Psychology 1XX3 Notes – Vision I – Mar 1, 2010

- Nearly 1/3 of the brain is devoted to processing visual information.
- If our visual sense is giving us information that is in conflict with information from another sense, we tend to bias our trust towards our sense of vision.

Our Visual Sense

- The eye is primarily an instrument to collect, focus, and sense the light. Although there is some initial processing done on the information collected, the heavy duty processing occurs in the brain.

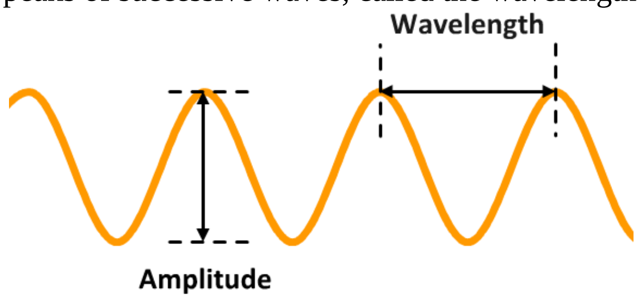
The Stimulus: Light

Intro to Light

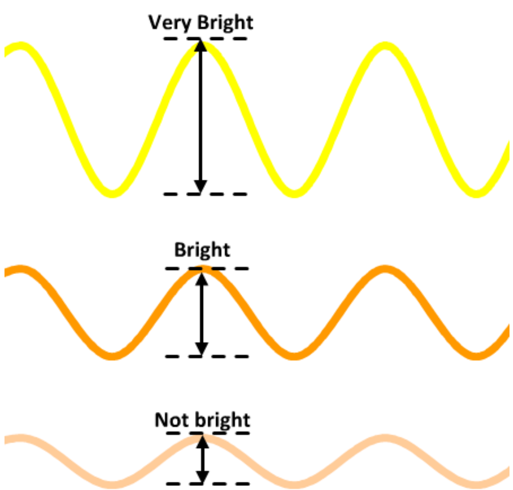
- Properties of light: There are three **physical characteristics of light** that translate into the three **psychological perceptions** of our visual world.

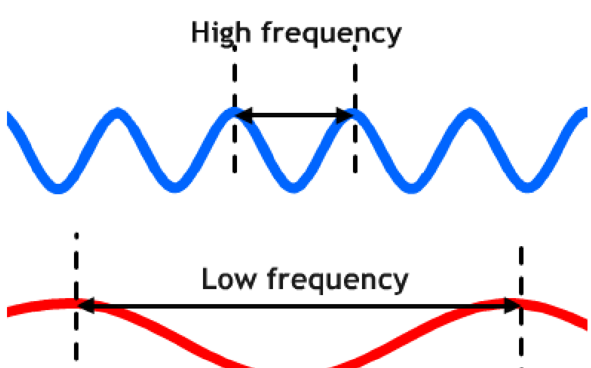
Amplitude:

- Light travels as a wave that moves at about 300 000 km/sec. Light waves can vary in two respects: the height of each wave, called the amplitude, and the distance between the peaks of successive waves, called the wavelength.(See image below).



- Variations in **amplitude** affect the perception of brightness. Generally, the greater the amplitude of the light wave, the more light is being reflected or emitted by that object, and so that object appears brighter or more intense to us. (See image below, left.)





Wavelength:

- Variations in **wavelength** affect the perception of colour. Wavelength is measured in nanometers. Smaller wavelengths refer to light waves with a higher frequency, because there is less distance between successive peaks. Larger wavelengths refer to light waves with a lower frequency. (See image above, right.)

- Humans are only sensitive to a tiny portion of the total range of wavelengths of electromagnetic radiation, and this tiny portion that we're sensitive to is called the **visible spectrum**. The shortest wavelength that we can see is around 360 nanometers, which looks violet to us, and the longest wavelength that we can see is around 750 nanometers, which is red.
- However, other species can see light outside our visible spectrum. For example, insects like bees can see wavelengths shorter than 360 nm in the ultraviolet spectrum, and may perceive differences in the colours of flowers that all look the same colour to us.
- Other species like snakes can see light made up of wavelengths longer than 750 nm in the infrared spectrum, which allows them to find prey in the dark by being able to see the body heat that is emitted by the prey.

Purity:

- The final physical characteristic of light is **purity**, which affects the perception of the saturation, or richness, of colours.

