63: THE EYE (physiology)

The eye must constantly adjust its focus from near to far, far to near. All day long we are looking back and forth from distant objects to things that are very close. The light from these objects must be focused onto the **macula** of the retina, and onto the **fovea**, in particular. The fovea is the "sweet spot" of the retina because it contains millions more cones than any other place on the retina. In order to make sure that the light entering the eye hits the fovea, the lens can change shape. When an object is far away, the lens must be more flat. When an object is very close, the lens must become more round. The physics of lenses is the same, whether the lens is made of glass, plastic, or living tissue. Flatter lenses focus on distant object and rounder ones focus on closer objects. However, with glass and plastic the shape of the lens cannot change, of course.. Only living lenses can change their shape to adjust for all circumstances. The process of adjusting is called **accommodation**.

We learned that the ciliary body is in charge of changing the shape of the lens. Inside the ciliary body is a ring of muscle. When this muscle relaxes, it gets larger. This stretches the zonules (those "zonules of Zinn"), pulling the lens into a flatter shape. When the muscles contract, the lens appears to get pushed into a more round shape. Exactly how this happens is still being debated. There are two leading theories. One theory says that the zonules all relax, and the other theory is that only some of them relax. It's important to remember that scientists don't have everything figured out. There is still a lot we don't know.

The ring of muscles in the iris is also contracting and relaxing all the time. There is a feedback mechanism in the eye that automatically controls the size of the iris. If there is too much light, the muscles contract and shrink the pupil. If there is not enough light, the iris will open wider.

The image that hits the macula is upside down. That's just the way light works. The optic nerve will take this information to the brain, and the brain will flip the image and make us think we are seeing it right side up. The vision center in the brain is not right behind the eyes as you might expect, but at the very back. Also, the sides are reversed with the right side of the brain controlling the left eye and the left side of the brain controlling the right eye.

If you look into an eyeball with an ophthalmoscope, you will see two distinct spots. One will be the macula. The other is the **optic disc**, the place where the optic nerve leaves the eye. The optic nerve also contains many blood vessels, so you will see vessels coming out of the optic nerve area. The nerve is to the outside of the eye from this viewpoint.

The receptor cells in the retina are of basically two kinds: **rods** and **cones**. (We must say "basically" because a third kind was discovered in the 1990s and is believed to be the cell that controls the pupillary reflex. However, almost every source you will read in a book or on the web will say there are two kinds.) The rods are very long and thin, and the cones have a cone shape on their ends. They have a similar structure, with a nucleus located in a central area, and the skinny rod or cone shape on one end and a "synaptic" ending on the other. The synaptic endings look a bit like an axon terminal and they do a similar job, but technically these are not nerve cells in the same way that neurons are.

The rod or cone shaped ends of these cells contain about a thousand discs made of phospholipid membrane. The membrane is there to hold a very important molecule in place: **rhodopsin**. ("Rhodopsin" comes from the Greek word "rhodon" meaning "pink," and the Greek word "opsis" meaning "sight.") This is the molecule that responds to light. The rhodopsin molecule contains a smaller molecule called **retinal**, which the cells make from vitamin A. The retinal molecule changes shape when light hits it. This change of shape starts a short cascade of events that leads to the cell's sodium gates being opened up. Strangely enough, the cell is already full of sodium ions (Na^+). The addition of even more sodium ions causes it to become **hyperpolarized**. As we learned in lesson 52, **polarized** means more negative on one side and more positive on the other. This makes a cell ready for an action potential. The action potential happens when the ions rush back to the other side, **depolarizing** the cell. Then the cell has to reset again. In this case, light causes even more polarization. This STOPS the cell from sending a signal. So light stops these cells from sending signals! This seems backwards and certainly must have surprised the scientists who discovered it.

We have a strange system here. When they are NOT being stimulated by light, rod and cone cells are constantly releasing neurotransmitters (**glutamate**, from lesson 9) at their synaptic end. These transmitters, however, are **inhibitory.** (Excitatory transmitters cause (excite) cells to start action potentials, and inhibitory transmitters prevent (inhibit) them from doing so.) When light hits rod and cone cells, they stop releasing their inhibitory transmitters. The cells that they are connected to, the **bipolar neurons**, are then released from inhibition and can send a signal to the next cells in the line, the **ganglion cells**. The ganglion cells are the ones that have axons extending into the surface layer of the retina and then on into the optic nerve. Ganglion cells are the only ones that start a true action potential. The rods, cones, and bipolar cells use what is called a **gradient potential**, more like a dimmer switch than an off/on switch.

There are other nerve cells in and around the bipolar and ganglion cells. **Amacrine** and **horizontal** cells form horizontal connections between cells. (Amacrine comes from "a-" meaning "not," and "macro"meaning "big.") Amacrine cells connect rods and cones in such a way that they can function cooperatively. Horizontal cells connect ganglion cells.

Rods are very sensitive to light and a single rod can detect a single photon of light. Because of their sensitivity, rods can function when there is very little light. They give us our night vision. Rods are found all over the retina, but mainly outside of the macula. Because rods are found very far from the central focal point, they also give us our **peripheral vision**, at the edges of our field of sight. Cones are found primarily inside the macula and need a lot of light in order to function. As you go away from the fovea, the number of cones decreases and the number of rods increases. The total number of rods in the entire retina is about 100 million, and the number of cones is about 6 million. Cones are of three types and can detect one color of light: red, green or blue.

Notice that the rods and cones are in the back layer of the retina. Light must pass through all the nerve cells to reach them. Good thing the nerve cells are transparent! The cells that have pigment (color) in them are **retinal pigmented epithelial (RPE) cells** behind the rods and cones. The pigment absorbs extra light so it doesn't scatter about the retina. The pigmented epithelial cells also nourish and protect the rod and cone cells. These epithelial cells are very unusual because they do not go through mitosis, and must last your lifetime. If they stop functioning you experience **macular degeneration**, which can lead to blindness.