LISC-322 Neuroscience

THE VISUAL SYSTEM

Retinal Anatomy & Physiology

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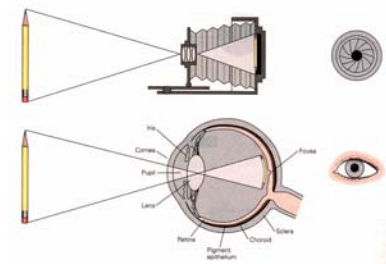
The Property of the Eye

As in a camera, the retinal image is an inversion of the physical image and the retina is a two-dimensional sheet.

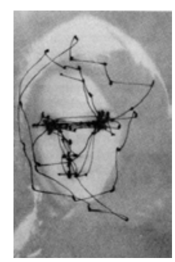


The Property of the Eye

Unlike photographic images, the resolution of the retinal image is not uniform.

The Property of the Eye

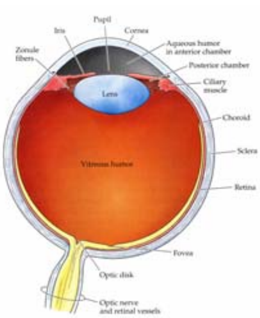
Because only the central region of the retina provides high resolution, we see the world by moving our eyes.



Ocular Anatomy

The eye is a fluid-filled sphere enclosed by three layers of tissue:

1) The outer layer is composed of the *sclera* and the *cornea*.
2) The middle layer includes the *iris*, the *ciliary body*, and the *choroid*.
3) The inner layer is the actual *retina* containing the photoreceptors.

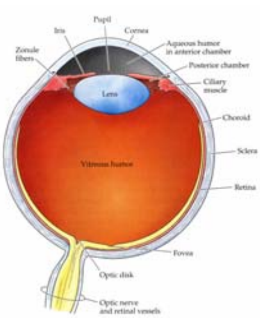


Ocular Anatomy

The *iris* contains a musculature that control the pupil size.

The *ciliary body* encircles the lens. It contains a musculature that adjusts the lens' refractive power.

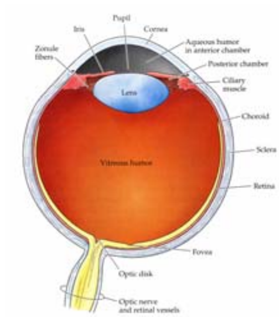
The *choroid* is a capillary bed supplying oxygenation and metabolic sustenance to the photoreceptors.



Ocular Anatomy

En route to the retina, light successively travels through:

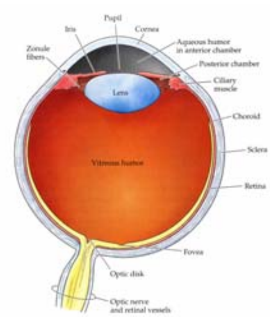
1) the *cornea*,
2) the *aqueous humor* of the anterior chamber,
3) the *lens*,
4) the *vitreous humor*.



Ocular Anatomy

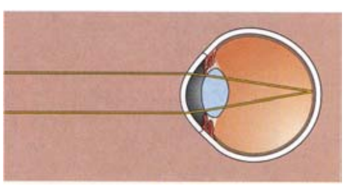
The *aqueous humor* is a clear, watery liquid in the *anterior chamber* produced by ciliary processes in the *posterior chamber*. It regulates the intraocular pressure.

The *vitreous humor* is a thick gelatinous substance between the back of the lens and the retina. It accounts for the size and shape of the globe.



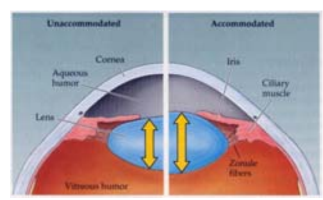
Retinal Image Formation

The formation of focused images on the photoreceptors depends on the refraction of light by the ***cornea*** and the ***lens***. The refractive power of the cornea is unvarying, but that of the lens is adjustable thanks to the ciliary muscle.



Retinal Image Formation

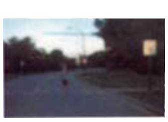
The dynamic changes in the refractive power of the lens are referred to as *accommodation*. The lens is made thin and flat to reduce its refractive power and allow the viewing of distant objects. It becomes thicker and rounder to increase its refractive power during near vision.

