Opponent color theory

David O. Rico, Otto B. Larsen

Report on opponent process theory and relevant topics

Sensation Perception Cognition
Southern Denmark University
Denmark
6.11.2021

1 History

The two major theoretical accounts of color vision are those classified as the Young-Helmholtz and the Hering types of theories. For many years the former has been judged by most workers in the field to provide the simplest explanation of the way in which light stimuli give rise to color sensations. [1]
The Young–Helmholtz theory is a theory of trichromatic color vision. Young postulated the existence of three types of photoreceptors (now known as cone cells) in the eye, each of which was sensitive to a particular range of visible light.[2] The opponent color theory was first proposed in 1892 by the German physiologist Ewald Hering.

2 Basic concepts

The Hering theory is like the Young - Helmholtz theory in that it, too, postulates three independent variables as the basis for color vision, but the Hering variables are three pairs of visual processes directly associated with three pairs of unique sensory qualities. The two members of each pair are opponent, both in terms of the opposite nature of the assumed physiological processes and in terms of the mutually exclusive sensory qualities. These paired and opponent visual qualities are yellow-blue, red-green, and white-black. [1]
In figure 1 Hering's idea of opponent colors can be seen. The inner circle represents the hue dimension of the HSB spectrum, while the outer circle shows how combinations between the two opponent pairs make up the hue dimension. Note that are no combinations between the pairs itself as there does not exist color such as a reddish green according to Hering.[3]
The opponent-process theory explains color vision as a result of the way in which photoreceptors are interconnected neurally. The opponent-process theory applies to different levels of the nervous system.

3 Hue cancellation

In 1957 two American psychologists by the names of Dorothea Jameson and Leo Hurvich set about developing a new way of quantifying Herings' theory regarding colour-opponency, dubbed 'Hue cancellation'. Jameson and Hurvich reasoned that given a light that appears to be of a certain colour, one could cancel the colour, or one of its specific colour components by adding a certain amount of its opponent colour. [3] The two psychologists provided

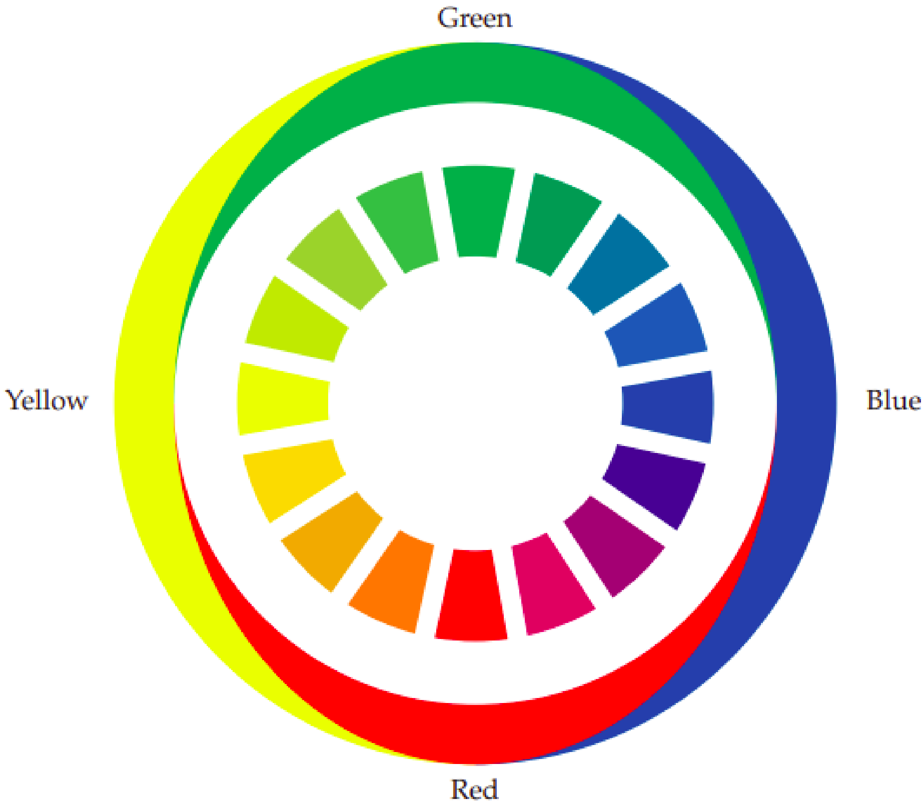

Figure 1: Hering's idea of opponent colors [3]

the important quantitative data needed to revive Herring's colour-opponent theory by conducting hue cancellation experiments for lights across the spectrum. [3]
Jameson and Hurvich conducted their experiments by presenting a participant, the observer, with a monochromatic test light. If the test light was judged to be red in appearance, the participant would be asked to cancel out precisely the red component by adding a certain amount of its opponent colour green. If the test light was judged to be green in appearance, the participant would be asked to cancel out the green using a red light.

