READING AND INDIVIDUAL PREFERENCES FOR ILLUMINANT CHROMATICITY

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A simple optical device enabled observers to vary the hue and saturation of light incident upon a page of text, without any associated change in luminance. Observers were instructed to select a light they found comfortable for reading. Many chose coloured light that was strongly saturated. Those with migraine tended to avoid reddish hues, as did children with reading difficulties.

INTRODUCTION

It is important to read "in a good light". But what constitutes "good light"? It is widely assumed that text should have a luminance of about 50 $cd.m^{-2}$ for optimum performance (1). It is also assumed, but on poorer evidence, that the best illuminant chromaticity is close to that of daylight. In this review it is shown that, for many individuals, white light is not the most comfortable for reading. The most comfortable colour varies considerably from one observer to another. The individual differences in preference may have a basis in pathology.

The studies were based on a simple but novel apparatus for mixing coloured light. The apparatus enabled hue angle (h_{uv}) to be varied independently of saturation (s_{uv}), at constant luminance.

AN INTUITIVE COLORIMETER

A wide variety of colours can be produced by mixing coloured lights in varying amounts, but it can be difficult and time consuming to mix the lights to match any particular shade of colour. Colours exist in three intuitive dimensions: *hue* (colour), *saturation* (depth of colour) and *brightness*. All three dimensions change when one of the lights is varied. The way in which the lights interact to produce a given colour is not obvious (for example, yellow is produced by mixing red and green light).

Burnham (2) overcame some of these difficulties with a device that enabled colour to be explored without a change in brightness, and Boynton and Nagy (3) developed Burnham's device in an apparatus that produced chromatic differences suitable for investigating colour blindness. Neither Burnham's apparatus nor that of Boynton and Nagy provided an observer with the opportunity of mixing colours in an intuitive manner, that is, by varying hue and saturation independently. We therefore developed a simple variant of the Burnham colorimeter that enabled an observer to change just one dimension at a time. For example, hue could be varied, keeping saturation and brightness nearly constant (4).

A collimated cylindrical beam of white light from a tungsten-halogen lamp (L in Figure 1) was reflected from a heat-transmissive mirror (M) and passed through a wheel (W) and into a box with matt white inner surfaces (S). The wheel was divided into three sectors, each covered with a different filter so as to transmit light of a different colour. One sector transmitted long-wavelength light (and was red in colour), one intermediate wavelengths (appearing green) and one short wavelengths (blue). The coloured light was mixed as it was reflected and scattered from the inner surfaces of the box. Text (T) was mounted on one surface of this box and viewed through an aperture. When the wheel was concentric with the beam, the three filters each passed a similar proportion of the light. The spectral characteristics of the filters were adjusted so that the mixed light then had a chromaticity similar to that of daylight (D65).

The wheel was free to translate (between positions W1 and W2) so that the beam could pass eccentrically through it. The filters then no longer had similar area. The colour of the mixed light became progressively deeper and deeper (increasingly saturated) as eccentricity increased. The wheel was also free to rotate. This changed the colour. Figure 2 gives a demonstration of the principle of the colorimeter.

In the Uniform Chromaticity Scale diagrams in Figure 3 are shown the chromaticities obtained by rotating the wheel and by varying its eccentricity in the beam. Rotating the wheel gave chromaticity coordinates with near-circular loci. Changing the eccentricity gave coordinates that varied along radial curves (4).

The colorimeter had several advantages for research: (i) colour (hue angle, h_{uv}) and depth of colour (saturation, s_{uv}) could be varied intuitively and nearly independently; (ii) the variation was continuous rather than discrete; (iii) no coloured surfaces were visible within the colorimeter, so it was unnecessary to consider the particular spectral power distribution of the illuminating light, and related colour constancy mechanisms.

REVIEW OF STUDIES

In the following studies two versions of the above colorimeter were used. In the initial studies the colorimeter had the gamut shown in Figure 3b and in later studies involving precision tinting, the gamut in Figure 3a. Observers viewed letters arranged to resemble text. The letters were chosen at random from all the letters of the alphabet, and arranged in strings randomly 1-8 letters in length, set in a single paragraph, laser printed in 12pt Times. The intention was to draw the observers' attention to the appearance of text by making it difficult to read. Observers were shown how to operate the colorimeter, and were instructed to find a light that made the text comfortable and clear to read. In all the studies the mean luminance was in the range 20 - 40 $cd.m^{-2}$ and remained constant.

