ERGONOMIC CONSEQUENCES OF DICHROMACY

I Used To Be Color Blind

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Received 24 August 1999; accepted 20 October 1999

Abstract: The color deficient often seek visual aids to mitigate their color confusions. The most popular aids are red high-pass filters worn monocularly. Any benefit offered by such aids is limited to specific tasks and/or hue regions and may be negated by deleterious side- effects, including reduced luminance and visual acuity, induced visual distortions, altered stereopsis, and impaired depth perception. Different types of filters, taking into account advances in the molecular genetics of color vision and in coating technology, may offer greater advantages. © 2000 John Wiley & Sons, Inc. Col Res Appl, 26, S269–S272, 2001

Key words: color blindness; color vision; color-vision deficiency

INTRODUCTION

The world is filled with the color blind. In fact, in America alone, a region of high incidence (see Fig. 1), some 11,000,000 men and 900,000 women are estimated to be afflicted with some form of inherited color blindness. Very few of these individuals, however, are actually totally color blind. Most are better described as being color-vision deficient or partially color blind. Nevertheless, given the importance of color coding in our visual world, their color deficiency is severe enough to disadvantage them at certain tasks (e.g., picking fruit[4]) and to disqualify them from several professions. As early as 1853, standards for color vision were introduced for railroad transport (the Great Northern Railway Company, UK); in 1877, for maritime transport (the Swedish Royal Navy; the British Board of Trade); and in 1919, for aviation (The Aeronautical Commission of the International Civil Air Navigation Authority). For an excellent review of color vision standards and their practicability, see Ref. 5.

Given the high incidence and the occupational disadvantages of being color deficient, it comes as no surprise that many of the afflicted seek cures or visual aids to enable them to experience the full color sensations enjoyed by others. Or, as sung by Fred Astaire in the 1938 RKO film, "Carefree," they hope to see "things as they really are":

> *I used to be color blind*
> *But I met you and now I find*
> *There's green in the grass,*
> *There's gold in the moon,*
> *There's blue in the skies.*
> (From: "I Used To Be Color Blind,"
> by Irving Berlin, 1938)

Attempts to "cure" color blindness, or at least to evade failure on standard color-vision tests, reached a sort of climax during World War II, when military requirements for normal color vision were rigorously enforced.[6] Unfortunately, then as now, a medical cure is unattainable for the "physiologic deficiency," The most common forms of color blindness arise from alterations in the genes encoding the photopigment molecules: either genes are lost (due to intergenic nonhomologous recombination), rendered nonfunctional (due to missense or nonsense mutations or coding

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Contract grant sponsor: Deutsche Forschungsgemeinschaft; Contract grant number: SFB 430, Tp A6

