-down and reversed right to left

Emmetropic eye (normal)
Figure 15.13a

Lens
Inverted image
Ciliary zonule
Ciliary muscle
Nearly parallel rays from distant object

(a) Lens is flattened for distant vision. Sympathetic input relaxes the ciliary muscle, tightening the ciliary zonule, and flattening the lens.

Refraction

- Refracting media
  - Light is refracted by
    - Cornea
    - Aqueous humor
    - Lens
    - Vitreous humor
- Change in lens curvature
  - Allows for fine focusing of an image

Sympathetic activation

Accommodation

- Eye is adapted for distance vision
  - Ciliary muscle is relaxed = lens is flat
  - As light moves closer greater curvature required
    - Ciliary muscle contracts = lens is curved

(a) Lens is flattened for distant vision. Sympathetic input relaxes the ciliary muscle, tightening the ciliary zonule, and flattening the lens.

(b) Lens bulges for close vision. Parasympathetic input contracts the ciliary muscle, loosening the ciliary zonule, allowing the lens to bulge.

Accommodation

- Near vision
  - Light rays from near objects require extensive refraction
  - Accommodation
    - Ciliary muscles contract
    - Lens shape changes
    - Eye strain
Accommodation

- **Near point**
  - Closest point at which an object can be brought into focus
  - Typically 25cm
  - Maximum bulge
  - Presbyopia - Aging

Close Vision

- Close vision requires
  - Accommodation
  - Pupil constriction
  - Prevents most divergent light rays from entering the eye
  - Convergence
    - Medial rotation of the eyeballs toward the object being viewed (binocular vision)

Pupil Manipulation

- Contraction of the circular muscles = constriction
- Contraction of the radial muscles = dilation

Photoreception

- Sensory transduction
  - Light energy is converted into nerve impulses
- Takes place in retina
  - Photoreceptors
Photoreception

- Rods and cones
  - Outer segment of each contains visual pigments
  - Molecules that change shape as they absorb light

The outer segments of rods and cones are embedded in the pigmented layer of the retina.

**Process of bipolar cell**
- Outer fiber
- Apical microvillus
- Discs containing visual pigments
- Discs being phagocytized
- Pigment cell nucleus
- Basal lamina (border with choroid)

**Rod discs**
Visual pigment consists of
- Retinal
- Opsin

(b) Rhodopsin, the visual pigment in rods, is embedded in the membrane that forms discs in the outer segment.

**In the dark**
- cGMP opens sodium channels and depolarizes photoreceptors
- Inhibitory neurotransmitter is released (glutamic acid)
- Bipolar cells are constantly inhibited in the dark

**In the light**
- cGMP-gated channels close, so Na\(^{+}\) influx stops; the photoreceptor hyperpolarizes.
- Bipolar cell is no longer inhibited.
- No neurotransmitter is released.
- Calcium channels open in ganglion cell.
- Action potentials propagate along the optic nerve.
Photoreception

- Excitation of cones
  - Method of excitation is similar to that of rods
  - There are three types of cones
  - Named for the colors of light absorbed: blue, green, & red
  - Light absorbed depends upon opsins present

- Light adaptation
  - Occurs when moving from darkness into bright light
  - Large amounts of pigments are broken down instantaneously
    - Produces glare
  - Pupils constrict
  - Dramatic changes in retinal sensitivity
    - Rod function ceases
  - Cones and neurons rapidly adapt
    - Visual acuity improves over 5–10 minutes

- Dark adaptation
  - Occurs when moving from bright light into darkness
  - The reverse of light adaptation
    - Cones stop functioning in low-intensity light
    - Pupil dilates
    - Rhodopsin accumulates in the dark
      - Retinal sensitivity increases within 20–30 minutes

- Duplicity theory
  - Why do we have 2 kinds of photoreceptors?
    - Neural circuits for night are not suited for day
    - Rods: Bipolar cell
      - 600:1
      - Spatial summation of large field = poor detail
    - Cones: Bipolar cell
      - 1:1
      - Best for detail in small receptive fields

Visual Pathway to the brain

- Axons from medial portion of each retina cross at optic chiasma
  - Continue as optic tracts
- Optic radiation fibers connect to the primary visual cortex in the occipital lobes
  - Visual input from both eyes is interpreted by brain
    - Distance
    - Depth perception

The visual fields of the two eyes overlap considerably. Note that fibers from the lateral portion of each retina do not cross at the optic chiasma.
Abnormalities of Vision

- **Myopia** (nearsightedness)
  - Close objects seen clearly
  - Image is focused in front of the retina
  - Correction = concave lens

Abnormalities of Vision

- **Hyperopia** (farsightedness)
  - Distant objects seen clearly
  - Image is focused behind the retina
  - Correction = convex lens

Abnormalities of Vision

- **Astigmatism**
- Detached retina
- Conjunctivitis
- Glaucoma
- Cataract
- Night blindness
- Diplopia
- Color blindness
- Macular Degeneration

Abnormalities of Vision

- **Astigmatism**
  - Abnormal curvature of eye
  - Light rays don’t meet at a common focus
  - Causes visual distortion

Abnormalities of Vision

- **Detached retina**
  - Retina becomes separated from underlying choroid
  - Causes loss of vision in affected area
Abnormalities of vision

- Conjunctivitis
  - Inflammation of the conjunctiva
  - Causes by bacteria, viruses, irritants, allergies
  - “Pink eye”

- Glaucoma
  - Increased pressure in the eyeball
  - Leads to optic nerve damage
  - Causes gradual loss of sight
  - Damage is irreversible, but may be slowed or stopped

- Cataract
  - Lens becomes progressively opaque
  - Results in blurred vision
  - Can be surgically removed and replaced with an artificial lens

- Diplopia
  - Double vision
  - At least 20 different causes
    - Cranial nerve III palsy
    - Aneurysm
    - High blood pressure
    - Diabetes
    - Inflammatory conditions
    - Guillain-Barré syndrome
    - Problems with the lid, pupil, or eye muscles
    - Etc.

- Nightblindness (nyctalopia)
  - Loss of low light vision
  - Most common cause: retinitis pigmentosa
    - Rods lose ability to respond to light

- Colorblindness
  - Defect in perception of colors
  - Defect in cones
  - Can be acquired, usually genetic
Abnormalities of vision

- Macular degeneration
  - Damage to macula and retina
  - Risk factors
    - Genetic
    - Lifestyle

Bonus: amblyopia
- “Lazy eye”
- Decreased vision in eye that appears normal
- Developmental problem of the brain
- Brain doesn’t recognize image from one eye