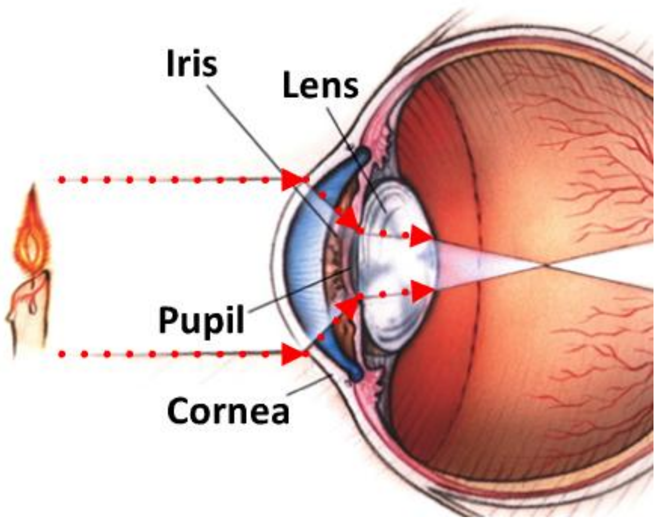
Physical Light Property	Our Psychological Perception
Amplitude	Brightness
Wavelength	Colour
Purity	Saturation

- A light that is made up of a single wavelength is said to be a pure light and the perceived colour would be described as completely saturated.
- At the other extreme we could have a light that is a combination of all wavelengths this light would be perceived as white and would be described as completely desaturated.
- Most of the colours we see in everyday life are not pure but a mixture of wavelengths and are less intense than pure colours.

The Eye:

- Light first passes through the curved **cornea**, which begins the focusing process.
- The **cornea** is a transparent window at the front of the eye. The rest of the eye is covered by the white part of the eye called **sclera**, a tougher membrane.
- After the cornea, light passes through the **pupil** of the eye, which is the round window that you see as a black dot in the middle of your eye.
- The **iris**, or the coloured part of your eye, controls the size of the pupil. The iris is basically a band of muscles that is controlled by the brain, so that if not enough light is reaching the retina, these muscles cause the pupil to constrict into a tiny opening.
- After going through the pupil, light passes through the **lens**, a transparent structure that does the final focusing of light on the retina.
- See image on next page.

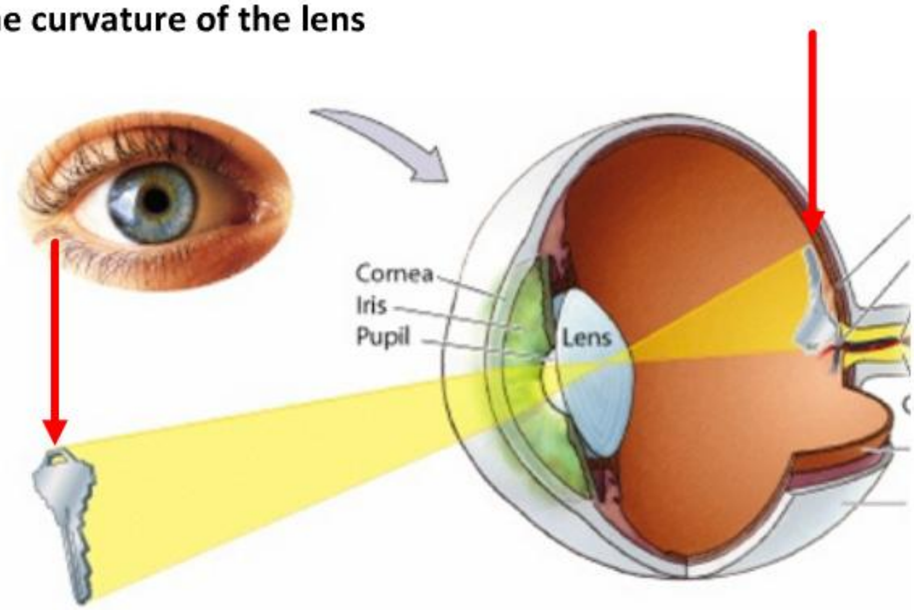
Light passing through the eye



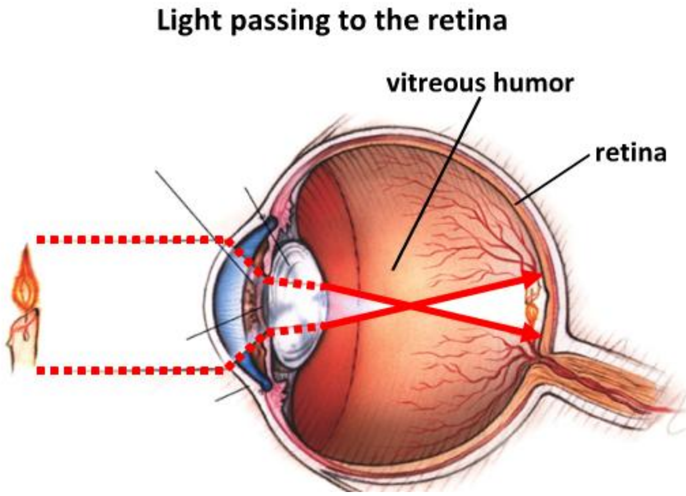
The Lens:

- The curvature of the lens causes images to land on the retina upside-down and reversed from left to right. However, the final perceived image is a product of brain activity.
- Thus, rather than seeing everything upside-down and reversed, there is a correction that allows us to see a properly oriented image.

