9.35 Sensation And Perception

Spring 2009

9.35 – The Retina

Last time

- Optics – How images are formed in cameras.
- The eye as a pinhole camera
- How to use lenses to correct focusing problems.

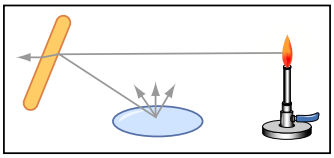

Figure by MIT OpenCourseWare.

This time…

- The Retina – the "recording surface" of the eye.
- Retinal anatomy – What kinds of cells do you have?
- Retinal topography – What is the organization of the retina?
- Retinal pathology – What can go wrong with your retina?

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Poke yourself in the eye

(wait for instructions, please…)

- Observe the flickering light
- Why does it look like light?
- Mueller's law of specific nerve energies
- Where is the light in visual space?

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The retina

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The retina and the eye

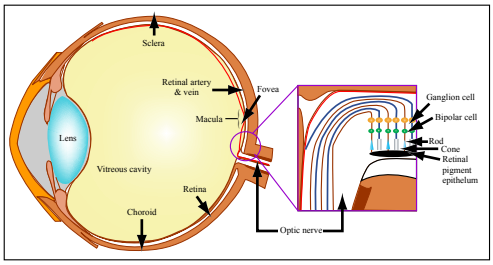

Figure by MIT OpenCourseWare.

Red-eye and reflection from the retina

When pupil is large, and flash is next to lens, light is focused and bounces back along same line. Human retina has dark backing (pigment epithelium), but blood vessels give red cast.

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Note: Cats are nocturnal, rod dominated, with "reflective tapetum" to give photons a second chance to be absorbed.

Why don't you see all the junk in the way?

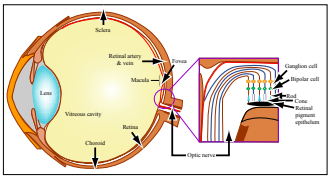


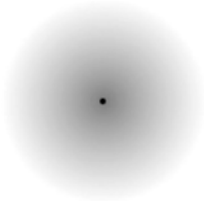
Figure by MIT OpenCourseWare.

Because all that stuff is *stabilized* With respect to the retina.

It turns out that our visual system is Insensitive to things that are Perfectly still relative to the retinal Surface.

When you go to the optometrist (or Stick your own bright light at the side Of your eye) you can get a transient View of the blood vessels because You've interrupted the stable image.

Stabilization demo



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Beyond the receptors

5 primary cell types:

- Rods and Cones
- Horizontal Cells
- Bipolar Cells
- Amacrine Cells
- Ganglion Cells

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Rods and Cones

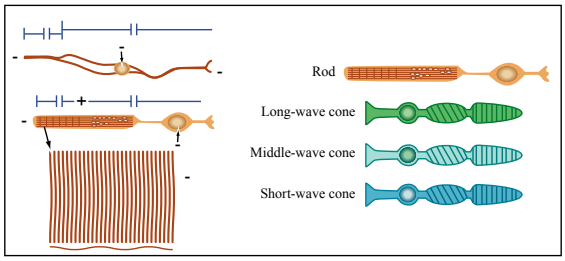

Figure by MIT OpenCourseWare.

The outer segment of a rod or a cone is filled with photo-sensitive chemicals. In rods, we call this **rhodopsin** and in cones we usually just call it **color pigment**.

Visual purple and rhodopsin

1876: Franz Boll saw a reddish pigment in frog retina, which bleached to yellow when exposed to light.

Kuhne called the pigment visual purple (now called rhodopsin). He had a rabbit stare at a window, killed the rabbit, and found the inverted image where the rhodopsin was bleached away.

Figure removed due to copyright restriction.

Mythology: "Thus it was alleged that if the last object seen by a murdered person was his murderer, the portrait drawn upon the eye would remain a fearful witness in death to detect the guilty, and lead to his conviction. " (New York Observer).

The rhodopsin cascade

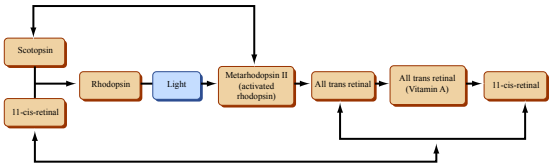

Figure by MIT OpenCourseWare.

