
How Humans See Color
Section 2: And How we don't...

How Humans See Color, and How We Don't:

• Anatomy of the Human Eye

Light passes through the pupil and is focused by the ciliary muscles around the lens. The light forms an image on the retina and it converts the "light" information into electronic signals processed by the brain.

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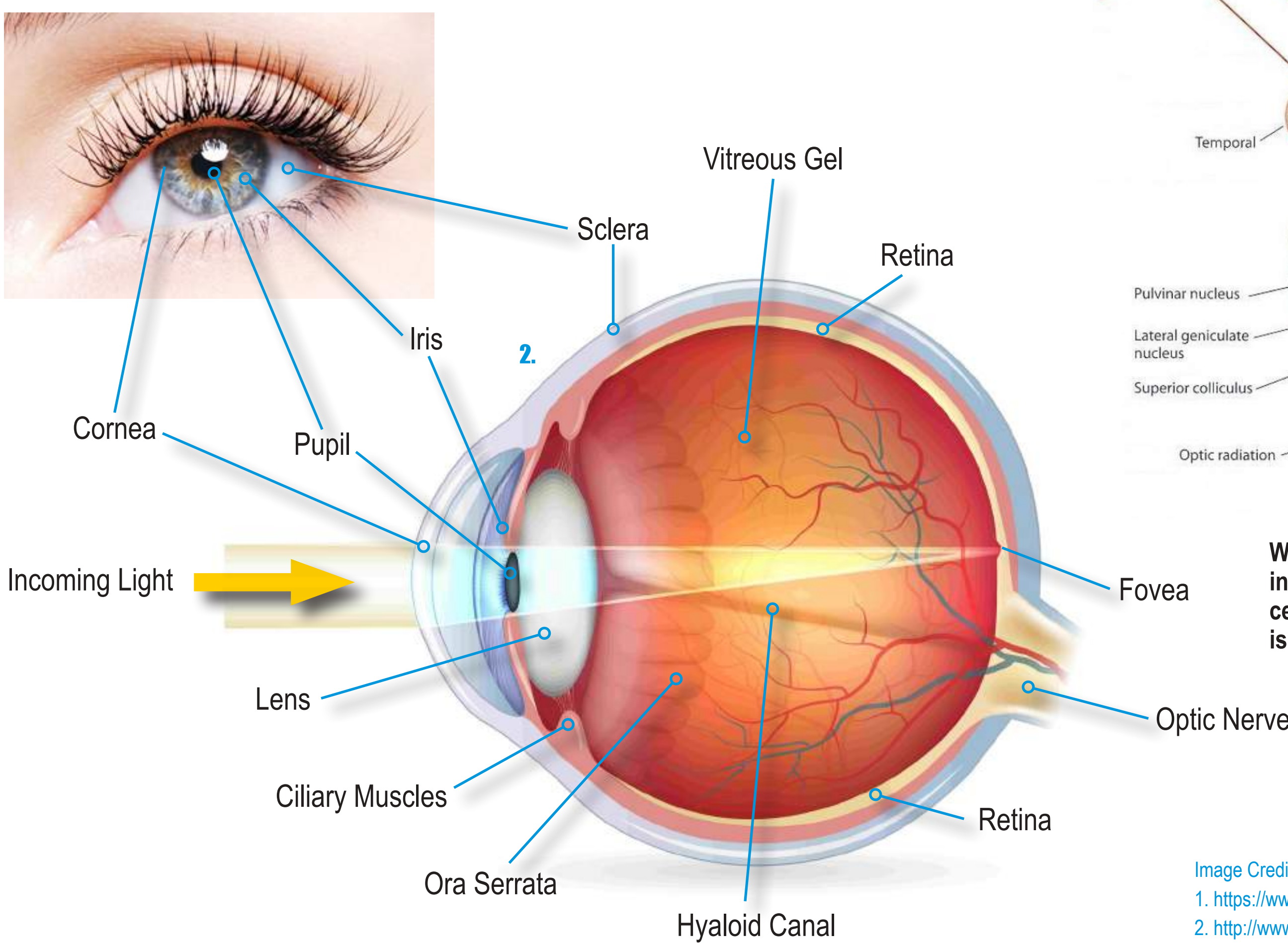

