

## **Colour Vision Conflict**

We have all experienced the sensation that occurs when we close our eyes while in bright sunlight and face towards the sun. The light penetrating our eyelids produces a bright red glow over our whole field of vision. Another common visual experience is the phenomenon of 'after-images', the temporary shapes of colour we see after looking at a bright object or light. These after-images are usually in a complementary colour to that of the bright object.

On a recent train journey from Melbourne to Sydney, the early morning sun was streaming into the carriage as I reclined in my seat, eyes closed. As the train sped along, the trees growing close to the track repeatedly interrupted the sunlight shining through the window with a random play of shadows. The result was a sensation of flickering colours and shapes filling my eyes, changing quickly from bright red to deep blue, green, purple, crimson, and back to red again. The alternation of bright shapes and coloured after-images produced a kaleidoscopic effect that was wonderfully entertaining.

Theories of colour vision explaining such effects were first proposed during the mid-nineteenth century by two rival German scientists, Herman von Helmholtz (1821-1894) and Ewald Hering (1834-1918). Drawing on earlier work by the British scientists Thomas Young and James Clerk Maxwell, Helmholtz put forward a three-colour theory of vision. The Young-Helmholtz theory stated that the range of colours we see arises as differing combinations of three primary colours: red, green, and violet. Three types of nerve endings, each sensitive to

one of these colours, line the retina of the eye, and when stimulated by light of a suitable wavelength pass their signals to the brain, where the corresponding colour combinations are perceived. Thus the impression of yellow, for example, arises from the stimulation of red and green sensitive nerve receptors.

This theory was challenged by Hering, who proposed an alternative, and in some ways more elegant, theory. The retina does indeed contain three types of nerve receptors, but each responds to two colours, not one. Each nerve receptor can be in one of two opposing states, depending on how it is stimulated, or be in an intermediate state. Thus the three nerve receptors represent the following *six* colours: red-green, yellow-blue, and black-white. Hering's theory, then, recognised a fourth primary colour, yellow. It also viewed white and black as fundamental sensations, not merely as the sum of all primary colours, or as the absence of colour, respectively.

The Young-Helmholtz theory explained negative after-images as follows: the nerve receptors in the eye that respond to the colour of the bright object soon become fatigued, more so than those receptors which respond to other colours, and which remain more active. Thus when the bright object is removed, and light of normal intensity re-enters the eye, the more active receptors create an image in a complementary colour to that of the original object.

Hering's theory, however, explained after-images in terms of two related but opposing processes in the nerve receptors. Light from the coloured object causes a chemical reaction leading to the breakdown, and eventual exhaustion, of a visual substance in

the nerve (dissimilation). After the stimulus is removed, the depletion of the visual substance allows the opposite reaction, a build-up of the visual substance, to predominate (assimilation). This results in an after-image of a complementary colour to that of the original object. When equilibrium is restored, neither colour is perceived. For example, looking at a yellow object in strong light for a few seconds causes dissimilation in the yellow-blue receptor and thus the perception of yellow. On looking away from the object, assimilation occurs, producing a blue after-image. Eventually equilibrium is restored and the after-image fades.

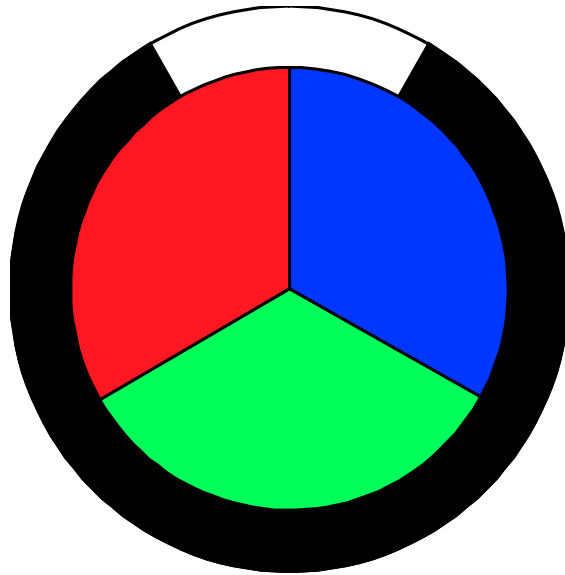
Moreover, the roles of the retina and the brain in our perception of colour were also hotly debated. Helmholtz emphasised mental inference or judgement in our colour sense, while Hering laid stress on the state of nerves in the retina. For example, a bright disc placed on a black background will produce a dark negative after-image against a lighter visual field. This after-image is surrounded by a border that is brighter than either the image or the field. Helmholtz explained this light border as an illusion of judgement caused by our tendency to mentally exaggerate clearly seen differences in brightness. However Hering countered that in the opposite case, where a black disc is viewed against a white background, no dark border is seen around the after-image, although the same conditions are present for an illusion of judgement.