Rhodopsin is a mixture of a protein called **scotopsin** and **11-cis-retinal.** This stuff is Made from Vitamin A, which is why you should eat your carrots to avoid vision problems!

All trans Retinal is "straightened" II-cis-Retinal.

Note: This pathway is rod-specific, but the pathway for cones looks pretty much just the same.

Hyperpolarization

You're probably used to thinking about neurons doing something like this:

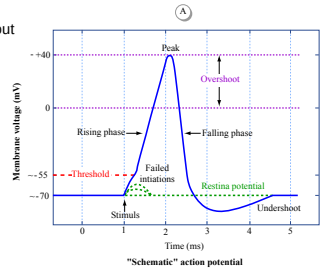

Figure by MIT OpenCourseWare.

The rods and cones actually work differently.

1. They **hyperpolarize** when stimulated with light. This means they actually are producing *less* neurotransmitter when they're stimulated (glutamate).
2. The produce **graded potentials** rather than "all-or-none" potentials.

Why hyperpolarize?

Might reduce noise – depolarization all the time means lots of Na+ ions around all the time. Random ion channel closing/opening won't make much of a dent against the background of lots of ions, so harder to get spurious activity without a photon.

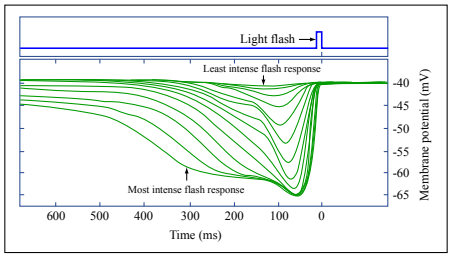

Figure by MIT OpenCourseWare.

Rods and Cones

Question: How do you design a visual system that can respond to the high illumination levels that occur during daytime, and to the low light levels that occur at night?

Answer: The "*duplicity theory*" of vision (J. von Kries, 1896): *Use two different classes of photosensitive receptors that operate in different luminance regimes*

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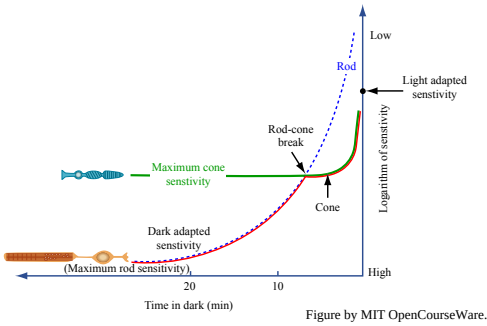
- *Scotopic* vision: Low light levels, rod dominated
- *Photopic* vision: High light levels, cone dominated
- *Mesopic* vision: Medium light levels, mixed rod and cone response.

Dark adaptation experiments



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Scotopic vs. Photopic sensitivity

Photopic vision has peak sensitivity at ~550nm.

Thus 5mw green laser pointers (532nm) look much brighter than 5mw red ones (~635-670nm), although equal in power.

Scotopic vision has peak sensitivity at ~505nm (Purkinje shift), and are effectively "blind" to red light.

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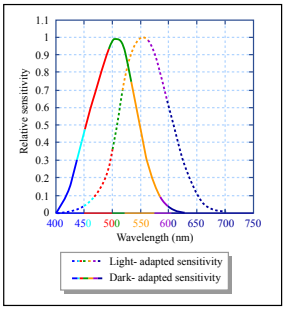

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Rod Vision vs. Cone Vision

- Rod vision is more sensitive than cone vision
  - individual rods are more sensitive to light cones.
  - higher convergence from rods to ganglion cells (120 to 1) than from cones to ganglion cells (6 to 1; in the fovea it's very often 1 to 1).
- Rod vision has lower acuity than cone vision
  - higher convergence from rods, i.e., larger integration area.
  - rods also are slower, i.e., have longer integration time.

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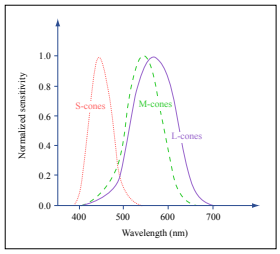
- Rods offer no color vision, since only one type. Cones provide color vision, with three cone types.
- Rods are absent from the fovea; scotopic sensitivity is highest slightly in the periphery (Arago's phenomenon).