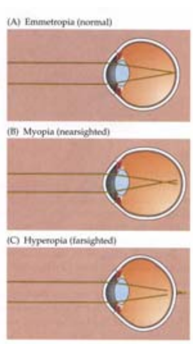


Retinal Image Formation

The ability to focus an image on the retina also depends on the *shape* of the eye globe.

When both the lens and the shape of the eye fail to focus retinal images, it's very time for corrective lenses!



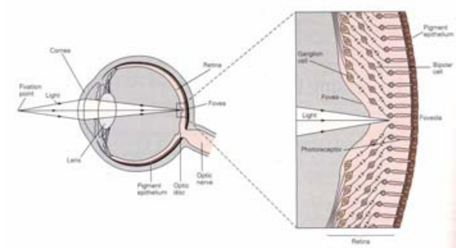


Retinal Image Formation

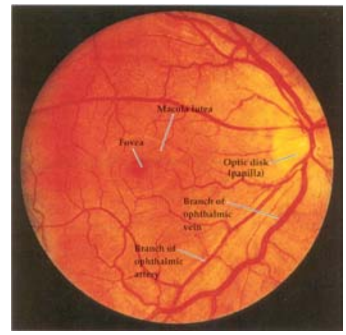
Adjustments in the size of the *pupil* also contribute to the retinal image formation.
Narrowing the pupil reduces both spherical and chromatic aberrations. It also increases the depth of field, i.e., the distance within which objects are seen without blurring.

Retinal Organization

The retina contain five types of neurons distributed in five layers as well as a specialized central region (*fovea*).

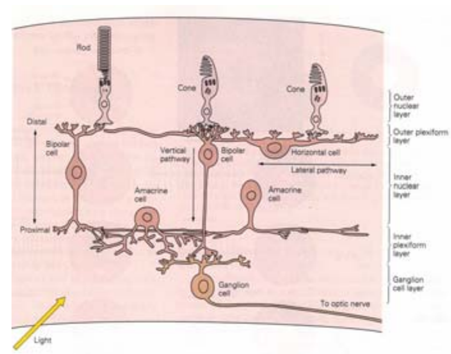


A Direct Look at the Retina



Blind Spot Demonstration

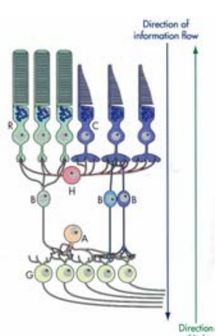
Retinal Organization



Retinal Organization

A direct *three-neuron chain* – from photoreceptor to bipolar to ganglion cell – is the major route of information flow from the light source to the optic nerve.

The horizontal and amacrine cells are primary responsible for *lateral interactions*.

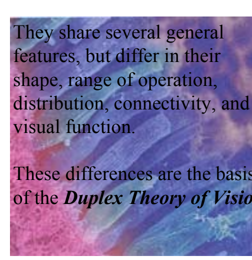


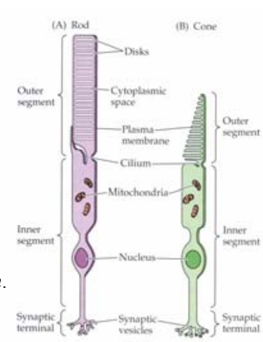
Photoreceptors

There are two types of photoreceptor: *rods* and *cones*.

They share several general features, but differ in their shape, range of operation, distribution, connectivity, and visual function.

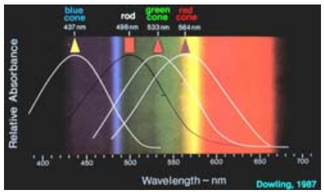
These differences are the basis of the ***Duplex Theory of Vision***.





Duplex Theory of Vision

Rods contain a single visual pigment (*rhodopsin*), sensitive to blue-green light. Cones are sensitive to short, medium or long wavelengths of light, permitting *color perception*.