In the first study (5), patients with migraine were compared with age- and sex-matched controls. They were asked to find a light that made the text comfortable, and one that was uncomfortable. Their choice of saturation was constrained, but they were free to vary hue angle. Figure 4 shows the chromaticities selected by the two groups as uncomfortable. The controls' choice of illuminant chromaticity showed an even distribution of hue angles. The patients tended to find reddish hues uncomfortable. There was no association between the hue angles chosen and the individuals' "favourite" colour, as previously expressed using the same apparatus when viewing an unpatterned surface.

In the second study (6), 26 children with reading difficulties took part. Most reported perceptual distortion of text. Most had migraine in the family. The children were free to vary both saturation and hue in an attempt to reduce the distortions. Figure 5a shows the chromaticities selected as eliminating the distortions. Note the tendency to avoid reddish hues.

A third study (7) was part of a placebo-controlled double-blind study of precision ophthalmic tinting for children with reading difficulty who reported perceptual distortions of text. The children underwent a thorough optometric assessment, and then selected a chromaticity that reduced the perceptual distortions of text, using methods that involved a combination of adjustment and two-alternative forced choice. The chromaticity coordinates are shown in Figure 5b. Despite the different gamut of the colorimeter, there is again a tendency to avoid reddish hues. The settings made by the few children who required refractive correction did not differ from the remainder. In general, the hue angles selected as improving the perception of text were complementary to those which exacerbated the distortions.

In a fourth (unpublished) study by Robert Milroy, 40 normal adult volunteers (from the Applied Psychology Unit subject panel) were examined using the above methods and asked to select an illuminant comfortable for reading. Eight exhibited a "strong" or "quite strong" preference for a those of daylight. There was a moderate but significant correlation (rs=0.348, p=0.028) between degree of preference for colour and degree of chosen saturation (s_{uv}).

In a fifth (unpublished) study by Anne Maclachlan, all the 7th year children in a secondary school were given identical pages of text printed on white paper and covered by theatre filters having chromaticities of similar saturation (s_{uv}) and evenly distributed hue angles (h_{uv}) when placed upon the page. The set also included three uncoloured pages, one covered by a neutral density filter, one a transparent plastic sheet, and one remaining uncovered. The children were asked to rank the pages of text in order of their comfort and clarity for reading: 81 of 145 children selected text covered by a coloured filter as clearest. There was a weak but significant tendency for the filter with the highest rank to have a hue complementary to that of the filter with the lowest rank. In other words, the selection of colour preference was not capricious.

DISCUSSION

In all the above studies, a surprisingly small number of subjects chose an illuminant chromaticity similar to that which they would conventionally experience. The preferences expressed were idiosyncratic but the group data depended on pathology, subjects with migraine or a family history of migraine tending to avoid reddish hues.

In the visual cortex are blob cells which differ from interblob cells in that they show colour opponency, and project to cells in more anterior areas that code for colour appearance (8). The blob cells have a high metabolic rate (9,10), and might be selectively affected by diseases such as migraine that compromise blood supply (11). Whatever the neurological basis for the preferences, it is clear that they are related to pathology. Migraine is a very common disorder (11) and its effects on vision may need to be accommodated by allowing individuals the opportunity of adjusting the colour of the illuminant under which they read.

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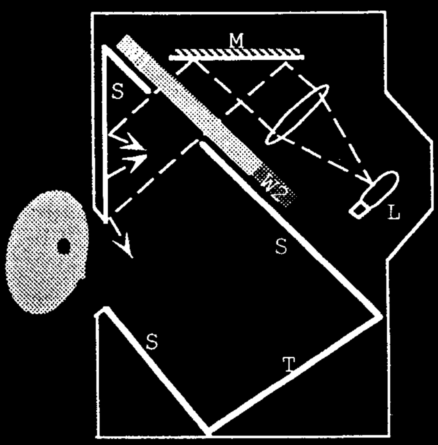

Figure 1. Cross section of colorimeter.

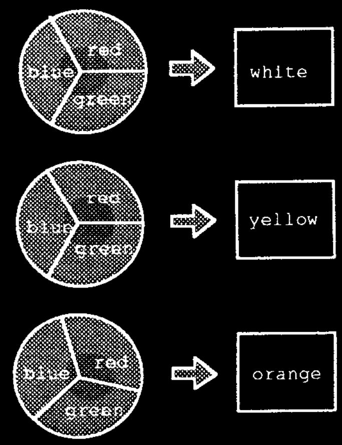

Figure 2. Principle of colorimeter.

