
Comments

All's jazzy and unstable on the colour front: the impact of Gregory's pioneering paper on vision at equiluminance

Reading Richard Gregory's 1977 paper was a turning point in my scientific journey. No, I lie. I never read the article until much later. My research in 1977 was mostly about memory but in 1979 I attended a SIGGRAPH conference in Chicago where Richard presented his demonstrations of the loss of face recognition with an image having colour but no luminance contrast. The effect was magical and, inspired by Richard's flapping eyebrows, his big smile, and a laugh boasting of the fun of vision research, I abandoned my memory studies, bought all sorts of computer gear to capture the world on video and turn it into pure colour, stuck every imaginable image under the camera and within two days, with the help of Stuart Anstis and Olga Favreau, I was a vision scientist with material for a decade of papers. Thank you Richard, vision research is a fabulous, roller coaster ride of adventure. Memory research is, of course, very, very important, but really so slowly paced in comparison.

I followed Richard's lead in a number of ways, as so many have. First, I went on a pilgrimage to Yodabashi camera in Tokyo where we brought all the chroma flow filters we could manage. Richard had shown us how to use these in front of a slide projector to adjust the relative red to green luminance and find the treasured 'Critical Zone' of equal luminance, where all turned to jelly. We used them as well to look through, to test displays in pure colour contrast without having to adjust the display itself. This was all in Richard's spirit of instant demonstrations to explore effects as fast as we could think of them. Richard's 1977 paper and his demonstrations set a fire of interest in the properties of pure colour images for many of us. We explored the esthetically and scientifically delightful effects and rediscovered the pioneering Gestalt papers on perception in the 'Critical Zone' (Susanne Liebmann 1927, in West et al 1996) and the slowing of motion (Pleikart Stumpf 1911, in Todorović 1996). We found that many of the lost properties of colour stimuli were really a loss of visibility, not a loss of illusion or perspective or depth. If the test pattern scale was increased until it was clearly visible, all was good. Except for patterns that required linking of spatially separated elements, as Richard and Marge Livingstone and others pointed out: subjective figures, structure from motion of unconnected elements and other tasks requiring integration across colour boundaries failed, suggesting that pure colour boundaries always denote object boundaries across which no linking is allowed, whereas luminance boundaries, often caused by shadows, are a weekend pass to promiscuous surface combinations.

But Richard's 1977 article was mysteriously numbered '1'. Where was number 2? Was Richard channeling Marcel Duchamps? When Ted Adelson wondered if we could turn the whole world into pure colour, we had an opening. The resulting article (in 1992 in *Perception* with Priscilla Heard as third author) took the number 2 spot in this series and corrected Richard's unfortunate mixture of Latin and Greek roots, "Vision with equiluminant colour contrast: 2. A large-scale technique and observations". In the end we didn't make the whole world into pure colour but we did succeed with half of the world. The display required twenty thousand watts of yellow light (in its second version), a viewing aperture 8 m long and 2 m high covered with the world's biggest blue filter (through which to see the display area) and transparent reflector (from which the yellow light reflected, saturating the red and green cones à la George Wald, leaving only the pure blue-cone chromatic response), a rotating cube 2 m high, and, of course, real people walking through the resulting world of pure colour like bugs through blue molasses. It was, just as Richard promised, magic. And what of number 3? Who will send in the next in this series?

Patrick Cavanagh

Laboratoire Psychologie de la Perception, Université Paris Descartes, 45 rue des Saints Pères, 75006 Paris, France; also Department of Psychology, Harvard University, 33 Kirkland Street, Cambridge, MA 02138, USA; e-mail: patrick.cavanagh@parisdescartes.fr, patrick@wjh.harvard.edu

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Unlocked edges or contradictory edges?
Is there a master signal for edge locking?

In 1977, when Richard Gregory published his classic paper on equiluminance, it was conventional to model the visual system with two chromatic channels and one 'luminance' channel. The signals of the long- (L) and middle-wave (M) cones were summed in the putative luminance channel; and so this channel would be silent at an edge between surfaces of different colour but equal luminance. There was then no edge signal to corral the more diffuse signals carried by the chromatic channels. Gregory suggested that this loss of edge-locking led to the several curious features of vision at equiluminance.

The passage of 30 years has revealed a much larger number of parallel channels within the visual system. At least fifteen morphologically and functionally distinct types of ganglion cell are now known (Dacey et al 2003; Petrusca et al 2007), each extracting different combinations of cone signals. Each type tessellates almost the whole retina and has its own specific projections within the brain. These different cells vary vastly in the extent of their dendrites and thus, presumably, in the sizes of their receptive field.

On the one hand, this means that Gregory's question becomes a more general one: Is there one channel, carrying a spatially precise signal, that coordinates the signals representing other stimulus attributes, such as colour, flicker, and texture? On the other hand, it has become unlikely that all the types of chromatically non-opponent ganglion cell will look on in silence when an equiluminant red/green edge is swept across the receptor array (Mollon 1980). First, the non-chromatic cells may vary in their equiluminous points. Second, their responses may not be linear: transients signalled by different classes of cone may be transmitted without complete cancellation (see eg Cavanagh 1991; Mollon 1982). Certainly, the parasol cells—traditionally taken as the substrate for the luminance channel—give a frequency-doubled response to a red–green grating traversing their receptive field, and there is no relative intensity of the component colours at which the cell is silenced (Lee et al 1989). Only one special subset of equiluminous edges is invisible to parasol cells: these are tritan edges, those between chromaticities that give identical quantum catches in the L and M cones and differ only in the short-wave cone signal (Tansley and Boynton 1976).

The midget ganglion cells might be thought to be good candidates for carrying Gregory's master signal, since they have the smallest receptive fields. In the fovea, the midget cells—certainly the OFF type—draw their centre input from a single cone (Kolb and Marshak 2003) and so should offer the most precise local sign. Then, however, the issue becomes less straightforward. For the midget cells carry one of the main chromatic signals: at low spatial frequencies, they signal the ratio of L and M cone excitation. At high spatial frequencies, however, they respond to achromatic contrast, to local variations in luminance (Ingling and Martinez 1983; Lennie and D'Zmura 1988).