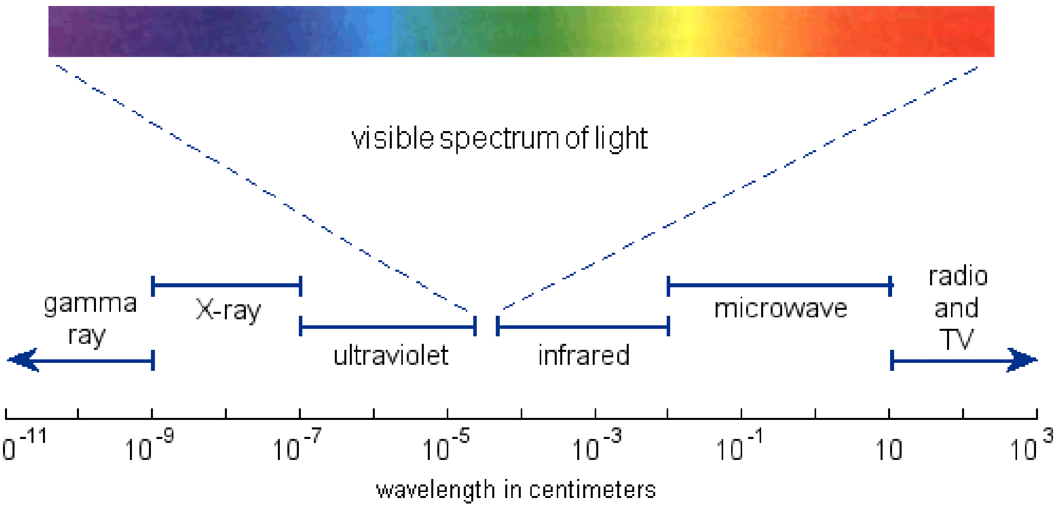
PRIMATE COLOR VISION

Vision among vertebrates is a result of having specialized light receptor structures known as **rods** and **cones** at the back of the eye in the retina. Rods are extremely sensitive to even dim light but provide relatively coarse, colorless images. Cones provide the sharpest images and are responsible for the ability to see color, but they only function effectively when the light is bright. Consequently, all vertebrates are more or less blind to color in the dark at night. They may be able to see with the faint light of the moon, but color differentiation is reduced as it becomes darker until the world essentially seems to be in shades of black and white. This is easy to demonstrate for yourself. During the daytime, pick a well lit area with only natural light and observe the colors. Return again when it is dark at night to look at the same scene. This difference is particularly easy to see when looking at dark green, blue, gray, or silver cars. At night, they are usually much more difficult to distinguish.

Different types of cones are "tuned" to different portions of the narrow visible spectrum of electromagnetic radiation (see illustration below). Near the surface of the cones are light sensitive protein pigments called **opsins**. These are encoded by 2-9 genes on the X chromosome of humans. The opsins in different cones are sensitive to different wavelengths of light. Colors are identified by the brain based on responses from the different opsins. The key to color vision is the ability to differentiate between different wavelengths. Most mammals have only two kinds of opsins. These are normally sensitive to short and middle wavelength light that includes blues and greens. Having this form of limited color vision capability is known as **dichromacy** (literally "two colors"). Most birds have far better color vision, being able to see not only blues and greens but also reds (long wavelength light) and often ultraviolet wavelengths, which are shorter than those of the visible spectrum. Some bees and other insects also see ultraviolet. Rattlesnakes can perceive infrared wavelengths, which are longer than those of the visible spectrum. However they do not accomplish this with their eyes. They have infrared detectors in a hole or pit in front of each eye. For this reason, they are referred to as pit vipers.



Note: The "visible spectrum" of light is so named because it is all that normal trichromatic humans can see. This is, of course, a human-centered perspective.

There is considerable variation between primates in terms of the ability to see colors. The best color vision exists in diurnal species. This is not surprising. Color sensitive cones would be of little use to nocturnal primates due to the fact that they require the relatively bright light of daytime to detect color. Humans, apes, and most, if not all, of the Old World monkeys are **trichromatic** (literally "three colors"). They have three different kinds of opsins on their cones which allows them to discriminate between blues, greens, and reds. In contrast, prosimians, such as lemurs and lorises, have relatively poor color vision being dichromatic. They can differentiate blues and greens but not reds. Color vision among New World primate species is surprisingly variable. Some of them are dichromatic and others are trichromatic. Most females in some species can distinguish reds but no males can. This is the case with marmosets, tamarins, squirrel monkeys, and spider monkeys. All males of these species only see blues and greens. About 40% of the females apparently are also dichromatic, but the other 60% are trichromatic. Both male and female howler monkeys are trichromatic. At the other extreme, the nocturnal owl monkeys are monochromatic (literally "one color"). They see only black, white, and intermediate grays. A rare genetic disorder in humans known as achromatopsia causes a similar inability to see colors due to defective cones.