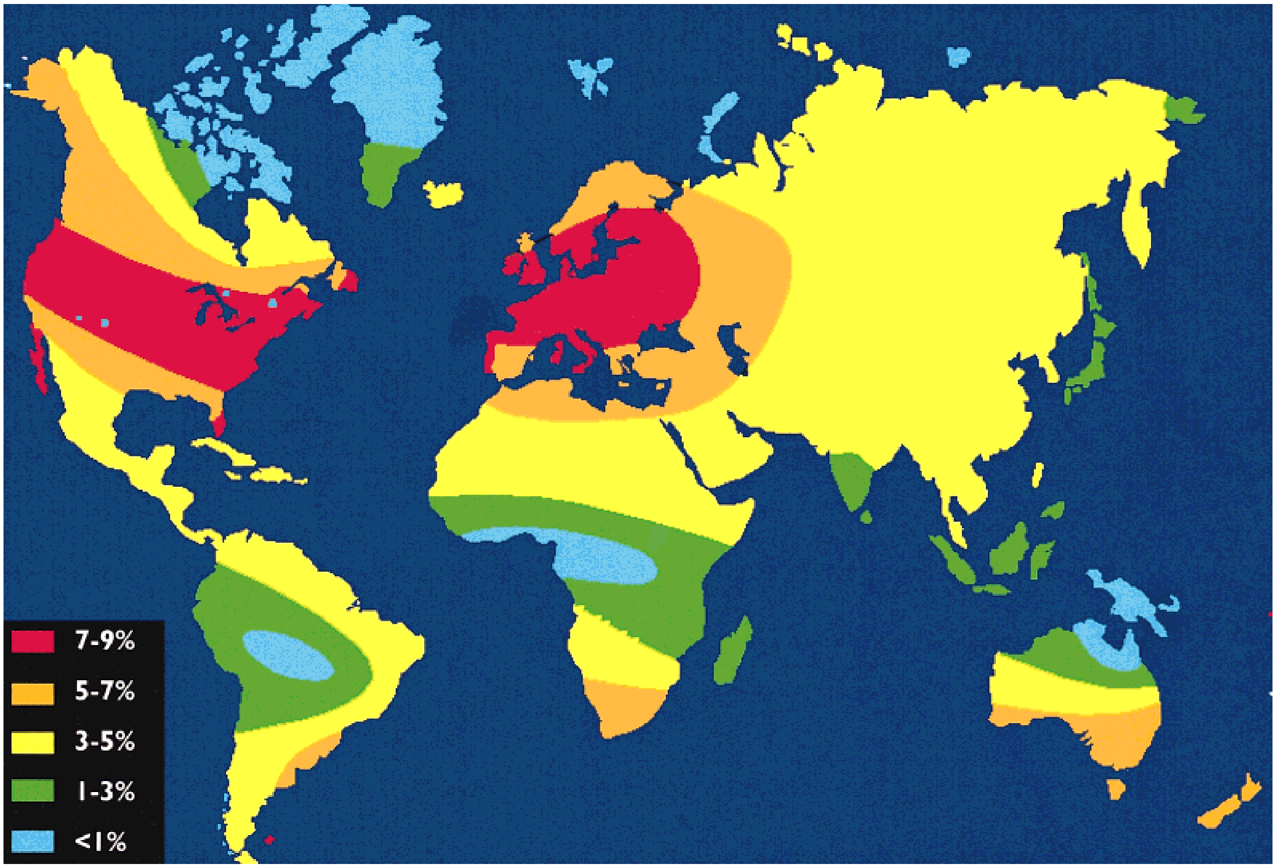

FIG. 1. The distribution of inherited color vision deficiencies in human males throughout the world. The map is only very roughly approximate. It is based in part on incidences reported by Cruz–Coke for surveys using pseudo-ischromatic color plates[1] (see Refs. 2 and 3). The frequencies in human females are roughly those of the males raised to a power of two. The much lower female frequencies arise, because the most common (red-green) color-vision deficiencies are inherited as X-chromosome-linked recessive traits.

sequence deletions), or altered (due to intragenic recombination between genes of different types of possibly point mutations) (for an introduction, see Ref. 3). All these deficiencies are unaffected by conventional medicine, training, or other therapy. However, certain visual aids may allow the color blind to make color discriminations of which they are otherwise incapable.

COLOR FILTERS

Almost beginning with the earliest accounts of "Persons who could not distinguish Colours,"[4] mountebanks and men of science have offered palliatives for color blindness. Some of the remedies or cures have been charlatanic: injecting extracts from cobra venom, marigolds, or lobsters. Some have been naive or misguided: coaching in colour naming,[7-9] prescribing multidoses of vitamins, warming one eye,[10] administrating electrical shocks.[11] But, others have been reasoned. Most prominent among the last are the use of color filters (for a thorough review of the subject, see Ref. 12).

The idea of color filters was initially proposed by Seebeck,[13] who prescribed them for successive brightness comparisons. By looking first through a red and then through a green filter, the color blind could differentiate red from green upon observing their relative brightening and darkening.

The idea was revived by Maxwell,[14] who fashioned a pair of spectacles for a color-blind observer, who could not distinguish red from green:

> *By furnishing Mr X. with a red and a green glass, which he could distinguish only by their shape, I enabled him to make judgements in previously doubtful cases of a colour with perfect certainty. I have since had a pair of spectacles constructed with one eye-glass red and the other green. These Mr X. intends to use for a length of time, and he hopes to acquire the habit of discriminating red from green tints by their different effects on the two eyes. Though he can never acquire our sensation of red, he may then discern for himself what things are red, and the mental process may become so familiar to him as to act unconsciously like a new sense.* (Maxwell, 1855)

Subsequently, it was adopted by others[15-19] and modified to assist the color deficient in performing specific tasks such as identifying traffic lights,[20-23] recognizing anatomical stains,[24] and selecting color-coded resistors.[25]

Cornsweet[26] extended the idea to human physiology. He reasoned that a potential increase in the dimension of color vision could be effected by differentially filtering the two eyes, to create an altered set of cone sensitivities in one eye that could interact binocularly with an independent set in the other. A sophisticated test of the principle in dichromatic eyes,[27] using a green bandpass and a red highpass filter, did in fact reveal a filter-aided increase in the dimensionality of color vision. However, the actual enhancement was dismissed as being virtually negligible in any practical situation.

