WHAT'S THE BIOBUZZ?

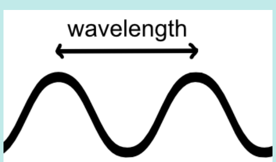
A journal for students by students

Color Vision in the Fruit Fly Brain

Key Terms

Color:
All light is made up of electrical and magnetic waves; the color of light is related to the the length of the wave.

Wavelength:
The distance between two peaks in a wave. Wavelength can be measured for light waves, ocean waves, or any other kind of wave.



Photoreceptor:
Cells that are activated by light. Humans have photoreceptors in our eyes that are activated by red, green and blue light.

Calcium Imaging:
A technique that uses a calcium-indicator to measure activity in the brain. When a brain cells is active calcium enters into it and the calcium-indicator fluoresces, making the cell light up.

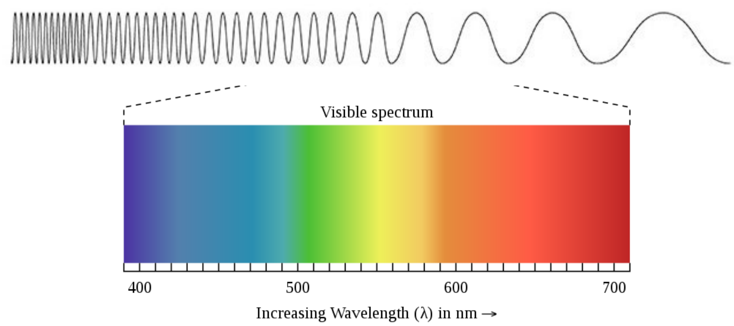


Figure 1: Light is made of electrical and magnetic waves that are so tiny that they are measured in nanometers (nm), which are billionths of meters. Different colors of light have different **wavelengths**. Humans are able to see colors ranging from violet (400nm) to red (700nm), while shorter or longer wavelengths are not visible to us.

ABSTRACT

How do animals see **color**? Color vision is the ability to distinguish light of different **wavelengths**; for example we see 450nm light as blue, and 650nm light as red. We know that vision starts with light-sensitive cells in the eye, called **photoreceptors**, but scientists are still trying to figure out how vision works in the brain.

The Behnia Lab studies vision using fruit flies. Fruit flies are naturally attracted to certain colors and might even be able to learn when a specific color is relevant for food. We are interested in how their color vision systems work starting with photoreceptor cells in the eye. Ultimately, learning about the brains of simple animals like fruit flies can help scientists to learn more about how more the more complicated human brain works.

WHY FLY EYES?

It's easy to ask a human what color they see, but without opening a human's head we can't figure out how the cells in their brain encode color. That's one reason we use animals like fruit flies! The fruit fly color vision system has four photoreceptor types called pR7 (deep UV), yR7 (UV), pR8 (blue), and yR8 (green) (**Figure 2**). This is different from a human eye, which has only three color photoreceptors for red, green, and blue. One problem for color vision in humans and flies is that it is hard to tell the difference between similar colors. You'll notice in **Figure 3** that even though the photoreceptors are most activated by UV, blue or green, they each respond to a wide range of colors.

How then, if the photoreceptors are not very specific to any one color, can the brain manage to figure out what color we are seeing? That is the question we asked in this paper.

Fruit Fly Photoreceptors

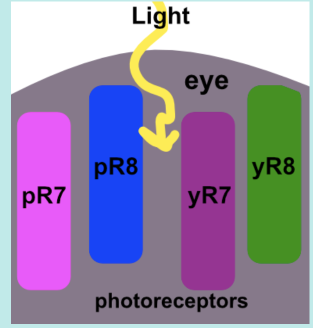


Figure 2: Light from the environment enters the eye and activates photoreceptor cells. Information from the photoreceptors is sent to all the other cells in the visual system.

Photoreceptor Sensitivities

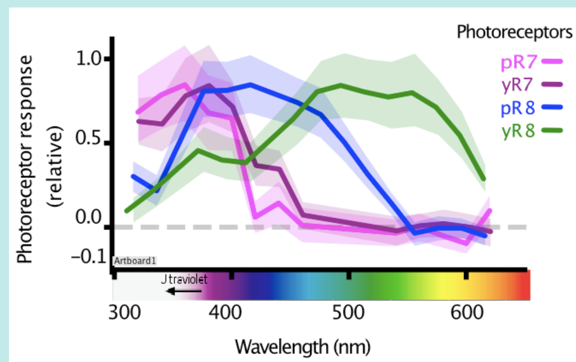


Figure 3: This plot shows the wavelengths that the photoreceptors respond to. pR7, yR7, pR8, yR8 are mainly activated by UV (360nm), UV (360nm), blue (420nm) and green (500nm), but they respond to a range of wavelengths.