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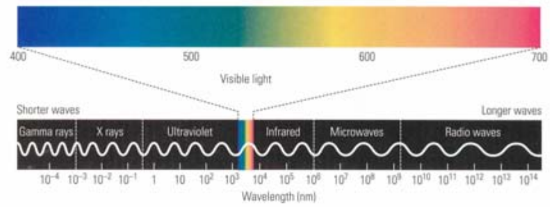
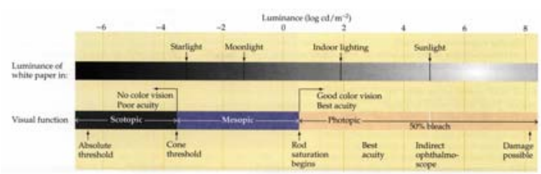


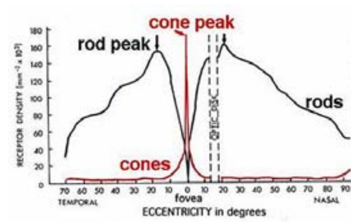
Duplex Theory of Vision

Rods are very sensitive to light and are solely responsible for *scotopic* vision, whereas cones are much less sensitive to light and solely responsible for *photopic* vision. Both photoreceptors are active during *mesopic* vision.



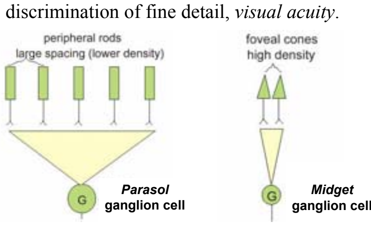
Duplex Theory of Vision

Rods and cones are unevenly distributed. The density of rods exceeds that of cones, except in the fovea where the cone density is highest and its central region (*foveola*) is rod-free.



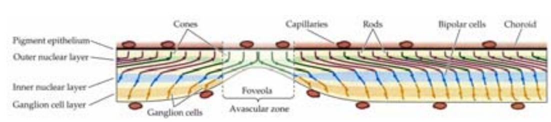
Duplex Theory of Vision

Rods and cones differ in their degrees of convergence onto ganglion cells. *Convergence* makes the rod system a better *light detector*, but reduces its spatial resolution. The near one-to-one mapping within the cone system maximizes the discrimination of fine detail, *visual acuity*.



Duplex Theory of Vision

The high density of cones with their one-to-one relationship with bipolar and ganglion cells allow the fovea to mediate high visual acuity. The superior foveal acuity further benefits from *reduced optical distortion* provided by the displacement of the inner nuclear and ganglion cell layers.

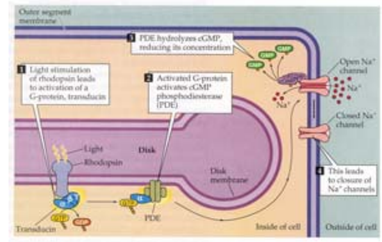


Duplex Theory of Vision

Rod System	**Cone System**
Achromatic	*Chromatic*
High convergence	Low convergence
High light sensitivity	Low light sensitivity
Low visual acuity	*High visual acuity*

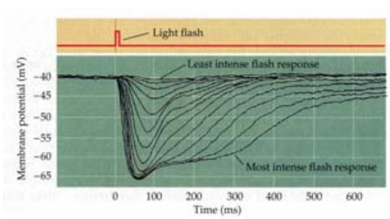
Phototransduction

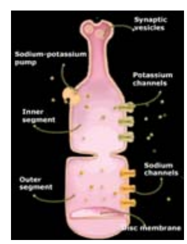
On the photoreceptor’s disks, photons strike photosensitive molecules and trigger a molecular cascade that modulates the photoreceptor’s release of neurotransmitter (*Glutamate*).

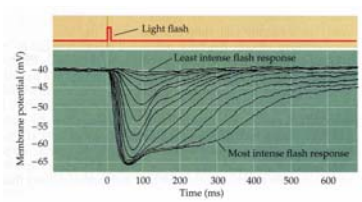


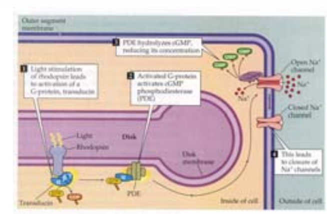
Phototransduction

In the dark, high cGMP concentration keeps Na+ channels open and generates the *dark current*: the photoreceptor is depolarized. Light lowers cGMP concentration, which closes Na+ channel: the photoreceptor becomes hyperpolarized.