Cone sensitivities



"red" cones = "long wavelength" cones = L cones
"green" cones = "middle wavelength" cones = M cones
"blue" cones = "short wavelength" cones = S cones

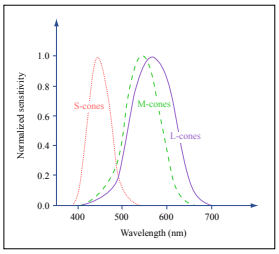
Figure by MIT OpenCourseWare.

Principle of *univariance*: A receptor responds only to how much light is absorbed, not to its wavelength. It delivers a single scalar.
(The wavelength has to be "inferred" by the responses of the three cone types.)

Coarse coding and color vision

Let's say you want to locate something along a continuum. How do you do it?

1. Build lots of finely-tuned sensors that can cover or "tile" the whole continuum.
2. Build a few broadly-tuned sensors to do the same, and let 'em overlap.



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Beyond the receptors

5 primary cell types:

- Rods and Cones
- Horizontal Cells
- Bipolar Cells
- Amacrine Cells
- Ganglion Cells

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Bipolar cells

Remember our photoreceptors who are hyperpolarizing away in response to Light and releasing *less* glutamate? An OFF bipolar cell will hyperpolarize when this Happens, an ON bipolar cell will depolarize.

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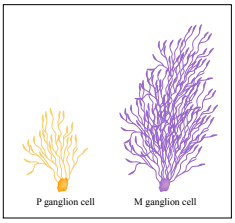
We actually learned about the Ganglion Cells first for technical reasons…

Ganglion cells

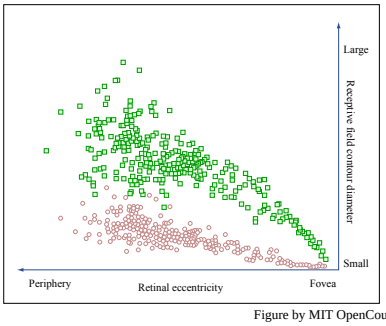
- Two main kinds of ganglion cells defined anatomically:
- *midget* and *parasol.*
- Two main kinds of ganglion cells defined functionally (recordings):
- *parvocellular* and *magnocellular*.
- Don't get confused about M and P: parasol -> magno, and midget -> parvo.
- M = Magno cells are larger, achromatic (no color), and prefer transient/ moving stimuli.
- P = Parvo cells are smaller, care about luminance and color, and prefer steady stimuli.



For both cell types, the size of the dendritic field (and the receptive field) increases with eccentricity (distance from fovea)

Figure by MIT OpenCourseWare.

RF size and eccentricity



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Center-surround cells

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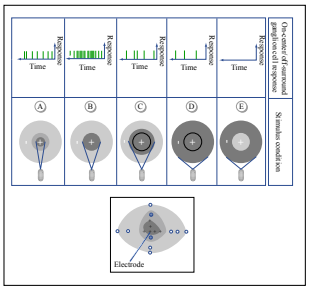

First center-surround RF discovered by Kuffler (1953) This is an example of a "circularly symmetric" center-surround organization

Figure by MIT OpenCourseWare.

What do these cells respond to?

• Luminance of a homogeneous region?

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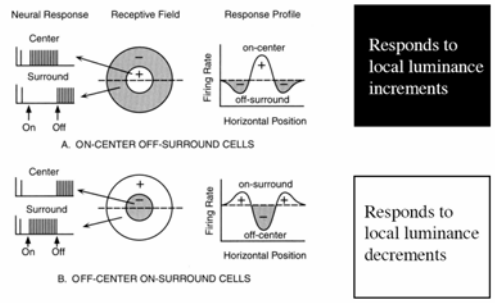
• Difference between center luminance and average surrounding luminance

On-center and Off-center cells



Responds to local luminance increments

Responds to local luminance decrements

Courtesy of Palmer, Stephen E. 1999. Vision Science: Photons to Phenomenology. The MIT Press. Used with permission.

Breaking down center-surround

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The Hermann Grid

What do you see at the Intersections?

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Bergen grid

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Count the black dots!