The curvature of the lens



- The lens is a flexible piece of tissue, the shape of which can be altered by surrounding muscles, allowing it to focus on objects that are close or far away.
- If the object is close, the lens of your eye gets fatter or rounder to produce a clear image, but if the object is far away, the lens of your eye gets elongated to focus the image on the back of your eye.
- This change in the shape of the lens to focus on objects that vary in distance is called **accommodation**.
- After travelling through the lens, light passes through the vitreous humor, which is the clear, jelly-like substance that comprises the main chamber inside the eyeball, until it finally lands on the retina, which is the neural tissue that lines the back of the eye. (See image on next page.)

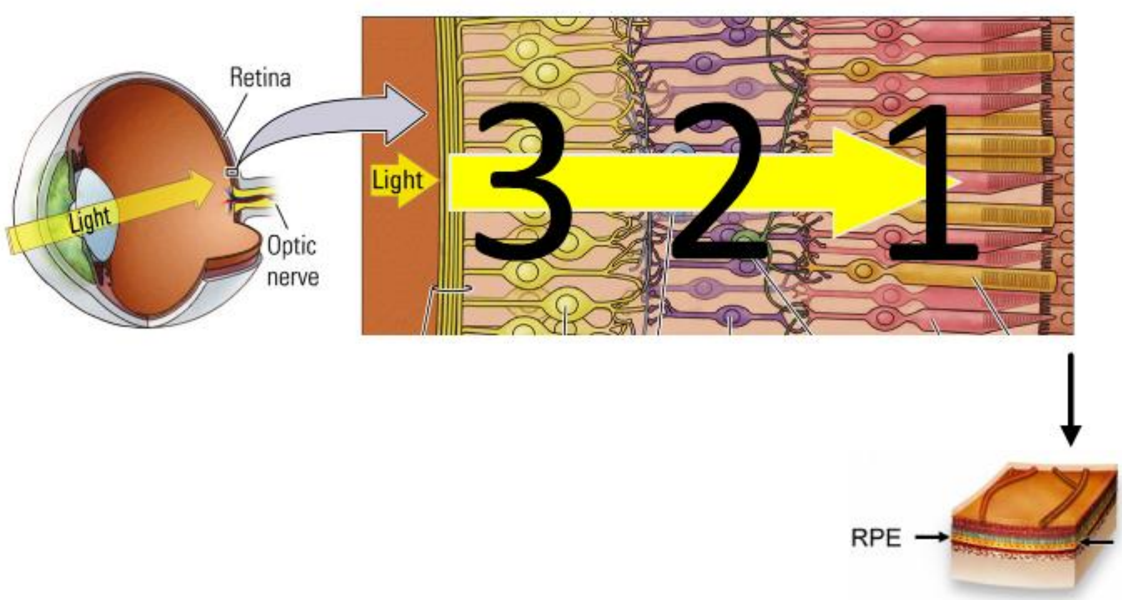


The Retina:

- Neural processing of visual information: the retina, because this is where the physical stimulus of light is first translated into neural impulses.

