Functions of visual system

- Respond to photons of light from environment
- Change photon stimulation into neuronal activity

- Involves mechanisms to:
  - Focus images from different distances
  - Adjust to diff. Light intensities
  - Discriminate diff. Wave-lengths (color)
  - Distinguish location of object
  - Detect shapes of objects
  - Detect movement of images
• Globular structure 25mm diameter
  – Fluid contents maintain shape
  – Lens suspended in middle

• Layers:
  – Outer - tough connective tissue: * Cornea - transparent * Sclera - white
  – Middle - choroid: vascular; smooth muscle
  – Inner - retina; neural
• **Chambers:**
  - Aqueous - in front of lens; fluid like ECF
  - Vitreous - behind lens; gel

• **Fluid environments:**
  - Aqueous – high turnover rate (replaced 12 x a day)
  - Vitreous – kept clear by phagocytic cells that remove blood and other debris (floaters, due to limited “clean-up capacity”)

**Visual system**
Retinal surface

ophthalmic artery (1), vein (7)

Optic disc (5)  Fovea (2)  (macula lutea)

Visual system
**Papilledema**

- **C:** normal optic disc

- **D:** Papilledema
  - Subarachnoid space surrounding optic nerve is continuous with brain
  - Excess intracranial pressure results in swelling of disk
  - Optic nerve head is elevated into vitreous

- **Glaucoma - depressed optic disc**
Aqueous Chambers

- Aqueous humor
- 200 µl / eye
- Composition like ECF
- Secreted by ciliary body
- Drained through canals of Schlemm
- Glaucoma -
  - Outflow impeded
  - Pressure increases
  - Damage to retina
- Pupil diameter controlled by smooth muscle of iris
- Parasymp - constricts; symp - dilates

Visual system
Cataracts

- Clear light path to retina needed
- Most common pathology: Cataracts
- Deterioration of lens proteins
  - UV; metabolic
- Treatment: replace with plastic lens
  - Can no longer adjust for near vision
  - Multifocal lenses
Refraction of light rays

- Light must be bent so all rays from the same origin fall on the same point on the retina

- Most bending occurs at air / cornea interface
  - 45 diopters
  - Corneal refraction eliminated when swimming under water (refractive index of cornea = water)

- Crystalline lens adds from 15 - 27 additional diopters

- (Image is inverted on the retina)

Visual system
Accommodation

- Crystalline lens adds from 15 - 27 additional diopters
- Only variable component: Needed to adjust for near vision
Accommodation

- More bending power needed for near vision
- At rest lens is under tension by suspensory ligaments - flattened
- Lens is normally elastic

Visual system

**NEAR VISION**

- Increased firing of parasympathetic nerves to ciliary muscle
- Contraction of ciliary muscle
- Relaxation of zonular fibers
- Relaxation of lens so that it becomes more spherical
- Near objects brought into focus
Presbyopia - loss of accommodation with aging

- Due to loss of lens elasticity
Farsightedness - hyperopia

- Eyeball too short, or too little bending power
- Distant objects clear, near objects blurry (no more accommodation left)
- Correct with convex (converging) lenses
Nearsightedness - myopia

- Eyeball too long, or too much bending power
- Distant objects blurry, near objects clear
- Correct with concave (diverging) lenses
Retinal layers

- Five main cell types
- Cell layers alternate with synaptic layers
- Photoreceptor cells are at the back (outside) of the retina

Photoreceptors convert absorption of light into electrical signal
Photoreceptors

Visual system
Transduction from light to neural activity

- **Photoreceptors**
  - Rods - fatter, blunt, more discs
    - Sensitive in dim light, monochromatic
  - Cones - thinner, tapered
    - High acuity, need bright light, trichromatic

- **Outer segment**
  - Membrane discs
  - Site of photopigment

- **Inner segments**
  - nucleus; mitochondria
  - Synaptic vesicles
Rhodopsin - photopigment

- Photopigment has 2 components
  - Small light-sensitive molecule = retinal; derived from Vitamin A
  - Embedded in G-protein = opsin