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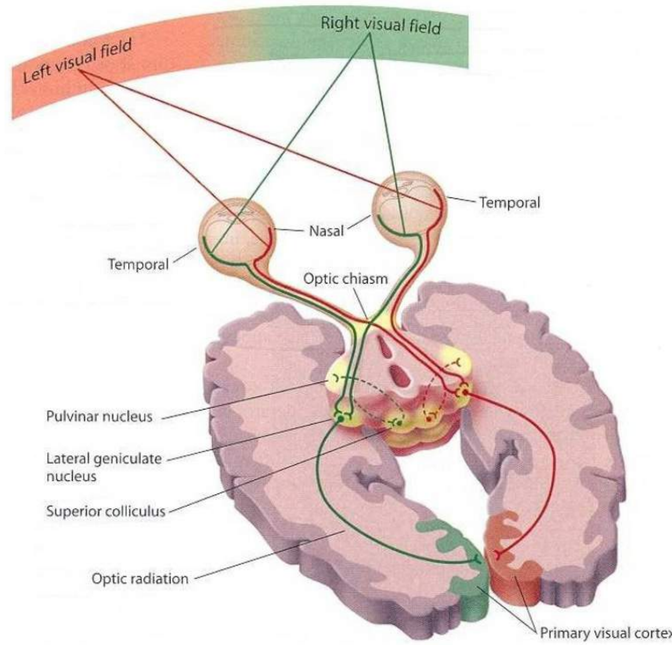


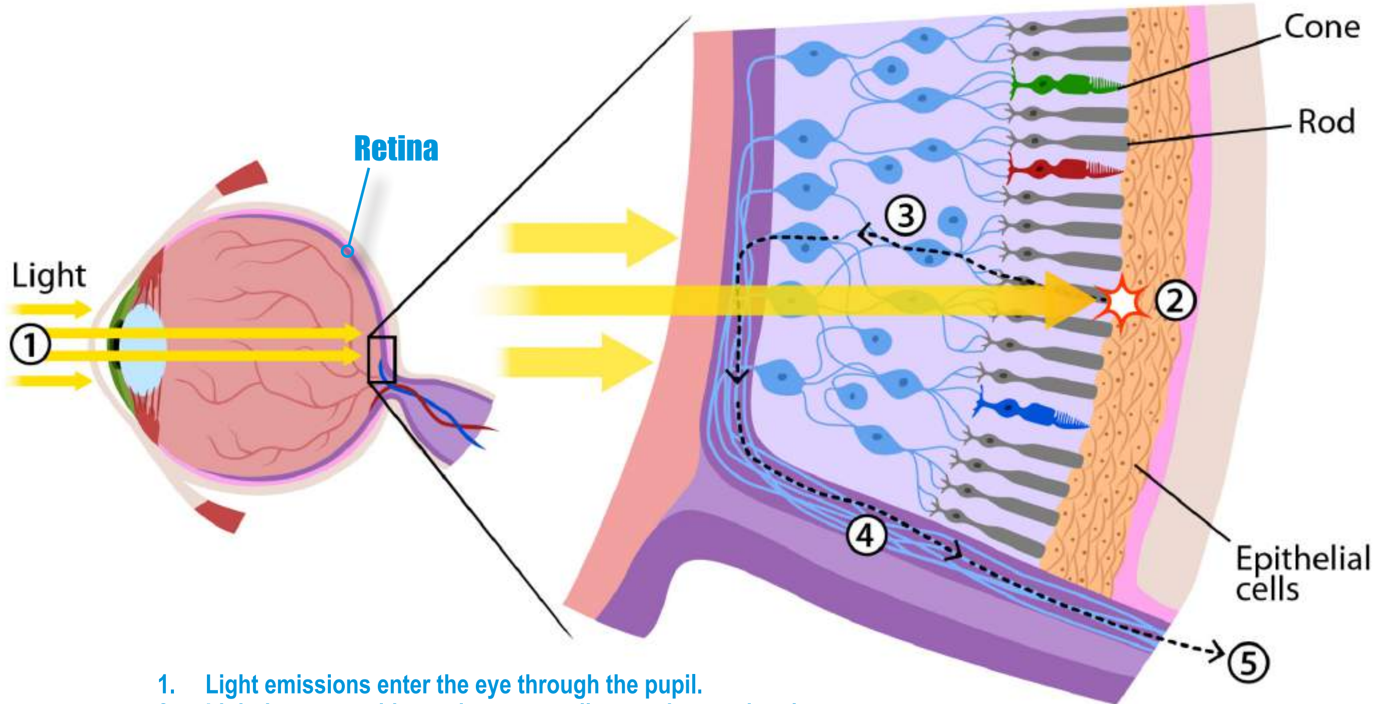
Without the brain to process the sensory input from the eyes, there would be no perception of color or movement. In the end, it is the mind that sees, not the eyes!