METHODS

In order to see how cells in the fly brain respond to light, a fruit fly is placed under a microscope and cellular activity in the brain is measured with a technique called **calcium imaging**, as seen in **Figure 4.** The fruit fly is first dissected so that the brain is visible. While recording from the brain we show the fly lights of various wavelengths (colors) and intensities (brightness) in order to find out what the cells respond to.

RESULTS

If each photoreceptor responded to only one color of light, then color vision would be easy. (You could tell the color just by the knowing which one type was active). In reality each photoreceptor responds to a range of colors. To solve this problem, cells in the brain decode color by comparing the activities of the different photoreceptors. For example, in **Figure 5** you can see that UV light and blue light each activate all four fruit fly photoreceptors. However, UV mostly activates pR7 and yR7, while blue mostly activates pR8. Decoding color is in some ways like taking a vote from each of the photoreceptors. Each vote on its own has little information, but after considering all of votes you can tell the difference between every color of the rainbow. It seems strange, but one photoreceptor alone can tell you very little about color.

We were able to identify a cell in the fly brain called Dm9, which is involved in collecting the photoreceptor "votes", which are really just cell signals. As illustrated in **Figure 6**, the active photoreceptors all send their signals to the Dm9 cell. Dm9 is involved in helping to compare the signals and determine the color of light that is seen.

Experimental Setup

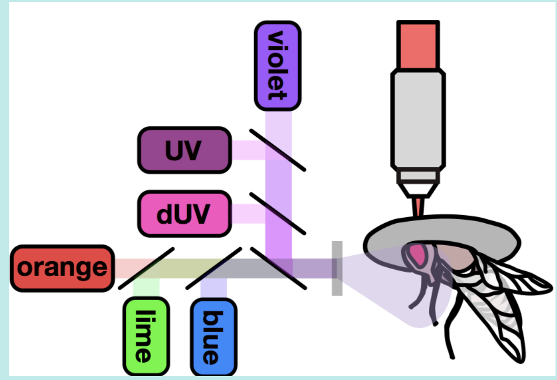


Figure 4: A live fly is fixed under a microscope so that we can do calcium imaging while showing the fly all different colors of light.

Decoding Color

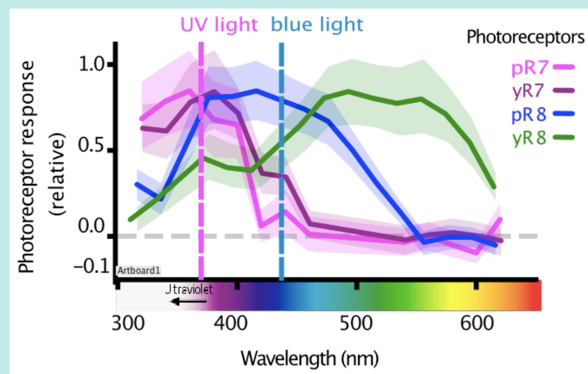


Figure 5: Comparing the amount of photoreceptor activity is necessary for decoding color. For example UV and blue light can each activate all the photoreceptors at the level of the eye, but the amounts that each is activated is unique.

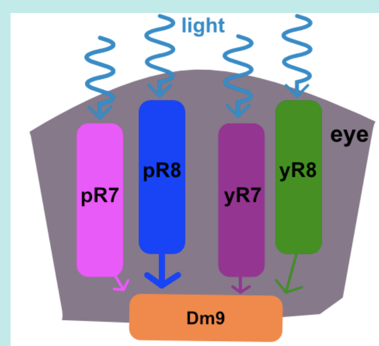


Figure 6: The Dm9 cell gets signals coming from each of the photoreceptors. By comparing all of these signals, Dm9 helps to decode color.

DISCUSSION / CONCLUSION / SO WHAT?

- Humans have photoreceptors for red, green and blue, while fruit flies have photoreceptors for UV, blue and green.

- A problem for color vision is that photoreceptors are not super specific about which colors they respond to. For example, a blue photoreceptor will have responses to some colors that are similar to blue, like violet.

- To tell what color we are seeing, cells in the brain have to compare how much each photoreceptor is activated. We discovered that in flies this is partly done by a brain cell called Dm9.

- Comparing photoreceptor activities is also what lets humans see the vast number of colors that we see with our 3 color photoreceptors. Think about it this way- we see much more than red, green or blue, we can tell the difference between all sorts of similar colors like baby blue, navy blue and sky blue.

- Sensory systems like vision, hearing, taste or touch are very complicated, but having simple animals helps us to learn more about how they work.

- Can you think of an experiment that would prove that fruit flies can see color? What behaviors would prove to you that they can tell the difference between different colors?

Adapted by Maia Weisenhaus from *Circuit Mechanisms Underlying Chromatic Encoding in Drosophila Photoreceptors* by Sarah L. Heath, Matthias P. Christenson, Elie Oriol, Maia Weisenhaus, Jessica Kohn, and Rudy Behnia. *Cell*, 2020