

Colour and Colorimetry Multidisciplinary Contributions

Vol. XVII A

Edited by Andrea Siniscalco



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Piazza C. Caneva, 4

20154 Milano

C.F. 97619430156

P.IVA: 09003610962

www.gruppodelcolore.it

e-mail: segreteria@gruppodelcolore.org

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Changes in the ‘conspicuity’ of coloured objects caused by coloured lenses and / or pre-receptor filters in the eye

John L Barbur^a, Benjamin EW Evans^a, Marisa Rodriguez-Carmona^a, Elisabetta Baldanzi^b, Regina Comparetto^b, Alessia Fava^b and Alessandro Farini^b

^aApplied Vision Research Centre, School of Health Sciences, Northampton Square, City, University of London, UK

^bCCNR-Istituto Nazionale di Ottica- Largo Enrico Fermi 6 50125 Firenze, Italy

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Background

When the visual world surrounding us is imaged on the retina by the optics of the eye, all available information is encoded in this image as spatial and temporal variations in intensity and / or spectral content. Of particular interest are edges and boundaries which help define objects and areas of interest. The perceived ‘conspicuity’ of coloured objects, a quantity that relates directly to visual performance, is often determined by a combination of colour and luminance contrast signals^{1 2}. When coloured objects are involved, the wavelength composition of the ambient light, the spectral absorption of any coloured filters external to the eye and / or pre-receptor filters within the eye can cause significant changes to luminance and colour contrast signals and hence to the visual appearance of the objects we see. The expression of variant cone-pigment genes in some subjects, large differences in L/M cone ratio or the absence of either L or M cones in red / green dichromats can produce large deviations in both luminance and colour contrast signals with inevitable consequences on visual performance³. The purpose of this study is to explore how changes in these parameters can enhance or diminish colour appearance and the conspicuity of coloured objects.

Methods

We examined how thresholds for detection of red / green (RG) and yellow-blue (YB) colour differences relate to cone contrasts when the state of chromatic adaptation of the retina corresponds to daylight (D₆₅). We used the CIE (x,y) chromaticity diagram to alter systematically the spectral composition of the test target so as to measure colour thresholds along chromatic displacement directions away from daylight chromaticity. We then used the normal, cone-pigments spectral responsivity functions and the spectral radiance of the stimulus to calculate the cone-contrasts needed at threshold when one can just discriminate RG and YB colour differences⁴. We also repeated the same experiments under conditions of chromatic adaptation over a range of retinal illuminances to establish how the level of photoreceptor excitation affects cone photoreceptor contrasts at threshold⁵. The invariance of cone contrasts at threshold made it possible to model chromatic discrimination sensitivity for different states of chromatic adaptation and retinal illuminance level. We were also able to model how coloured filters external to the eye as well as pre-receptor filters within the eye alter the state of chromatic adaptation of the retina and hence the measured RG and YB colour thresholds. The generic model developed in this investigation allows for the use of variant cone pigments, as expected in subjects with congenital colour deficiency, and the normal variation in L/M cone ratio. The model also computes subject-specific deviations from isoluminance as a result of variant L- and M-cone pigments, pre-receptor filters and unusual L/M cone ratios.

Results

The results show that with the exception of a narrow range of chromatic displacement directions that correspond to the tritan axis, colour detection thresholds measured in young, normal trichromats are mediated entirely by the RG chromatic mechanism. The corresponding, polarity sensitive, median, L- and M-cone contrasts at threshold in young subjects are $\sim 0.4\%$ and $\sim 0.8\%$, respectively. In comparison, the yellow-blue mechanism requires $\sim 7\%$ contrast to reach threshold⁴. The results also show that these cone contrasts at threshold remain invariant with cone excitation and follow Weber's law. An exception to this was observed when examining yellow-blue thresholds at lower light levels when S-cone contrast thresholds were found to increase more rapidly with decreasing S-cone excitation⁵.

External, blue-blocking filters cause systematic shifts in chromaticity, approximately along the daylight locus, with little or no effect on either RG or YB thresholds. More surprisingly, moderate absorption of short wavelength light by the macular pigment or / and the lens has equally small effect on colour thresholds under normal photopic levels of ambient illumination. This was, however, no longer the case under lower ambient illumination. The further decrease in S-cone excitation in older subjects caused by selective absorption of short-wavelength light by the macular pigment and the lens can cause significant loss of YB chromatic sensitivity, even when YB colour vision remains normal at higher ambient light levels. Not unexpectedly, when external coloured filters block large amounts of short wavelength light, the model predicts significant loss of YB chromatic sensitivity, matching well the experimental observations.

Conclusions

The cone contrasts needed to detect RG or YB colour signals at threshold remain invariant with cone excitation level and follow Weber's law. This is less so when examining S-cone thresholds which increase more rapidly with decreasing S-cone excitation at lower light levels. The generic model based on these findings predicts colour thresholds under conditions of chromatic adaptation which includes the effects of coloured filters external to the eye as well as pre-receptor filters within the eye. Blue-blocking filters employed in typical spectacle lenses used with daylight illumination cause only small shifts, approximately along the daylight locus, without any significant loss of either RG or YB chromatic sensitivity. Older subjects with high levels of macular pigment and stronger absorption of short wavelength light by the lens in the eye can experience reduced YB chromatic sensitivity, particularly at low ambient light levels. Other model predictions such as the enhanced or diminished conspicuity for coloured objects in subjects with congenital colour deficiency remain to be validated experimentally.

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