4 Color in the visual cortex

The famous studies of V1 and V2 cortex in monkeys by Livingstone and Hubel, 1984, supported the modular concept and linked it to parallel pro-

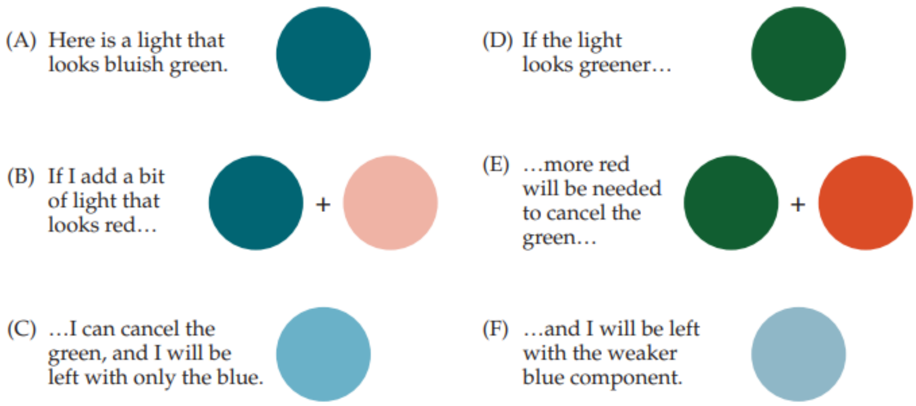

Figure 2: A hue cancellation experiment involving green colour components [3]

cessing in the retina and the lateral geniculate nucleus (LGN). The landmark studies of De Valois (1965) first suggested that color opponent neurons existed in the primate visual system and could be important for color vision. [4] The opponent cells found in the brain are of two types, single opponent cells and double opponent cells.

And of single opponent cells there are two kinds. First, the L–M or M–L cells that receive input from long wavelength (L) cones opposed by signals from middle wavelength(M) cones, for simplicity called red/green opponent cells. The S/(L + M) opponent cells are sometimes referred to as blue/yellow opponent cells. [4] In figure 3 (a) and (b) we can see an example of a single opponent cell that is excited by wavelengths corresponding to the red color in its center and inhibited by the green color in its outer layer. From the figure can be seen that single opponent cells convey information about color in a broad area. [3]

The defining characteristic of a double-opponent cell is that it is strongly responsive to color patterns but weakly or non-responsive to full-field color stimuli. [4] The double-opponent cells were described as strongly responsive to color bars but insensitive to full-field color stimuli.[4] Thus being able to detect chromatic edges. [3] The center of of each double opponent cell gets excitatory input from one cone type and inhibitory from another. The pattern is opposite in the outer layer. In figure 3 (c) (d) the behavior of the double opponent cell can be seen. Notice the difference of excitatory input near the edge.

Studies in which parts of the brain are connected to color come from cases of achromatopsia. Which is a condition that results in loss of color vision after brain damage. Vision is largely intact but color perception is impaired. [3]

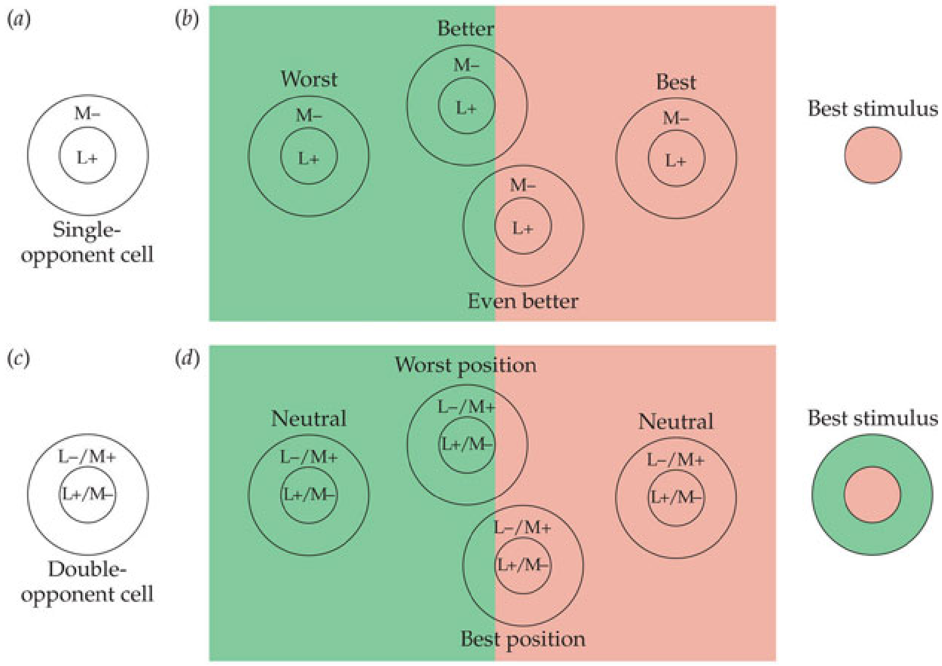

Figure 3: Color opponent receptive fields [3]