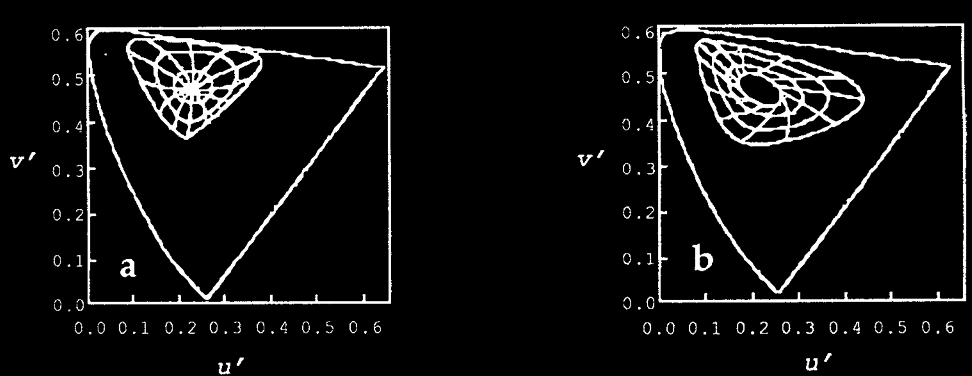

Figure 3. Loci of chromaticity coordinates obtained in the intuitive colorimeter when the wheel rotated (continuous curves) and varied in eccentricity (radial curves). The outermost curves give the limits of the gamut. (a) Final version. (b) Version used in preliminary studies.

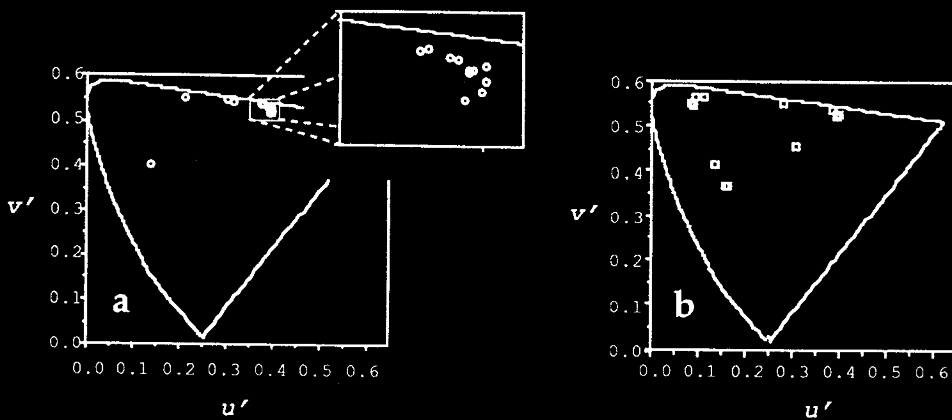

Figure 4. Chromaticity coordinates of an illuminant selected as maximally *un*comfortable for reading. (a) Migraineurs; (b) Controls.

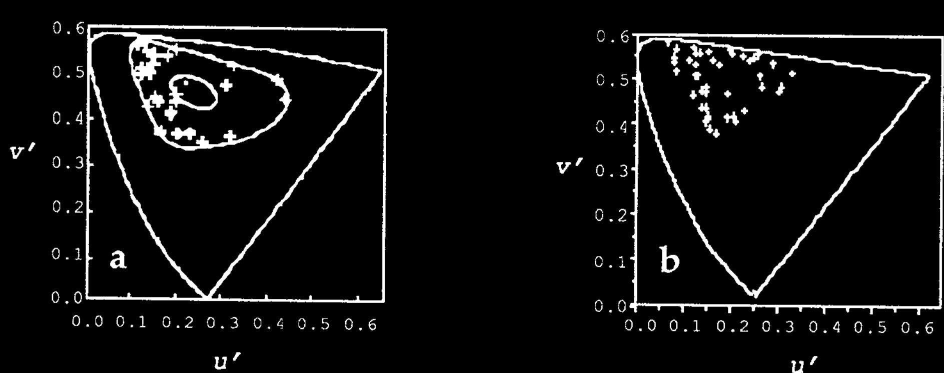

Figure 5. Chromaticities chosen by children with reading difficulty as *reducing* perceptual distortion of text. (a) Preliminary series; (b) Subsequent series.