Image Credits:
1. https://www.gumtree.com/p/eye-treatment-services/
2. http://www.outlanderanatomy.com/a-real-eye-opener-the-eye-part-4/
3. http://pt.slideshare.net/faropaideia/procesos-cognitivos-la-visin/

How Humans See Color, and How We Don't:

• How wavelengths of light are converted into the rainbow of colors we perceive

The retina has specialized cells called Rods and Cones that have evolved to be sensitive to certain wavelengths of light and shades of gray. These cells, along with other specialized neural eye cells help to focus the light and send it to the brain where it can be interpreted as the world we see around us.



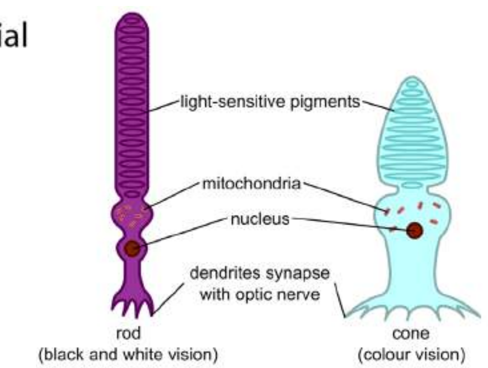
1. Light emissions enter the eye through the pupil.
2. Light interacts with a rod or cone cell to produce a signal.
3. The signal travels through the retina and is further refined through other specialized light sensing neural cells that fill in additional color information.
4. Neural cells route the signals to the optic nerve.
5. The optic nerve sends the signals to the brain to be interpreted.

Above Image Credit: http://anatomy-medicine.com/nervous-system/111-the-eyes-rods-and-cones.html

Anatomy of Rod and Cone Cells

Rods Cells have proteins that are sensitive to shades of gray or luminosity.

Cone Cells have proteins that are sensitive to red, blue and green wavelengths of light.



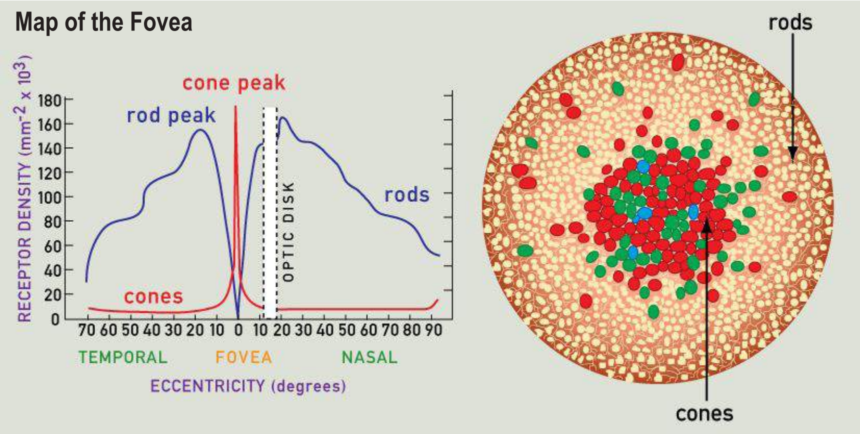
Above Image Credit: ABPI c.2013

Color Management Concepts

How Humans See Color, and How We Don't:

• How the Specialized Light Sensitive Cells of the Eye Really Work...