Trichromatic view
(blues, greens, and reds)

Dichromatic view
(only blues and greens)

Monochromatic view
(no blues, greens, or reds)

It is generally assumed that the ancestors of all monkeys were prosimians who were monochromatic or dichromatic. The Old and New World monkeys became separated 30-40 million years ago and have been traveling down their own evolutionary tracks since then. It is likely that mutations in the X chromosome gene or genes that provide the ability to see red colors occurred after this separation. Given that trichromacy occurs in both the New and Old Worlds, it is probable that the mutation for it occurred more than once. However, the switch to trichromacy was clearly more complete among Old World monkeys than New World ones. Natural selection very likely is responsible for this difference.

What in primate environments strongly selected for the ability to see red colors? Several researchers have proposed hypotheses about the nature of this selective pressure. Andrew Smith of the University of Stirling in Scotland believes that trichromacy provides an important advantage for fruit eating species. It can be a valuable aid in determining when fruit is ripe. It also makes it easier to find orange-red fruit against a background of green forest foliage. Dichromatic monkeys are like colorblind humans in that they have difficulty distinguishing visually between green and ripe fruit. While this hypothesis sounds plausible, it may not provide a complete answer because many trichromatic monkeys and the apes predominantly eat leaves. Once again, color may be a valuable clue for such species since the edibility of leaves from the same tree or shrub often varies with their maturity, which can be signaled by color. Peter Lucas of the University of Hong Kong observed that macaques use this as a clue in finding the most desirable leaves to eat. Whether the food is fruit or leaves, the ability to see reds would make it easier to pick out a food target in a green vegetation background. One other very different hypothesis has been proposed by Emily Liman of the University of Southern California. She links trichromacy to the fact that when females of some Old World monkey and ape species are in estrus, they develop reddish sexual skins or swellings. The male ability to see reds would presumably lessen the importance of their relatively poor sense of smell in detecting female pheromones.

About 6-8% of humans today are red-green color blind. Most of them are men. This X-linked inherited condition known as deuteranomaly is due to opsin pigments that are normally sensitive to green light behaving more like the red-sensitive ones. This results in a difficulty in distinguishing between colors in the red and green wavelength ranges. However, people with this condition are at an advantage in differentiating slight variations in khaki colors. This could have been a benefit in the dry grassland environments of East and South Africa where humans first evolved.

It is important to keep in mind that the visual images that our eyes send to our brain are interpreted in a way that makes sense to us based on our past experiences. In a very real sense, our brains reinterpret what reality is. That version of reality can be deceptive. The video below provides several interesting examples of this additional complexity to understanding vision.

Optical Illusions Show How We See--video from TED: Ideas Worth Spreading
This link takes you to a new webpage. To return here, you must click the "back" button on your browser program. (length = 16 mins 31 secs)

Additional Online Information

Anatomy and physiology of the eye and color vision:

- The Human Eye
- Color Vision Deficiency (American Optometric Association)
- Color Vision: One of Nature's Wonders
- The Evolution of Color Vision (from The Talk.Origins Archive)

Primate color vision:

- Primate roots of red-green vision (BBC News)
- Evolution of Primate Sense of Smell and Full Trichromatic Color Vision (from the online journal Public Library of Science--Biology)
- Primate Photopigments and Primate Color Vision (PDF file from the *Proceedings of the National Academy of Sciences*)

NEWS: In the September 15, 2009 online issue of Nature, Jay Neitz and his colleagues at the University of Washington, Seattle reported that they have successfully used gene therapy on male squirrel monkeys in order to give these normally red-green color blind animals the ability to discern the full spectrum of visible light. Human segments of DNA were implanted in the back of their eyes, behind the retinas. After 5 weeks, they began to acquire full color vision. Two years later, they could still distinguish reds and greens clearly. It is hoped that this research will pave the way for correcting the vision of red-green color blind humans.

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