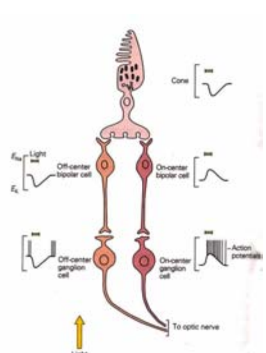




ON and OFF Channels

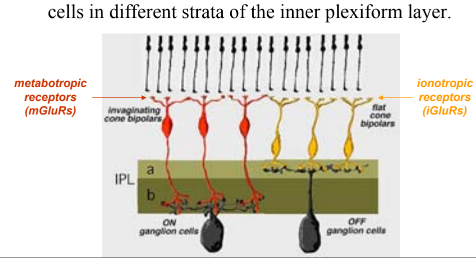
Light-induced hyperpolarization of photoreceptors triggers *both* hyperpolarization and depolarization within bipolar and ganglion cells.

These changes in membrane potentials lead to the production of *action potentials* in ganglion cells, permitting long-distance transmission within the optic nerve.



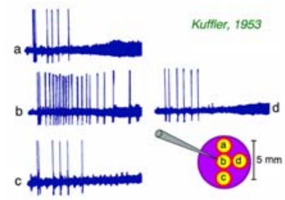
ON and OFF Channels

The ON and OFF bipolar cells respond differently to the photoreceptor signals because they express different receptors. They also make synaptic contact with ganglion cells in different strata of the inner plexiform layer.



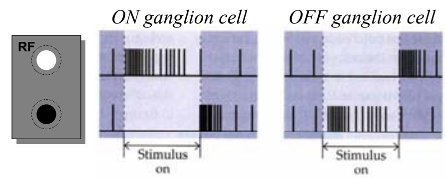
Retinal Receptive Fields

The part of the retina that needs to be stimulated to elicit action potentials from a ganglion cell is the cell's ***receptive field***. Retinal receptive fields are small and concentric and correspond to the part of the world that the cells can “see”.



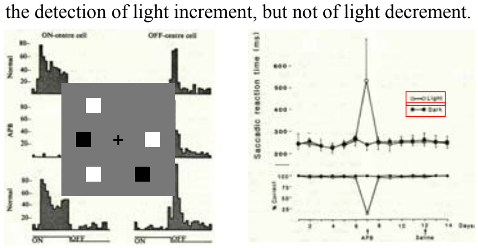
ON and OFF Responses

The ON and OFF bipolar and ganglion cells respectively detect increases and decreases in luminance within their small, concentric receptive fields.



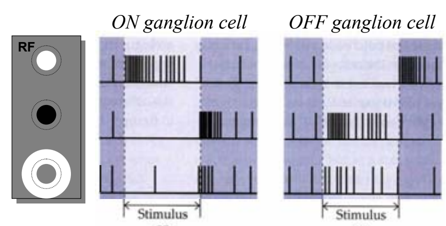
Function of ON and OFF channels

The application of 2-amino-4-phosphonobutyric acid (APB, a glutamate analogue) blocks the ON-channel at the bipolar cell level. In behaving monkeys, such reversible lesions impair the detection of light increment, but not of light decrement.



Center-Surround Organization

The receptive fields of ON and OFF retinal cells have a *center-surround organization*: stimulation of the region surrounding their receptive fields elicit opposite responses.



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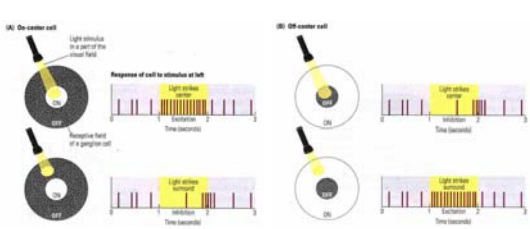
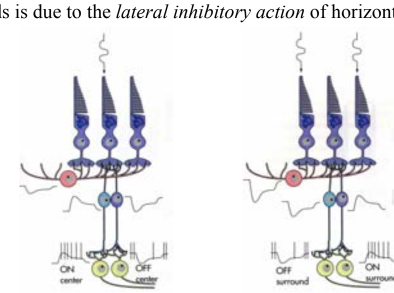


Center-Surround Organization

The center-surround organization of ganglion cells’ receptive fields is due to the *lateral inhibitory action* of horizontal cells.