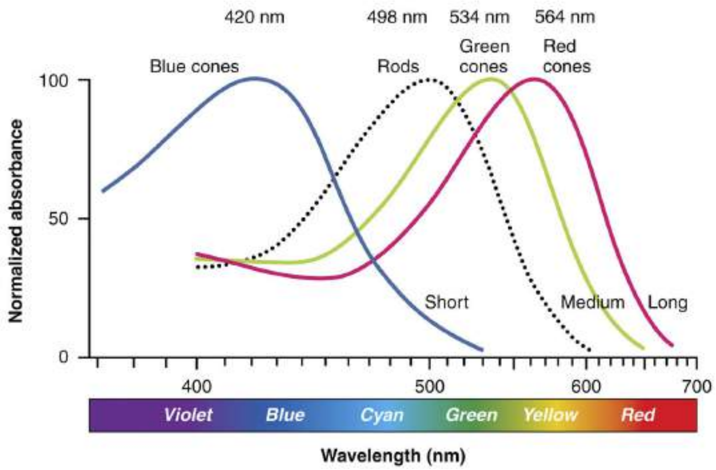
The retina is the back part of the eye that contains the cells that respond to light. These specialized cells are called photoreceptors. There are 2 types of photoreceptors in the retina: rods and cones. The cones are specialized to be sensitive to one of three colors (Red, Blue or Green) while the rods are good at distinguishing shades of gray in low light conditions to help you see in dim light. Cones cannot distinguish colors in low light conditions and the rods take over helping you to see. This is why it very hard to see color in dim light. By combining the relative signals from these three types of RGB cone cells, our brain can see a fairly continuous range of colors (about 10 million different colors in fact!). Thus, we see the colors that we see because these colors are just different frequencies/ wavelengths of light that our eyes are specifically tuned to pick up and our minds have developed to discern the colors in our uniquely human way.



The fovea (see page 9), shown here on the above right, is the central region of the retina that provides for the most clear color vision. In the fovea, there are NO rods...only cones. The cones are packed closer together in here than in the rest of the retina. Also, blood vessels and nerve fibers go around the fovea so light has a direct path to the photoreceptor cells.

- There are about 120 million rods in the human retina to help you see in dim light and perceive shape and movement.
- There are about 6 million cones in the human retina to perceive color and fine details in well lit areas.

Above Image Credit: http://www.webexhibits.org/causesofcolor/1G.html



Here is a diagram of the three types of cones:

- Red cones, accounting for 64% of the total, also known as L-cones (sensitive to long-wave light, 564–580 nm which is red).
- Green cones, accounting for 32% of the total, also known as M-cones (sensitive to medium-wave light, 534–545 nm which is green).
- Blue cones, accounting for 2 – 7% of the total, also known as S-cones (sensitive to short-wave light, 420–440 nm which is blue)
- There is much more to perceive, we just can see it.

Above Image Credit: https://en.wikipedia.org/wiki/Photoreceptor_cell

Color Management Concepts

How Humans See Color, and How We Don't:

• And now its time to blow your mind.

There is an extremely deep connection between life on Earth and the colors that we see. On the surface, this connection is very basic and well studied, but as we delve deeper, the questions become more profound and less explored or known about. We have covered how we see color and the mechanisms behind it, but we have not asked the fundamental question. Why do we see in color?

It is generally agreed upon that animals have evolved to see colors primarily to alert them to potential sources of food. For instance, many birds are sensitized to the ultraviolet spectrum which allows them to sense patterns found on flowers and other wildlife that are otherwise invisible to the human eye. Similarly, it is thought that the evolution of trichromatic (RGB) color vision in humans occurred as the result of our primate ancestors switching to greater daytime activity leading to a greater reliance on consuming fruits and leaves that were green, red, and orange in color.

Going deeper, the next question asks, "Well, I understand that animals evolved to see certain plants, but why are these plants colored this way to begin with?" To answer this question, we must understand how pigmentation works on a chemical level. Pigments are "molecules that absorb specific wavelengths (energies) of light and reflect all others." In order for a particular molecule to reflect a certain color, its chemical structure must be arranged in a special way. Specifically, the molecule's electrons must be able to absorb certain wavelengths of light, but not others. Take chlorophyll for instance. Chlorophyll's chemical structure causes it to absorb blue and red light, but hardly any green light at all, so the green gets reflected back to our eyes, which is why leaves appear green. In fact, Chlorophyll takes the energy its electrons absorb from light, and through a series of chemical steps (called photosynthesis) takes carbon dioxide and water and, using the energy from the sun, converts them into sugars and oxygen.

Now, why do pigments like chlorophyll absorb wavelengths of light in the visible spectrum? The answer is a Goldilocks's effect of sorts. If plants had pigments that absorbed UV and x-rays, too much energy would be absorbed, causing electrons to be knocked off their orbitals, destroying the molecule. On the flip side, if plants absorbed infrared and radio waves, there would not be enough energy for electron transfer and the photosynthetic reaction could not take place. So basically, pigments absorb in the visible spectrum because these frequencies provide just the right amount of energy for powering crucial chemical reactions.

