The Visual System: Retinal Processing
Seeing is Believing?
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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.
There is a one-to-one correspondence between a point in space and a place on the retina.
Iris: donut-shaped bands of contractile tissue that give the eye its color.

Light enters the eye through the **pupil**, the hole in the iris.

The pupil changes size in response to changes in illumination.
- Sensitivity
- Acuity
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
Depth Perception

Two eyes:
- Field-of-view
- Binocular vision (depth)

Convergence: eyes must turn slightly inward when viewing objects

Binocular disparity: the difference in the position of the same image on the two retinas
The Retina

Converts light to neural signals

“Inside-out”: light passes through several cell layers before reaching its receptors

5 layers: receptors, horizontal cells; bipolar cells; amacrine cells, and retinal ganglion cells
Regions of the Retina

- Fovea
- Blind spot
The Fovea

Fovea: high-acuity area at center of retina

Thinning of the ganglion cell layer reduces distortion due to cells between the pupil and the retina.
The Blind Spot

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

The visual system interpolates the blind spot based on surrounding detail and information from the other eye (called “completion”)
Rods and Cones 1

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)
Color Vision

The ratio of the three types of cones can vary widely in individuals with normal color vision (up to 1 million hues).

Two theories of color vision:
• component (trichromatic) theory: color is encoded by the ratio of activity in the three kinds of receptors
• opponent-process theory: color processed in an antagonistic manner (red/green, blue/yellow, white/black)

Courtesy Heidi Hofer, Austin Roorda, and David Williams
We continually scan the world with small, involuntary and quick eye movements: saccades.

These bits of information are then summated over time (temporal integration)

If stabilize image on retina, then see nothing in 1-3s.

The visual system responds to change.
Conversion of light to neural signals by visual receptors

Mechanism:
• In the dark, photoreceptive cells are depolarized (Na$^+$ influx) and releasing neurotransmitter
• Pigment receptor absorbs light and releases G-protein
• G-protein initiated signaling cascade closes Na$^+$ channels
• In the light, cell is hyperpolarized (less neurotransmitter released)
Output of the Retina

Receptive field: area of the visual field within which it is possible for a visual stimulus to influence the firing of a neuron

Retinal ganglion cells show center-surround receptive fields
Ganglion cell receptive fields match those of their bipolar cell inputs. Bipolar cells receive direct input from one or more photoreceptors above them forming the center of the RF, and indirect inhibitory inputs from an annulus of receptors around the center, via horizontal cells, forming the surround of the receptive field. There are two types of bipolar cells – On-center and Off-center – below each photoreceptor.

- **Off-center bipolar cells** have ionotropic glutamate receptors. When photoreceptors are in the dark (light is off) and releasing glutamate, these ionotropic channels are open allowing sodium to enter causing net depolarization.

- **On-center bipolar cells** have metabotropic glutamate receptors. When photoreceptors are in the dark and releasing glutamate, these receptors are activated, which in turn open channels allowing potassium to exit causing net hyperpolarization.
Opponent Ganglion Cells
Lateral inhibition refers to the inhibition that neighboring neurons in brain pathways have on each other. This process greatly increases the visual system's ability to respond to the edges of a surface because "edge" neurons (e.g., D and E below) receive less or more inhibition, respectively, from their neighbors.