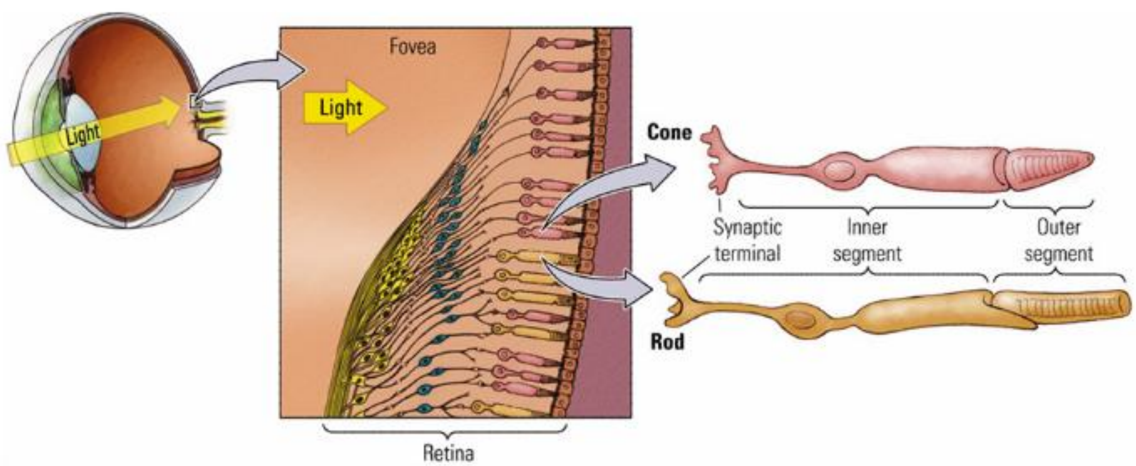
The Retinal Layer 1: Photoreceptors

- The retina is a paper-thin sheet that covers that back of the eye, and is made up of a complex network of neural cells arranged in three different layers.
- The organization of these layers may seem counter-intuitive; the layer at the very back of the eye, farthest away from the light, is where the photoreceptors are located.
- Photoreceptors are cells in the retina that are responsible for translating the physical stimulus of light into a neural signal that the brain can understand.
- To reach the photoreceptors, light must pass through the other 2 layers of retinal tissue which are transparent.
- The reason for this inside-out arrangement in the retina has to do with where the photoreceptors get their nutrients from, which is a layer of cells at the very back of the eye called the **retinal pigment epithelium, or RPE**.
- The photoreceptors would die without access to the RPE cells, and if the photoreceptors were located at the front of the retina, facing the light, then they would not have access to the RPE that they need to live. (See image below.)



Photoreceptors: Rods and Cones

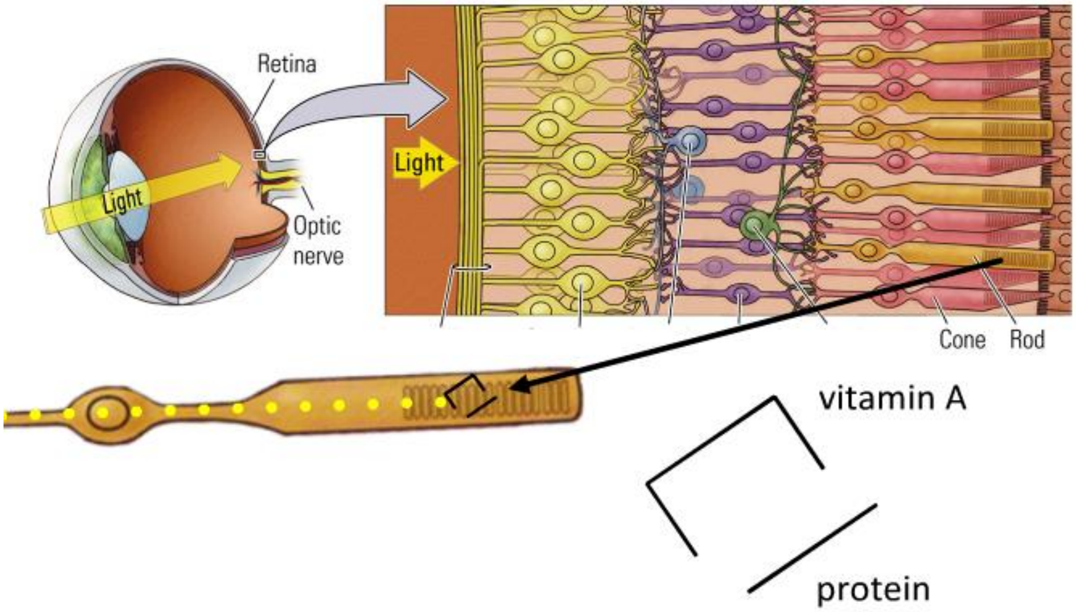
- There are two different kinds of photoreceptors, called rods and cones, each named for their respective shapes. (See image below)
- Humans have about 125 million rods but only 6 million cones.
- Cones are designed to operate at high light intensities and are used for day vision. The cones provide us with the sensation of colour and provide good visual acuity, or sharpness of detail. Cones become more concentrated towards the **fovea**, a tiny spot in the middle of the retina that contains exclusively cones. When you want to see something in detail, we move our eyes so that the image falls directly onto the fovea.
- Rods are designed to operate at low light intensities, and so are used for night vision. They provide no information from which colour can be determined, and offer poor visual acuity. There are no rods in the fovea itself, with increasing concentration in the region just surrounding the fovea. This arrangement make rods very useful for peripheral vision.



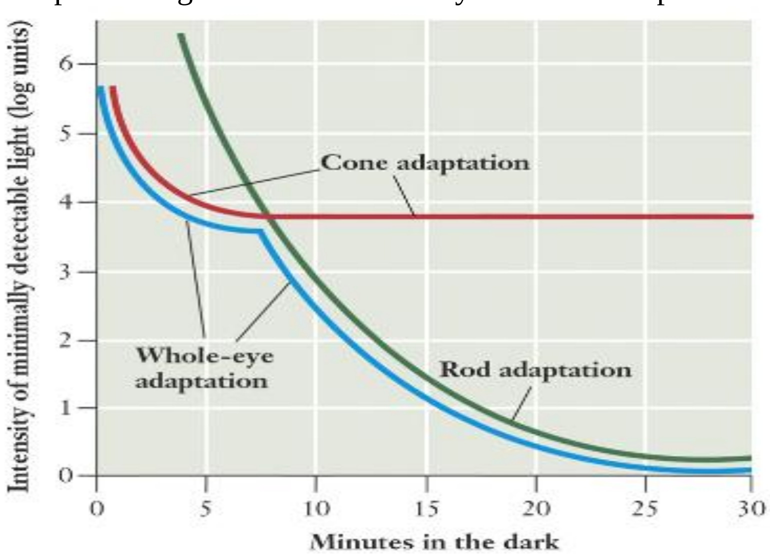
- This explains why, when you're trying to see an object in an environment that is dimly lit, you're better off looking slightly to one side of the object as opposed to trying to stare right at it.
- When you stare right at it you are using your cones, which do not work in a dimly lit environment. But if you stare to one side of the object, you'll be using your rods and increasing the chance that you will see it.

