Visual System I
Eye and Retina

Reading:
BCP Chapter 9
The Visual System

The visual system is the part of the NS which enables organisms to process visual details, as well as to perform several non-image-related response functions. It detects (sensation) and interprets (perception) information from visible light to build a representation of the surrounding environment.

Eye and Retina
- Structures
- Transduction

Retina-geniculate-striate cortex
- Pathway
- Receptive field properties

Striate and Association cortex
- Higher-order processing
All that we know about the world around us is obtained through our senses ("Esse est percipi"): "For there is no conception in a man's mind, which hath not at first, totally, or in parts, been begotten upon the organs of the Sense" (Thomas Hobbes, 1558-1679).

“What is real? How do you define real? If you’re talking about what you can feel, what you can smell, what you can taste and see, then real is simply electrical signals interpreted by your brain” (Morpheus to Neo in The Matrix, 1999).

Sensation:
• Related to the physical interaction of a stimulus with a sensory receptor.

Perception:
• Conscious awareness and interpretation of sensation.
• Related to the particular sensory pathway in the nervous system that processes information from a receptor.
• Influenced by “top down” processes: cognition, attention, experience.
Sensation ≠ Perception 1
Sensation ≠ Perception 2

Are the horizontal lines parallel or do they slope?
Properties of Light

No light, no vision

Light can be thought of in two different ways:
- Particles of energy (photons)
- Waves

Visible light (for humans) is waves of electromagnetic energy between 380-760 nm

Wavelength: color
Intensity: brightness
Principles of Optics

Light is change by objects it encounters in its path: reflected; refracted (bent); diffracted and absorbed.

Refraction is wavelength-dependent: for a given lens, short wavelengths (blue) are bent more than long (red) wavelengths.
There is a one-to-one correspondence between a point in space and a place on the receptor surface (retina) (an explicit map of space)

*Accessory structures (e.g., cornea, lens):* shape the input to the receptor
The Eye 2

**Cornea**: primary refractive element

**Iris**: donut-shaped band of contractile tissue that gives the eye its color and regulates the amount of light entering eye via the size of the pupil (hole in the iris)

**Lens**: secondary refractive element (for near-vision: “accommodation”)

**Retina**: epithelial tissue upon which image is projected, containing photoreceptors and associated neuronal circuitry

**Extra-ocular muscles** (horizontal, vertical, and oblique pairs) control eye movements:
- **Voluntary**: Saccadic and smooth pursuit
- **Reflexive**: image stabilization re head movements
The Lens

Lens: focuses light on the retina

Ciliary muscles alter the shape of the lens as needed.

Accommodation: the process of adjusting the lens

The lens adjusts so that longer wavelengths of light (red and green) are in focus on the retina
The retina converts light to neural signals

5 layers (from front to back):
- retinal ganglion cells
- amacrine cells
- bipolar cells
- horizontal cells
- photoreceptors

“Inside-out”:
Light passes through many cell layers before reaching its receptors. The pigmented epithelium absorbs any light that passes through the retina, and also provides metabolic support.
The retina exhibits two special regions:
- the fovea (in primates including humans, some birds and reptiles); and
- the optic disk.

**Fovea**: region of the macula (thicker area with an absence of blood vessels) where the layers of the retina above the photoreceptors are displaced laterally so that light can impinge more directly on the photoreceptors.

**Optic disk**: “blind spot”, exit point for optic nerve (axons of retinal ganglion cells).
The Fovea

Fovea: high-acuity area at center of retina

Processes visual information from central 1° of visual space.

Highest density of receptors, bipolar, and ganglion cells in retina; however, bipolar and ganglion cell bodies displaced, creating a “pit” that minimizes light scattering between the lens and the photoreceptors.
The Blind Spot

Blind spot: region of retina with no receptors where retinal ganglion cell axons exit the eye (optic nerve)

The visual system “fills in” the blind spot based on information from the other eye or surrounding detail (called “completion”)
There are two main types of photosensitive cells – rods and cones – which differ in a number of anatomical and physiological ways. Anatomical differences include size, shape, number and location on the retina.

There are no rods in the fovea, only cones. Rods predominate outside of the fovea.
Rods and Cones 2

Duplex theory of vision: rods and cones mediate different kinds of vision

Rods (scotopic vision):
• high sensitivity (nighttime)
• low-acuity (high convergence)
• no color

Cones (photopic vision):
• low sensitivity (daytime)
• high-acuity (low convergence)
• color
Spectral Sensitivity

Scotopic vs Photopic vision
- Rods do not supply information concerning color, but they are most sensitive to shorter wavelengths of light.
- Cones are sensitive to longer wavelengths.

There are three types of cones in the retina. Within the photopic range of wavelengths:
- red: most sensitive to long wavelengths (L)
- green: sensitive to the mid-range of wavelengths (M); and
- blue: sensitive to short wavelengths (S)
In the human retina, most cones are red and green type (but the relative ratio can vary widely) and few are blue because the lens focuses longer wavelengths of light onto the retina.

Component (trichromatic) theory: color is encoded (initially) by the ratio of activity in the three kinds of receptors.
Photoreceptors are modified epithelial cells or so-called short receptors:
- no axonal process
- “synaptic-mimetic”: functionally and morphologically similar to presynaptic nerve endings; transduction currents modulate release of neurotransmitter

Outer segment: **transduction**
- modified cilium, densely folded.
- photopigments respond to light, and alter membrane currents.
- replaced daily

Inner segment: **transmission**
- synapses with bipolar and horizontal cells
- transduction currents modulate release of glutamate.
The outer segments of photoreceptors contain disk-bound photoreceptor proteins, specifically rhodopsin (rods) and photopsins (cones). Photo-pigments consist of two components: retinal, a small molecule derived from vitamin A that changes shape as it absorbs light; and opsin, a protein which determines the spectrum of photons captured.
Photoreceptors are depolarized in the dark, and hyperpolarize in response to light

In the dark (i.e. unstimulated):
- cGMP-gated Na⁺ channels are open, leading to inward (depolarizing) Na⁺ current (the so-called “dark current”)
- \( V_{\text{rest}} \approx -40\text{mV} \)
- glutamate released

In response to light (stimulated):
- retinal changes shape
- opsin dissociates and activates a unique G-protein (transducin)
- transducin activates the enzyme phosphodiesterase (PDE) which breaks down cGMP.
- cGMP-Na⁺ channels close
- membrane hyperpolarizes (~ -70mV)
- reduced release of glutamate