5 Adaption and Afterimages

The principle of dark adaption [5] can be extended to colour. That is, adaption can be colour specific, as seen in the phenomena known as negative afterimages. A negative afterimage is, as the name suggests, an afterimage seen after viewing a stimulus composed of one or more colour components and then subsequently viewing an achromatic region. The achromatic region will appear to take on the opponent colour/colours of the initial stimulus, known as the adapting stimulus. Figure 4 illustrates two varying examples of adapting stimuli (B) (C), and the achromatic regions (A) (D) that combined result in negative afterimages.
After staring at the black dot in figure 4B, and then immediately exposing one's gaze to the black dot in figure 4A, the achromatic circles surrounding it will appear to take on the opponent-colours of the circles seen in figure 4B. By staring at the adapting stimuli (B), one's retina is being exposed to several coloured dots, one of these being red. The red-sensing cone cells, or L-cones, will be stimulated to a much higher degree than the M or S cones, which results in one seeing the colour red. After diverting one's gaze to the achromatic image (A), the opponent process is stimulated, due to the red-sensing cones being more adapted than the M or S cones. [3] This adaption

results in the red-green opponent colour mechanism overshooting the point at which the mechanism is not generating any form of signal, and “landing” on the green side. [3] As a result of this, the topmost grey circle (A) will take on a green appearance until the opponent colour mechanism moves back to the point where it no longer is generating a signal.

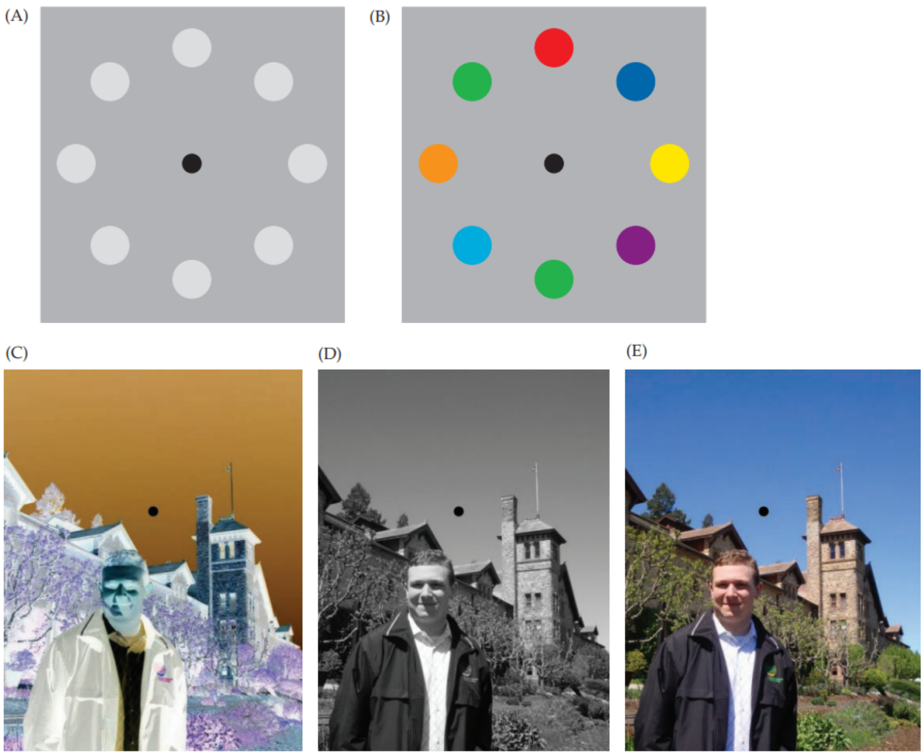

Figure 4: Two examples of negative afterimages [3]

References

[1] Leo M Hurvich and Dorothea Jameson. An opponent-process theory of color vision. *Psychological review*, 64(6p1):384, 1957.

[2] T. Young. On the theory of light and colours. 1802.

[3] Dennis M. Levi Jeremy M. Wolfe, Keith R. Kluender. *Sensation and Perception, Third Edition*. Sinauer Associates, Inc., Massachusetts U.S.A., 2012.

[4] Robert Shapley and Michael J Hawken. Color in the cortex: single-and double-opponent cells. *Vision research*, 51(7):701–717, 2011.

[5] Charles Luu. Michael Kalloniatis. Light and dark adaptation. 2007.