Photoreceptors: Response to Light

- How do photoreceptors actually translate the physical stimulus of light into a neural signal that the brain can read? → Photoreceptors contain a photo pigment, which is a complex molecule that is sensitive to light.
- The human eye has 4 different kinds of photo pigments, one for rods and three for cones, but they all basically work the same.
- When a photon of light is absorbed, it changes the chemical state of the photo pigment and splits into its two component molecules which sets off a biochemical chain reaction leading to an electrical current flowing across the membrane.
- The original light stimulus is now in a currency that can be understood and processed by the brain.



- Once light has caused a photopigment to split, high energy molecules within the photoreceptor cause the two molecules to recombine, so that the photopigment is ready to react to light again. However, there is a brief period of time during which the photopigment will not be able to react to light.
- Each photoreceptor has thousands of photopigments, and the number that are ready to react to light depend on the relative rate at which they are being split and recombined.
- When exposed to very bright light, the rate of splitting of photopigments is exceeds the rate at which they are being recombined.
- This can explain why it takes a few minutes for your eyes to get used to the dark, a phenomenon called dark adaptation.
- We have probably all experienced the situation where you enter a dark movie theatre on a bright day and for the first few minutes, you cannot see much, but gradually, you are able to see things more clearly.
- This is because at the time you enter the theatre, most of your photopigments, particularly those in the rods, haven't had time to recombine yet, leaving few that are ready to react to light, causing you to see very little.
- But after a few minutes, most of your photopigments will have recombined and be ready to respond to light. That is how the eye becomes adapted to the dark.



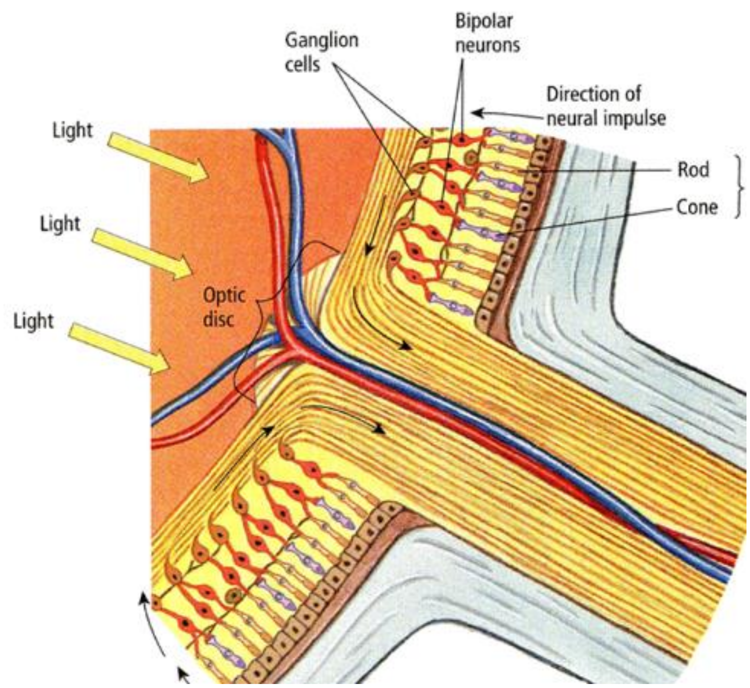
Bipolar and Ganglion Cells:

- This is how the first layer in the retina translates the physical stimulus of light into an electrochemical signal in the photoreceptors.
- The photoreceptors then send their information to the next layer of cells in the retina, called the **bipolar cells**, by means of a transmitter substance.
- In turn, the bipolar cells send their information on to the next layer of cells in the retina, called the **ganglion cells**.

Retinal Layer 2 and 3:

- The ganglion cells collect information from a larger segment of the retina, and the axons of these cells all converge on one point in the eye, called the **optic disc**, and then leave the eye to join the optic nerve, which travels all the way to the brain.
- Because the optic disc is basically like an exit hole in the eye for ganglion axons, this small area contains no photoreceptors at all, and so it constitutes our blind spot.

