John Mollon: Colourful notions

Studies in scarlet

What is colour? What actually happens when we perceive colours? John Mollon, a lecturer in experimental psychology at the University of Cambridge, looks at some significant experiments in colour vision.

In Paris in the late spring of 1789, Gaspard Monge presented a curious experiment to the members of the Royal Academy. On the wall of a house that faced the windows of the Academy, he had fixed a sheet of red paper. He invited his fellow *académiciens* to look through a piece of red glass and consider the colour of the red paper. The result was as counter-intuitive in 1789 as it remains today.

To those *académiciens* gazing at it through the red glass, one might suppose that the red paper would have looked a peculiarly vivid red—a lurid vermilion hinting at the bloodletting that was soon to touch even the select company of the Academy. But, in fact, the red paper looked white. And white objects also looked white through the red glass. Monge pointed out that the paradox was particularly clear when a complex scene was observed. Conversely, if the red glass were mounted at the end of a narrow tube and the tube were pointed at the red paper so as to exclude all other objects from view, then the paradox disappeared and a vivid red was perceived. This last observation suggested that the phenomenon had its basis in our perception rather than in the physical nature of light.

Technologist and geometer, Monge was a man of unusual clarity of thought. His talents earned him high administrative office under the ancien régime and he was to continue to enjoy the favour of administrations as diverse as the Comité de Salut Public and the First Empire. He realised that the paradox of the red glass was not an isolated illusion. Rather it was a by-product of a fundamental property of our visual perception, a property that normally serves us well and that is today known as *colour constancy*: objects in our world appear to retain an almost constant hue despite large changes in the colour of the illumination. A sheet of white paper, for example, will continue to look white whether we examine it in the yellowish illumination of indoor tungsten light or under the bluish cast of northern daylight. The composition of the light actually reaching our eye from a particular object depends on (*a*) the proportions of different wavelengths in the illumination and (*b*) the permanent tendency of the object to reflect some wavelengths more than others; but our perceptions depend almost exclusively on the latter of these two factors. Our sensations of hue are more stable than we might expect them to be.

Cameras do not yet have the automatic correction that our visual system exhibits. Many readers will at some time have made the error of using 'daylight' film to photograph an indoor scene lit by tungsten light: when our photograph is returned from processing it is little more than a chiaroscuro study in yellows and browns, a very poor representation of what we saw. It was 'colour constancy' that deceived us into supposing that the use of outdoor film would make only a trivial difference.

How is this 'colour constancy' to be related to the standard theory of colour vision that we learnt at school? We learnt that our colour vision depends on the cone cells of our retina. There are, the theory went, three kinds of cone, with maximal sensitivities in different parts of the spectrum; and our colour perceptions depend on the ratios in which the different cones are stimulated. As far as it goes, this statement remains completely correct, and in recent years direct measurements have been made of the individual types of cone in the human retina; but the phenomenon of colour constancy shows that there is not a fixed relationship between a particular hue sensation and the proportions of different wavelengths in the light falling on a local retinal region. Monge made the point with extraordinary prescience:

> Ainsi les jugemens que nous portons sur les couleurs des objets ne paroissent pas dépendre uniquement de la nature absolue des rayons de lumière qui en font la peinture sur la rétine; ils peuvent être modifiés par les circonstances, et il est probable que nous sommes déterminés plutôt par la relation de quelques-unes des affections des rayons de lumière que par les affections elles-mêmes, considérées d'une manière absolue.

Whatever is the property of light that causes colour sensations (in 1789 Monge could not know what that property was), it is not the absolute value of this property that determines what hue we see.

Between 1850 and 1950, the phenomenon of colour constancy was repeatedly demonstrated—and its limitations were quantified. There indeed are limits to our ability to make stable judgments of colour. We all know the perils of choosing clothes or furnishing materials in fluorescent light: a green may turn brown when we later see it in tungsten light; and the green fabric that in the shop perfectly matched our sample of green carpet may no longer match when we get it home. Monge's experiment corresponds to the extreme case where the illumination itself is strongly coloured, being confined to a narrow band of wavelengths: to look through a red glass is equivalent to illuminating the scene only with red light. In this case, our visual system does its best and represents white objects correctly, but it has no way of distinguishing between a white object and a red one that reflects to our eye the same proportion of the incident red light. If we are to see good reds, there must be a variation, across the spatial array, in the ratios in which our different types of cone cell are stimulated.

Although colour constancy was well known to those who studied colour vision, it remained in 1958 an esoteric matter, given only a brief and qualitative mention in student textbooks,