- Rhodopsin - rods
- 3 cone opsins - cones

Visual system
Retinal - response to light

- Effect of light on retinal - photo-isomerization
- Dark - 11-cis form, bent
- Light - all-trans form, straight
• Dark:
  – Retinal bound to opsin
  – High Na+/Ca2+ permeability
  – Inward current = dark current
  – Depolarized receptors
  – Continuous transmitter release (Glu)

• Light: Absorb photon -isomerization; retinal moves out of opsin
  – G-protein activated; cGMP (second messenger) is reduced
  – Na+/Ca2+ channels closed (1 Rho* closes 200 channels, ~2% are open in the dark); reduced dark current
  – Hyperpolarized receptors; reduced transmitter release
Transduction process

Visual system
Membrane potential response

- Higher light intensity = greater membrane potential response
3-types of Cones

- Three cone cell types
- Three opsins absorb at different peak wave-lengths
- Color specified by relative activity of the three cone types
- Some of x-type ganglion cells receive input from pairs of cone types
  - i.e. red excites; green inhibits
Color blindness

*Trichromats:* people who have normal color vision

*Dichromats:* are missing one whole group of photopigment (most mammals, including cats and dogs, have dichromatic color vision, missing long-wavelength pigment)

*Monochromats:* are very rare and cannot distinguish colors
Rod & Cone distribution

- Cones are densely located only in the fovea
- Rods are absent from the fovea; densest in intermediate retina and decrease in density close to the periphery
Properties of Rods versus Cones

- **Rods:**
  - High light sensitivity; lots of photopigment
  - Monochromatic
  - Convergent connections to bipolar cells
  - Low acuity
  - Located in peripheral retina

- **Cones:**
  - Low light sensitivity
  - Trichromic (color discrimination)
  - 1:1 transmission to bipolar cells
  - High acuity
  - Located in foveal retina
Foveal specialization

- Only cones; thinner cells
- Inner layers displaced to side
- 1:1 transmission to bipolars
Pigment (from disrupted RPE) is deposited starting with peripheral retina
Vision gradually reduced from periphery inward (starts with loss of rod photoreceptors)
30 genes have been identified (majority are rod specific; signal transduction cascade)
Adjustments for different light levels

- Change pupil diameter
  - Dim light - pupil dilates

- Rods versus cones
  - Rods used in dim light (reduced acuity)

- Adaptation - bleaching of photopigments
  - Photopigments split proportional to light intensity
  - Regenerated at constant rate
  - Bright light - decrease in amount of active photopigment
  - Dim light - increase in amount of active photopigment

- Neuronal adaptation
  - Ca2+-mediated effects
  - Neuronal interaction (HCs and PRs)
Retinal circuits

- Basic minimal path:
  - Photoreceptor to bipolar to ganglion cell to optic nerve

- Interneurons modify transmission
  - Horizontal cells - sharpen contrast, center/surround receptive fields
  - Amacrine cells - emphasize movement, phasic response
Center/surround receptive fields

- Important for high acuity vision
- Increase in contrast

- Receptors in center have one effect on bipolar cells
- Receptors in surround have opposite effect on bipolar cells mediated by horizontal cells

Visual system
Center/surround receptive fields

Center;
photoreceptors in the center
have one effect on bipolar cells
(depolarization of ON and
hyperpolarization of OFF BPs)

Surround;
photoreceptors in the surround
have opposite effect on bipolar cells
mediated by horizontal cells
(GABA)
Luminance contrast

- Most GCs respond best to small spots of light.
- Center/surround antagonism makes GCs sensitive to luminance contrast.
- Activity most affected in cells whose receptive field is along light-dark edge.
• **W cells:**
  – General light response
  – Pattern unimportant
  – Project to SCN, pretectum
  – Regulate pupil diameter, entrainment to circadian rhythm

• **X (P) cells:**
  – Tonic response, small r/f
  – Center/surround
  – Project to LGN (3-6) & visual cortex
  – Color vision, fine details (what?)

• **Y (M) cells:**
  – Phasic response, movement
  – Large r/f
  – Project to LGN (1,2) & Superior colliculus
  – Motion detection, no color information (Where?)
  – Control eye movement (SC)
Next lecture will follow RGCs into the brain