The Optic Disc



The Blind pot:

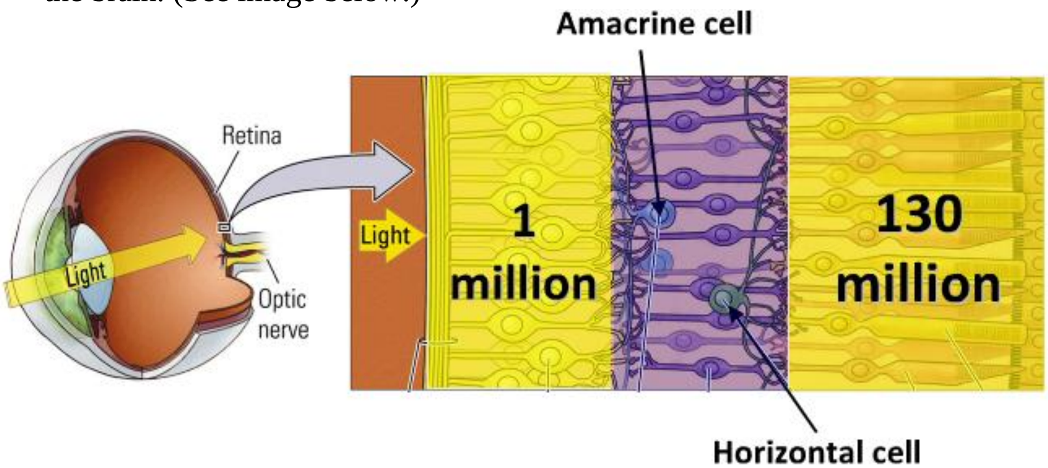
- We are not normally aware of our blind spot because our brains fill in gap by blending the surrounding image most of the time.

To recap, light enters the eye and must pass through the ganglion cells, bipolar cells, and strike the photoreceptors on the retina at the very back of the eye. At that point the light is converted into a neural signal that is sent from the photoreceptors to the bipolar cells, and then on to the ganglion cells, whose axons make up the optic nerve.

Processing in the Retina:

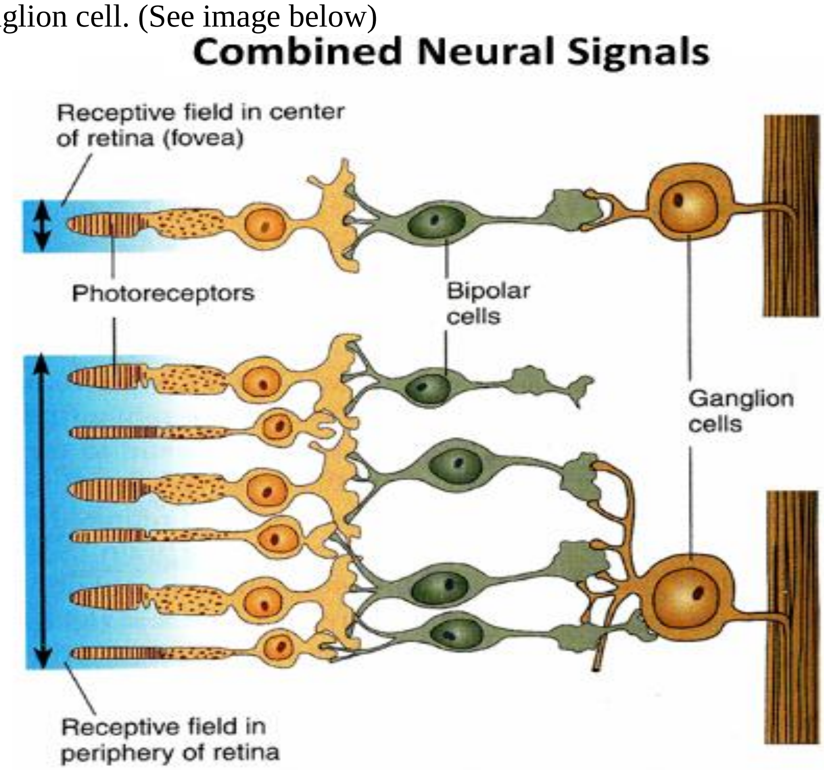
- There are also cells in the retina that allow areas within a retinal layer to communicate with each other, called **horizontal cells** and **amacrine cells**.
- These cells allow information from adjacent photoreceptors to combine. Information from over 130 million rods and cones in the retina converge to travel along only 1 million axons in the optic nerve. What this means is that some

amount of visual processing is done in the retina, before the signal is sent on to the brain. (See image below.)