Follow this to the next page...

Source Credit:http://mitchkirby.com/2015/05/04/color-and-existence-of-life/

How Humans See Color, and How We Don't:

• And now its time to blow your mind.

At this point, lets just reflect on our journey so far before we delve even deeper. We've gone from asking why we see the colors we do, to why we evolved to do so, to why these colors are the colors that they are, to finally understanding why biological pigments have evolved to use these specific colors. Now, the next set of questions will force us to think about the interactions between color and the existence of life on Earth.

Given that life first formed and evolved in water, how does this relate to the visible spectrum of color? Light is absorbed by water at different wavelengths. Amazingly, water absorbs the least amount of light right in the visible spectrum, which allows more visible light to pass through, and hence why water appears transparent to us. This means that if you are an early form of photosynthetic life in the ocean or a pond, you are still able to get the light you need to survive and thrive. This is unlikely a coincidence, but merely another reason why we see the light that we do. Not only is the light we see of ideal energy for supporting life, it is also able to easily pass through water.

Consider this: "How does the light we see relate to the light that is emitted from the sun?" You may not realize this, but all objects radiate electromagnetic radiation according to a specific spectrum and intensity that depends solely on their temperature – even people do! People, however, are relatively cool in temperature (98.6 F) and as a result, radiate primarily in the infrared spectrum so we can't see it with our eyes, but we can feel the heat of another person through our skin. Stars on the other hand, which are much hotter, tend to radiate closer to the visible spectrum, with relatively cool stars appearing red and super hot stars appearing blue. Incredibly, you'll notice, that our star, which is categorized as a yellow star, is at a temperature that causes its radiation to peak right in the middle of the visible spectrum. In fact, 44% of the sun's energy is emitted in the narrow band of electromagnetic radiation that comprises visible light. So visible light is of ideal energy for supporting life, able to easily pass through water, and also corresponds to the most light from the sun.

Given all of these connected pieces of science, one can't help but marvel at the elegance of our solar system. Putting these pieces together opens up much deeper questions, ones that I can't even hope to answer. Can life exist on a planet orbiting a star of a vastly different temperature? If it can, will life on this planet be incredibly different and optimized to the specific frequencies of light that are most prevalent? Could life exist at all if water had a different absorption spectrum that did not bottom out in the visible range? How much leeway on these physical properties does the universe give life, and do these properties all have to overlap? Will life find a way no matter what? Are these properties specifically designed to co-exist perfectly, or do we just happen to exist on a planet, orbiting a star, in a galaxy, within a universe in which all of these things are possible? Are we only capable of asking these questions because all of these things are true to begin with?

No matter how you think about these questions, it is truly a miracle of coincidences that all these things occur...or is it?

Source Credit:http://mitchkirby.com/2015/05/04/color-and-existence-of-life/

Color Management Concepts

How Humans See Color, and How We Don't:

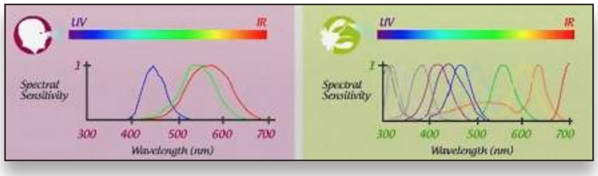
• How the Animal Kingdom sees completely differently from us...

Eyes are testaments to evolution's creativity. They all do the same basic thing, detect light, and convert it into electrical signals. But this is done in such a wondrous variety of ways. There are single and compound eyes, bifocal lenses and rocky ones, mirrors and optic fibers. And there are eyes that are so alien, so constantly surprising, that after decades of research, scientists have only, just about figured out how they work, let alone why they evolved that way. Here are a few examples of why we, as human, should be humbled that our seat is not at the top of evolution when it comes to seeing the world around us.

Eyes don't even have to be organic. While most animal lenses are made of proteins, the fuzzy chiton – an armored relative of snails and other mollusks – has eye lenses made of aragonite, a type of limestone and the same stuff that the chiton's shell is made of. Trilobites, that lived millions of years ago, had eyes made of Calcite, a kind of natural fiber optic mineral.