COMMERCIAL PRODUCTS

Commercial firms have exploited the color filter idea. Several products are on offer and have attracted considerable media interest. The two best known of these are: (i) the X-Chrom lens, developed by Dr H. I. Zeltzer (Boston) and marketed by the X-Chrom Corporation (International Headquarters, 6 Beacon St., Boston MA)[28,29] and (ii) the ChromaGen system, developed by David Harris (Leeds, England) and promoted by The Corneal Laser Centre (Oak House, Clatterbridge Hospital, Bebington, Wirral *L63 4JY*, UK). Both are mainly designed to be fitted to just one eye (the idea originates with Mauthner[30,12]) though they are sometimes fitted to both eyes. A subtle difference is that the X-chrom contact lens is completely tinted, covering the iris as well as the pupil; whereas the ChromaGen lens is discretely colored only in the center, covering the pupil.

Usually the single lens is tinted red (the X-Chrom lens is essentially a highpass red filter similar to a Kodak Wratten 23A or 30[31-35]). But other tints are available (e.g., the diagnostic set of the ChromaGen lens comprises a range of 26 tints, which extend across the spectrum). Phenomenologically, when a red tinted filter is placed over one eye, there is a darkening in the green and blue regions of the spectrum. Reds are often reported as tending to fluoresce; greens as having a lustre.

Several clinical tests of the X-Chrom lens have been reported[31-33,36], but as-of-yet no independent test of the ChromaGen system has appeared (see, however, Ref. 37). Colour defectives wearing the X-Chrom lens are found: (i) to improve performance (to a pass score) on the Ishihara and the Dvorine pseudo-ischromatic plate tests, which rely on confusion colours and which are, therefore, compromised by the filtering effects of the lens; (ii) to improve performance slightly (but not to a pass score) on the AOHRR and the AOC plate tests; (iii) to improve performance on the Panel D-15; (iv) to worsen performance on the FM 100-Hue test; and (v) to worsen performance on practical tests such as map reading (using colour codes) and color recognition tasks such as the Farnsworth lantern, the CTT lantern, and the US Aviation signal green test (for a finely written summary of the clinical tests, see Ref. 34).

Any advantages appear to be more than offset by the disadvantages: Wearing a moderately dense red filter over one eye may be hazardous for driving and flying, especially at night, owing to reduced luminance, lowered visual acuity, and distortions of apparent velocity.[38] Further, it can introduce visual distortions (e.g., Pulfrich stereophenomena) and impair depth perception, especially for tasks that require fine stereoscopic acuity.[34]

CONCLUSIONS

A total cure for color blindness, as depicted in the song "I used to be color blind," is still a romantic fantasy. Nevertheless, a partial amelioration might be achieved by using color filters. Further improvements could depend upon three lines of research.

First, tests could be conducted with a variety of filter types — notch, band-pass, high-pass and low-pass filters — in conjuction with representative natural and man-made surfaces to see which ones work best.[39] Although red highpass (cut-off) filters seem to be the preferred commercial product, they actually offer very little, if any, improvement in practical situations (see Ref. 27). Greater improvement might be obtained from a different set of filters.

Second, tests could be conducted in dichromats with monocularly worn filters designed to distort the remaining X-linked photopigment to resemble the missing one in one of their two eyes.[27] However, such filters would have definite disadvantages for depth perception.

Third, tests could be conducted in anomalous trichromats with binocularly worn filters designed to provide a greater spectral separation between the anomalous and the remaining normal X-linked pigment to yield a better approximation to the normal cone spectral sensitivities. The recent identification of the spectral properties of the anomalous photopigments in man (for reviews, see Refs. 3 and 40) by molecular genetic,[41] psychophysical,[42] and electroretinographic techniques[43] should greatly aid the development of such filters.

ACKNOWLEDGMENTS

This work was supported by the Deutsche Forschungsgemeinschaft (SFB 430, Tp A6) and a Hermann and Lilly Schilling Professor awarded to LTS.

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