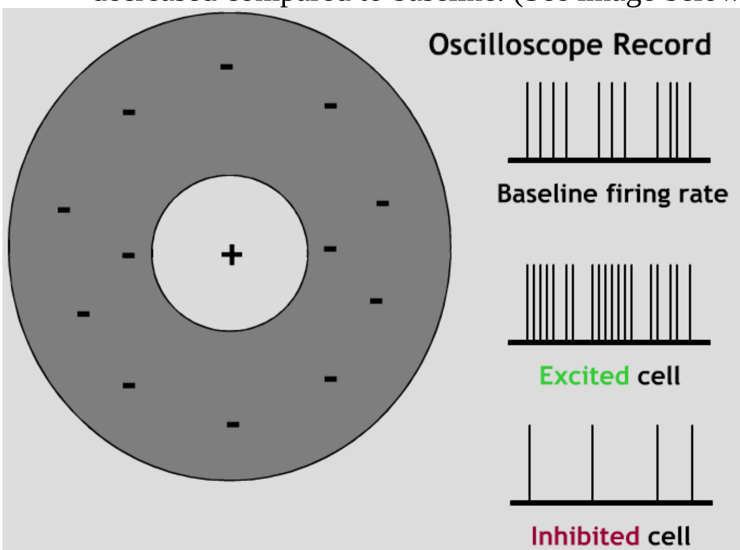


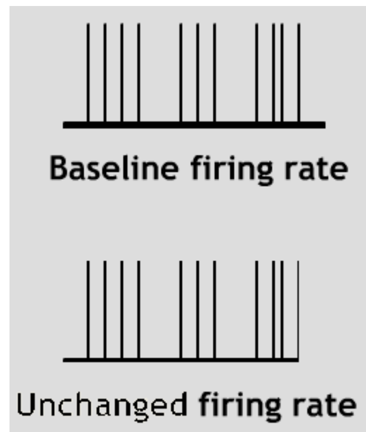
Receptive Field in the Retina:

- Think of the photoreceptors in the retina as being divided up into specific groups, and the information from each group getting assimilated into one signal that affects the ganglion cell down the line.
- In the fovea, the photoreceptor "group" for a particular ganglion cell may only contain one cone, which means the ganglion cell is representing a very small area of the image.
- Since each cone in the fovea has a direct link with the brain, a lot of the detail is preserved and more visual acuity occurs in the fovea.
- But more often, the input from many rods and cones is combined into one neural signal for one retinal ganglion cell.
- These groups get larger as we move toward the periphery of the eye, which is one reason why our visual acuity is so low for peripheral vision.
- The collection of rods and cones in the retina that, when stimulated, affects the firing of a particular ganglion cell is called the **receptive field** of that retinal ganglion cell. (See image below)



- These receptive fields in the retina come in a variety of shapes and sizes, but most of them are basically donut shaped, such that light falling in the center of the donut will either excite or inhibit the cell, and light falling in the surround part of the donut will have the opposite effect on the cell.
- Excitation and inhibition of the cell is determined by the rate at which that cell fires compared to baseline, or the rate at which the cell would fire normally, without any light signals.
- As you probably remember from our discussion of the brain, all cells have some baseline rate of firing. So a cell would be excited if the rate of firing of that cell increased compared to baseline, and it would be inhibited if the rate of firing decreased compared to baseline. (See image below, left.)

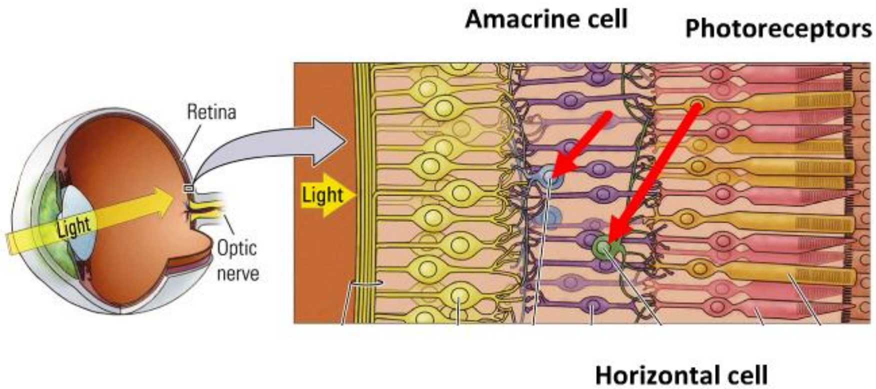




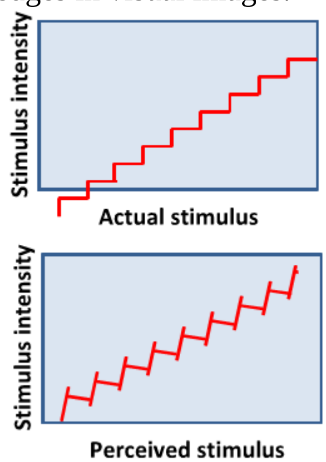
- Suppose we're looking at a receptive field on the retinal surface that has this donut shape, with the center being excitatory and the surround being inhibitory.
- This means that if light struck the center of the receptive field, this would cause an increase in the firing rate of the ganglion cell, but if light struck the surrounding of the receptive field, this would cause a decrease in the firing rate of the ganglion cell.
- If light covered both the center and surround of the receptive field, these two effects would basically cancel each other out, and the cell would fire at the same rate that it does at baseline, when no light is available.
- Either way, when a receptive field of a ganglion cell is stimulated, that ganglion cell sends signals towards the brain. (See image above, right.)