You see the black holes in the periphery, not where you are fixating. Need the right RF size.

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One of the most important things to note about the retina is that it is remarkably non-uniform.

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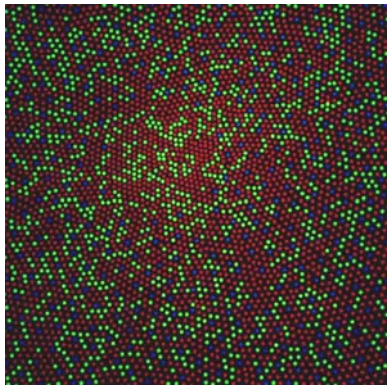
- Draw this on a piece of paper.
- Close one eye
- Fixate the 'X' and move the paper back and forth until the 'O' vanishes
- Discovered in 1688 by l'Abbe Edme Marriote
- Louis XIV supposedly enjoyed "beheading" courtiers this way.



Courtesy of Helga Kolb. Used with permission.

The retina is inhomogeneous

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Distribution of receptors in the eye

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Cones in fovea…NO rods. Periphery…mix of both.

Anstis eye chart

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Resolution falls in proportion to distance from fovea

A Natural Scene version of the same thing

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What about color sensitivity?

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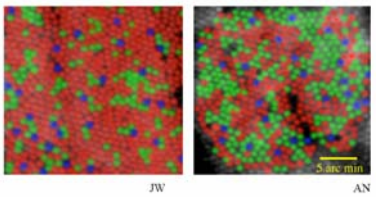
Cones get sparser and sparser as we move out to the periphery.

Individual variation



First Images of the Human Trichromatic Cone Mosaic
(Roorda, A. and Williams, D.R. *Nature,* Feb.,1999)

Courtesy of David Williams' Lab @ the Center for Visual Science. Used with permission.

David Williams

Problems you might have with your retina

- Spots and Floaters
- Retinal Detachment
- Macular Degeneration
- Retinitis Pigmentosa
- Color-Blindness

Spots and Floaters

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Retinal Detachment

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Macular Degeneration

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The **macula** is the central part of your retina.

Retinitis pigmentosa

Hereditary disease in which rods slowly deteriorate and die. The fovea is spared Leaving patients with “tunnel vision.”

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Color-blindness

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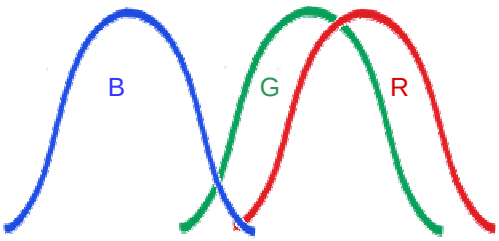
- Protoanomaly (~1% of men) – “Red Weak”
- Deuteranomaly (~5% of men) – “Green Weak”

•Dichromacy (Protanope & Deuterope) ~1% of men each

How does it play out?



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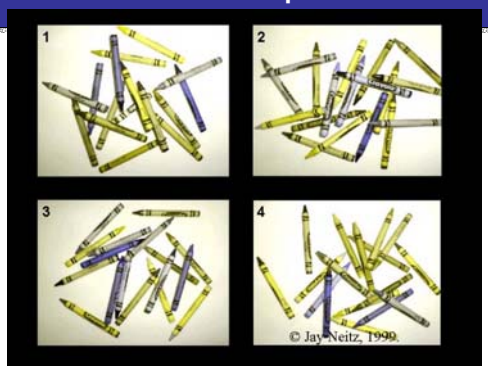
Deuteranopia



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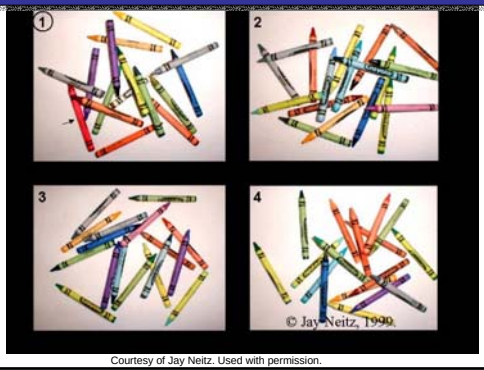
Color-blindness



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