Physiological Mechanisms of Primate Color Vision

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Abstract

An important objective of visual neurophysiology is to understand visual perception in terms of neuronal connections. In the case of color vision, some of the chief aspects of perception to be explained are color mixing and color constancy. Color mixing is now well understood in physiological terms; progress has been made in the area of color constancy, but there our understanding is far from complete.

Anatomically our visual system consists, broadly of a series of neuronal stages; the first three of these are housed in the retina, beginning with the rods and cones and ending with retinal ganglion cells, whose axons make up the optic nerve. Each ganglion cell receives input, via bipolar cells, from a small compact aggregate of rods and cones, which constitute the receptive field of that cell. In 1950, Stephen Kuffler, working with cats, found that each retinal ganglion cell receptive field is a few mm in diameter and is subdivided into a small excitatory ("on") center and larger inhibitory ("off") surround or, for about half the cells, an inhibitory center and an excitatory surround. This organization gives an immediate and simple explanation for the fact that object's whiteness or blackness depends on spatial differences in brightness, and not on the absolute levels of light coming from the object.

Cats have poor color vision, and retinal cells that register spectral sensitivity differences in their receptive fields must be very rare. Macaque monkeys, on the other hand, have color vision practically identical to ours. Thus it is no surprise that in monkeys, the lateral geniculate body (a brain structure one stage beyond retinal ganglion cells) contains a rich variety of color coded cells. Here, as in the retina, the commonest cell type again has a center-surround receptive field (on or off center with opponent surround, as in the cat); but the center is fed by cones of one class, red, green or blue) and the surround by cones of a different class. (Here I use "red cones" loosely, to indicate the cone-type containing the long-wavelength-sensitive visual pigment.) For example, a common receptive field type in the macaque monkey is red excitatory center: green inhibitory surround. Other cells pit blue against a mixture of red and green ("blue-yellow cells"). All these cells, which we term "Type 1", behave in a way strikingly reminiscent of the way we perceive mixtures of colors. A blue vs. yellow cell may be excited by blue light, inhibited by yellow, and be unresponsive to white—just as blue and yellow, mixed in the right proportions lead to the perception of white.

Such cells, while behaving in a way that parallels our perception of color mixing, seem to be organized in just the wrong way to explain color contrast or color constancy. I will discuss these perceptual phenomena, and will describe cells in the primary visual cortex whose physiology seems to parallel color spatial contrast and color constancy.