Lateral Inhibition

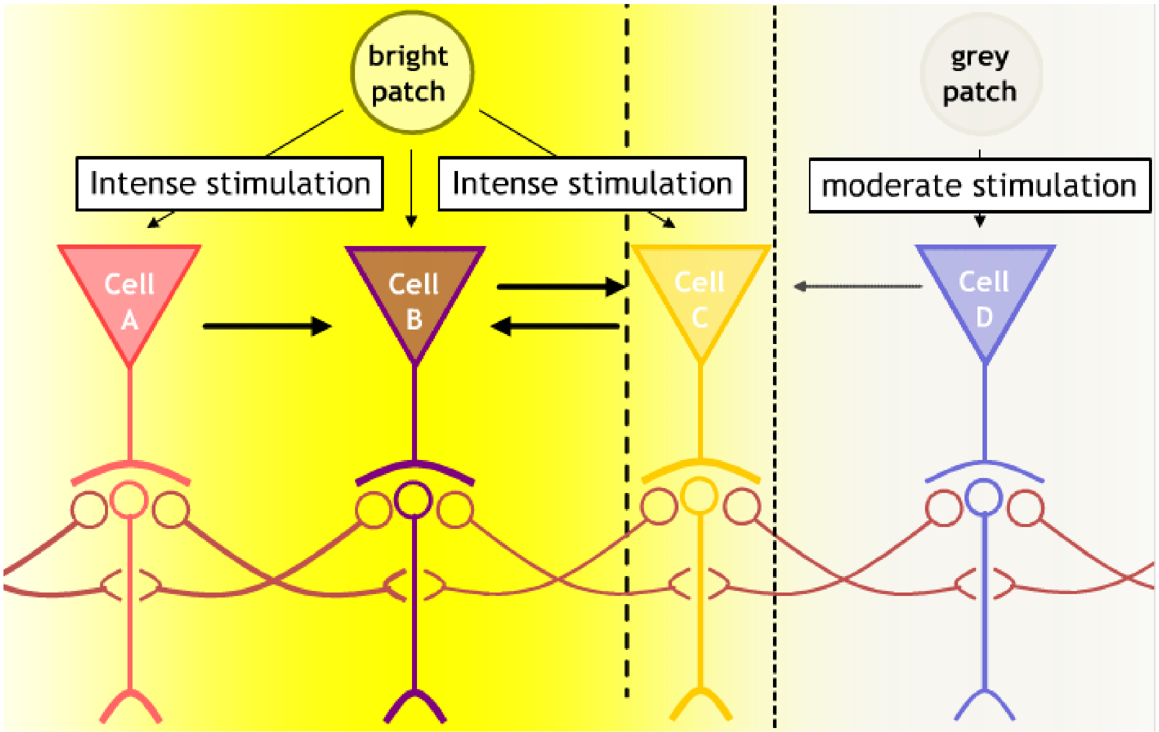
- Retinal cells can also affect signalling of adjacent retinal cells **through lateral antagonism or lateral inhibition**.
- This is done through the horizontal cells, which are activated by the photoreceptors, and also through the amacrine cells which are activated by the bipolar cells.
- Whenever a retinal cell is stimulated by light falling on its receptive field, that cell sends signals onto the brain, but it also sends messages sideways to neighbouring cells that inhibit their activation.
- The perceptual result of this kind of a physiological mechanism is that the edges of objects are easier to detect.



- This becomes obvious when we look at the illusory Mach bands, strips of greys that range from dark grey to light. Within each strip, the colour is constant. Yet it appears as though a darker band exists right at the border of each strip. This illusion can be explained by lateral inhibition, and this is one way in which the retina enhances our ability to detect edges in visual images.



- To illustrate the point, imagine we have 4 cells A, B, C, and D. Cell A, B and C are receiving intense stimulation from the same patch of bright light, whereas Cell D is receiving moderate stimulation from a dark grey patch of light.
- Thus, Cell C is on the edge of the bright and grey light, and you'll see that with lateral inhibition, this cell ends up sending more stimulation to the brain than Cell B, even though both cells receive the exact same input.
- So cells A, B and C are strongly stimulated, and since they are also neighbours, they are inhibiting each other as well. Since Cell D is only moderately stimulated by the dark grey patch, and it sends less inhibition to its neighbour Cell C than Cells A, B and C do to each other.
- As a result, Cell B receives a lot of inhibition from the intense stimulation of both of its neighbours, whereas Cell C only receives strong inhibition from one of its neighbours.
- Because of this, Cell C sends out a stronger signal to the brain than Cell B does, even though Cell C and B are receiving the same input from the world. The perceptual result for us is that edges look more distinct.
- See image on next page.



- The point here is that our retina is not just taking information in and passing it on to other areas for processing. Instead, cells just a few synapses away from our visual receptors are already beginning to process the incoming information by accentuating certain features of a stimulus, like its edges, while placing less importance on other features of the stimulus, like areas that are uniformly stimulated.