The clash between these two scientists and their schools produced one of the great scientific controversies of the nineteenth century, one which lasted well into the 1920s. The shrewd and combative Hering, who had a dedicated band of

followers among his students, took the fight up to Helmholtz. Although a reluctant combatant, Helmholtz had a towering intellect and reputation, as well as a larger group of supporters, and held his ground.

Many experiments in colour contrast were performed, and devices such as the colour wheel invented, to decide the issue. Colour wheels served a variety of experimental purposes. Most are familiar with the fact that a disc made up of seven equal sectors, each showing a different colour of the spectrum, appears white when spun rapidly. This also occurs with a disc of three coloured sectors: red, green, and violet. Conversely, a white disc with certain black markings on it produces a faint colour spectrum when spun. A plausible theory of colour vision must explain these facts.

Colour wheels were used also to study colour blindness for clues to the nature of the colour sense. By varying the relative areas on a colour wheel occupied by the primary colours, and comparing the shade perceived when the wheel was spun rapidly with a standard grey produced by black and white sectors around the perimeter, the amount of each colour contributing to the viewer's perceptions could be measured (see Figure 1).



**Figure 1.** A colour wheel designed to test colour blindness. The coloured sectors can be slid over or under each other to vary the area of each colour exposed. (To see the effect of after-images, stare at the centre of the disc for about 30 seconds, then look at a white surface. The complimentary colour of each sector will appear.)

One problem for the Young-Helmholtz theory was that people who are red or green colour blind still report seeing yellow and blue. How can this occur if yellow results from the stimulation of red and green sensitive nerve receptors? The loss of either red or green perception should result in the loss of yellow also. Hering's concept of a separate yellow-blue process in the retina accommodated this fact. Helmholtz's school originally held that the inconsistency arose from a confusion of terms, and that the 'yellow' colour seen by red colour blind people was really a bright green. The Young-Helmholtz theory eventually was modified to cover the anomaly.

On most points, however, there was little to choose between the two theories. Indeed, the Helmholtz-Hering controversy is a

good example of how different scientific theories can often explain the same facts equally well, and present day ideas of colour vision draw on both theories. Recent 'zone' theories suppose that the three nerve types, or cones, in the retina send signals to a special area in the visual system of the brain, where six different nerve types magnify and compare them. Thus the modern version has features of both the Young-Helmholtz theory, and Hering's theory.

Despite the dazzling effect of sunlight shining through our eyelids, we rarely, if ever, perceive a pure undiluted colour. This is because light entering the eye stimulates not only the receptors most sensitive to that colour, but also other receptors, albeit to a lesser extent. Even light from a sheet of paper of a strong red colour, for example, also stimulates the receptors sensitive to blue and green. The net result is a slight whitish dilution. Something approaching a pure colour, however, can be seen in the following way.

Take a large sheet of paper of a strong primary colour; say, red. Now place on top a smaller square of paper of a strong complementary colour; say, green. Mark a dot in the centre of the green square and look at the dot fixedly under a bright light for about half a minute. This fatigues the nerves in the eye and brain that perceive the colour green, but only over the area equivalent to the green square.

Now remove the green square and look at the red sheet underneath. It will appear to contain a square of red colour much purer than the colour around it, since the diluting effect of green cannot now be sensed over that area of the retina. A variety of

different effects can be produced using paper of different colours (yellow and blue, or black and white, for example), and makes an interesting weekend diversion.

And next time you take a train in the early morning or late afternoon along a route where the trees grow close to the track, sit on the sunny side of the carriage, and close your eyes, for the psychedelic trip of a lifetime.

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