Benjamin Franklin is credited with inventing bifocal glasses. These allow wearers to focus on both far and near objects by looking through different parts of the lens. But such lenses have been around for millions of years, on the nightmarish face of the sunburst diving beetle. The beetle's larva has six pairs of eyes, and the front set is unique in the animal kingdom. Each one has one lens and two retinas, one sitting behind and slightly below the other. The lens manages to focus sharp images onto both of them, so the beetle can see near and far objects at the same time, with equal sharpness. Its bifocal lens gives it two eyes for the price of one.

Mantis shrimps have the arguably most incredible eyes of any animal. Each eye has three areas that can independently focus on objects, which means that a single mantis shrimp eye has "trinocular vision". Our eyes have receptors that are tuned to three colors; those of mantis shrimp's are tuned to at least twelve, possibly sixteen. And they can tune individual light-sensitive cells to local light levels. Mantis shrimps can even see a special type of light – 'circularly polarized light' – that no other animal can. This ability allows them to send secret messages, produced by circularly polarized light reflecting off different parts of their shell. The ability hinges on a structure in their eyes that's similar to technology found in our CD and DVD players. The mantis shrimp's biological engineering completely outclasses our man-made efforts; if we could duplicate it, we could have the basis of tomorrow's multimedia players and hard drives.



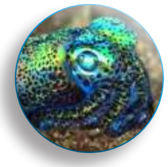
Snakes have two sets of eyes. One set is the normal eyes that you see, and they detect color quite well. But they also have vision pits that detect heat and "see" living creatures like an infrared detector. There is no getting away from a snake once you're spotted. Very handy for finding a mouse who thinks he is hiding in a pile of straw or a bird in a tree.

Above Image Credit: https://thinkingscifi.wordpress.com/2013/12/29/what-is-color/

How Humans See Color, and How We Don't:

• How the Animal Kingdom sees better than we do, cont.

Here are some more amazing eyes in the animal world for us to ponder about how they see the world. Why bring up other example of how animals see? Because it is important to know that what we see is not necessarily what real. Its just our reality.



The Hawaiian bobtail squid creates its own light, using special organs filled with glowing bacteria. But these organs don't just produce light – they sense it too. They are loaded with proteins that can detect light, and they produce nervous signals in bright conditions. They can expand and contract like an iris to control how much light gets through. They're covered with a thick, transparent tissue that acts like a "lens". The light organs are effectively an extra set of primitive eyes. They are living, 'seeing' flashlights.

How do birds detect ultraviolet (UV) light? To answer this question you must understand avian eye structure. The human retina has three kinds of cone cells (receptors used for color vision): red, green and blue. By contrast, birds active during the day have four kinds, including one that's specifically sensitive to UV wavelengths. There's another difference: In birds, each cone cell contains a tiny drop of colored oil that human cells lack. The oil drop functions much like a filter on a camera lens. The result is that birds not only see UV light, they are much better than humans at detecting differences between two similar colors. Many birds can see differently. Pigeons, for example, can see millions of different hues and are thought to be among the best at color detection ability of any animal on earth. They have many more cones than humans in their eyes, thus accounting for the ability to see at least five spectral bands. In addition to great color vision, many birds also seem to be able to sense magnetic currents and can "see" them to navigate across great distances. (Evolutionarily speaking, maybe dinosaurs could do this too.)

Cats have a wider field of view, about 200 degrees, compared with humans' 180-degree view. Cats also have a greater range of peripheral vision, all the better to spot that mouse (or toy) wriggling in the corner. Cats are crepuscular, meaning they are active at dawn and dusk. That may be why they need such good night vision. Their eyes have six to eight times more rod cells, which makes them more sensitive to low light than humans. They also have a special membrane in the back of their eyes that reflects light strongly. This gives the optic cells in their eyes a second chance at catching the light and why their eyes seem to glow when you shine a flashlight at them. Their night vision is 6x better than ours.

Because of segmented eye structure, many insects see objects very differently from what humans perceive. Insects are famous for their dot-like eyes, known as ommatidia. Some have as many as 30,000 lenses per eyeball. But perhaps most interesting is the dragonfly. This insect's brain works so rapidly, it perceives most movement in slow motion. Insects do see color, but not usually as clearly as other animals. Their vision assists them in detecting movements and distinguishing friend from prey.