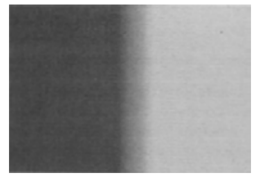
Center-Surround Organization

Lateral inhibition provides our visual system with a mean to emphasize areas of difference (*contrast*). In fact, our visual system detects local differences in light intensity rather than the absolute magnitude of light falling on our retina.

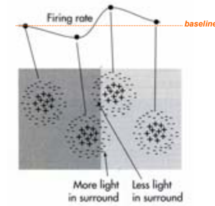
Center-Surround Organization

Lateral inhibition provides our visual system with a mean to emphasize areas of difference (*contrast*), i.e., it sharpens the boundary between objects of different luminance.

Mach bands



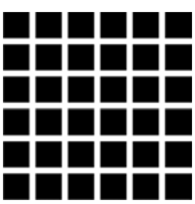
ON-center ganglion cells

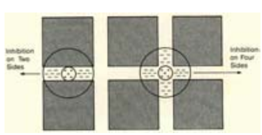


Center-Surround Organization

The phenomenon of *contrast* enhancement is the underlying mechanism of several striking effects.

Hering grid





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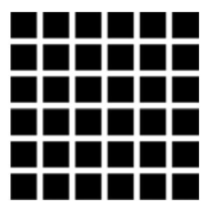
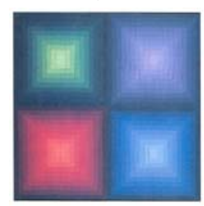
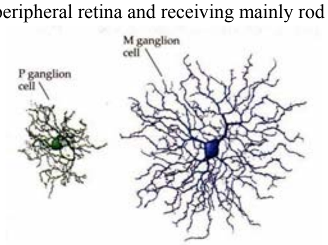


Vasarely Acturus



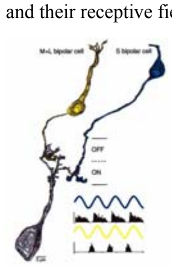
Output of the Retina

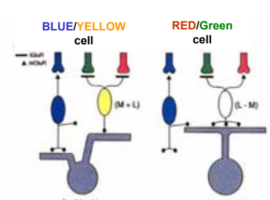
Ganglion cells form two main retinal output channels : 1) the *Parvo* (or midget) cells, mostly in the fovea and receiving mainly cones inputs; 2) the *Magno* (or parasol) cells, mostly in the peripheral retina and receiving mainly rod inputs.



Output of the Retina

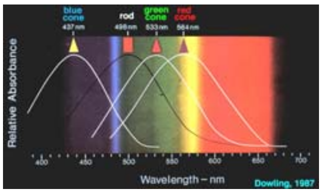
While the *parasol* ganglion cells participate very little in color perception, the *midget* ganglion cells are color sensitive and their receptive fields have a *color-opponent organization*.





Output of the Retina

Color-opponent cells provides our visual system with a mean to emphasize the relatively small differences in spectral absorption of the three types of cones.



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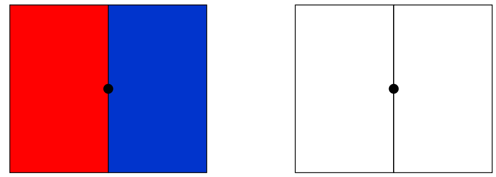

Visual System: Retinal Anatomy & Physiology

Reference for this Lecture:

- Neuroscience, 2nd edition (2001) by Purves et al., Chapter 11.

Reference for next Lecture:

- Neuroscience, 2nd edition (2001) by Purves et al., Chapter 12.

Lectures are posted:

- http://brain.phgy.queensu.ca/pare

Office Time:

- Tuesday & Thursday (15:00-17:00)
  Botterell Hall, Room 438