

Isolating colour vision mechanisms with hue substitution

from R. W. Bowen, J. Pokorny
and V. C. Smith

IN a review of new psychophysical techniques for isolating color-opponent neural mechanisms in human vision, J. D. Mollon¹ expresses the opinion that hue substitution² — a form of pure chromaticity modulation in which a chromatic field is briefly exchanged for a white of equal luminance — is not likely to activate selectively chromatic visual channels since it may generate receptor transients detectable by 'luminance' channels. At issue is whether data obtained with hue substitution reflects functional isolation of chromatic channels or not.

Studies of visual temporal processing with hue substitution stimuli have shown that visual latency³, two-pulse discrimination⁴ and duration thresholds⁵ follow a wavelength function resembling trichromatic saturation discrimination: slowest temporal response at 570 nm and brisker temporal responses at the spectral extremes, suggesting that the speed of the temporal response reflects activity in red-green and blue-yellow opponent-color mechanisms.⁶⁻⁸

Mollon is among those⁹⁻¹² who have suggested that the 'violet-sensitive' receptor does not contribute to luminance channels. If we accept this postulate, receptor transients in '565-nm' and '535-nm' cones cannot explain the wavelength dependence of hue substitution data. Consider hue substitution from white to an equiluminant spectral yellow or violet where these lights are collinear on a tritanopic isochromatic line. Such stimuli have equal quantal catch for the '565-nm' and '535-nm' receptors; therefore receptor transients cannot occur at stimulus presentation. Receptor transients predict only a 'tritanopic' wave-length dependence; in fact, such dependence has been found for two-pulse discrimination of brief chromatic stimuli.⁴ However, to ascribe this function to receptor transients demands the additional restraint that normalization of '565-nm' cone sensitivities is identical for both chromatic and luminance channels, a hypothesis difficult to reconcile with estimates of cone spectral sensitivities.^{10,11,13,14}

The issue is addressed directly in the case of duration thresholds⁵: just-detectable hue substitution stimuli are always perceived as chromatic, a phenomenon which cannot be mediated by receptor transients in luminance channels. Further, the wavelength

dependence of temporal processing in hue substitution is identical to that observed with an independent method of measuring chromatic channel function (discriminative reaction time).¹⁵ Finally, metacontrast masking¹⁶ and temporal brightness enhancement¹⁷ are abolished with hue substitution stimuli: these phenomena require physical luminance transients.

Transient receptor responses could in principle arise from pure chromaticity modulation and might be important in some situations (e.g., high luminance levels). However, there is strong evidence that chromatic neural mechanisms dominate observed effects on visual function in the hue substitution literature cited here. □

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J. D. Mollon replies

FOR validation of hue-substitution techniques, Bowen, Pokorny and Smith (their 2nd paragraph) turn primarily to the finding that measures such as reaction time vary with wavelength in hue-substitution experiments in the same way as does threshold in experiments on saturation discrimination. But this result is equally to be expected if the speed of response depends on the magnitude of transient responses generated by the 565-nm and 535-nm cones at the moment of substitution. For saturation depends ultimately on the degree to which the ratios of absorptions in different classes of cone differ from the ratios produced by white light. At a spectral locus close to 570 nm is a tritanopic neutral point (i.e. there is a yellowish monochromatic light that those who lack the short-wavelength receptors confuse with the white used in the experiment). I think we share a common theory of what this means: when this monochromatic light and the white are equated in luminance, the yellow produces exactly the same absorptions in the long- and middle-wavelength cones as

does the white. When the monochromatic light is substituted for the white there will be no change in the signals from these cones. Response to a substituted 570-nm field will be slow, either because it is mediated only by short-wavelength receptors or — if 570 nm does not exactly coincide with the tritanopic neutral point — because the residual transients in the long- and middle-wavelength cones are very small. As the wavelength of the substituted field increasingly diverges from 570 nm, the receptor transients must increase, since the ratio of absorption in the long-vs. the middle-wavelength cones must significantly differ from that produced by white light. (The short-wavelength tritanopic neutral point has not been examined in hue-substitution experiments.)

This argument does not require us to know the ratio of absorption that white light produces in the long- and middle-wavelength cones and there is no need to suppose that this ratio (or the ratio of any subsequent signals) is unity; we need allow only that these ratios remain constant (or, in practice, almost constant) across the substitution to 570 nm. Bowen, Pokorny and Smith's reference to 'normalization' (their 3rd paragraph) is obscure but I would diffidently suggest that they are confounding (a) the wavelength at which the two classes of cone deliver equal signals to a putative luminance channel and (b) the wavelength (c. 570 nm) that delivers the same ratio of signals as does white light. If wavelength (a) is indeed remote from (b), if, say, it is 500 nm, then the ratio of signals produced by white light must be very different from unity and large transients must occur at the passage to wavelength (a).

Reference 5 does not contain formal data on perceived hue, and, being concerned only with liminal stimuli, it cannot validate the entire hue-substitution technique. To say discriminative reaction time (ref. 15) depends on saturation is to say it depends on the extent to which the absorptions produced in the several classes of cones differ from those produced by white light; the magnitudes of receptor transients depend on these very differences. In the metacontrast experiment (ref. 16) the dependent variable was the degree of phenomenal darkening of the target; when the masking stimuli were 'equiluminant', receptor transients would be of opposite sign for different cone classes and hence the net effect on target brightness cannot be predicted. □

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