COMMUNICATIONS AND COMMENTS

An Opponent-Color Model for the Sanders–Wyszecki Helmholtz–Kohlrausch Effect Dataset

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INTRODUCTION

Chromatic test fields viewed against a neutral background with the same luminosity or luminous reflectance are invariable seen as brighter/lighter than the background. This effect is known as the Helmholtz–Kohlrausch Effect (HKE).[1] It has been extensively investigated in the past by Wyszecki and coworkers,[2,3] and by Evans.[4] More recently, much work on the effect has been done by Nayatani and coworkers.[5-7] They have discovered that the magnitude of the effect depends on the experimental conditions under which the effect is evaluated. It is smaller, if the chromatic field is held constant and the achromatic brightness/lightness can be adjusted (VAC effect) than vice versa (VCC effect). Nayatani has proposed a complex analytical formula to describe the effect, in which the ratio between the measured luminance and the perceived brightness is calculated from an analytically constructed spectral saturation discrimination function using CIELUV saturation, and a factor that adjusts the value based on the adapting luminance. Nayatani reported a correlation for the Sanders–Wyszecki dataset between calculated and experimental brightness ratio of 0.89. Most recently, Nayatani has proposed a colorimetric explanation, in which the saturation discrimination function is synthesized in three sections from the chromatic vector, the greenness vector, and the redness vector, respectively.

It was of interest to optimally fit an opponent-color model to a set of data to determine to what extent a purely colorimetric model could describe experimental HKE data. For this purpose the Sanders–Wyszecki dataset was selected.

SANDERS–WYSZECKI HKE DATA

In 1963, Sanders and Wyszecki reported an experiment in which 20 observers made direct heterochromatic brightness matches of 95 test stimuli against a "white" reference stimulus of fixed chromaticity, using a binocular colorimeter.[2] The test stimuli in one-half of the visual field were kept constant, and the observer adjusted the intensity of the reference stimulus until equality of brightness was perceived between the two semi-fields. The experimental method follows the VAC paradigm. The two luminances were compared using the 10° observer data and the result was given as the ratio between the two luminances. Sanders and Wyszecki described the results of their experiment with an analytical formula based on the chromaticity coordinates of the test stimuli. In a modified version, this formula is used in the OSA-UCS color-order system.

FITTING A FORMULA

In the present effort, a simple colorimetric formula was optimized to the experimental data to minimize the difference between the calculated and the experimental brightness ratios. The formula is based on simple subtractive opponent-color vectors calculated from

$$a = 2.393\ (X - Y) \text{ and } b = \ (Y - Z), \tag{1}$$

where X, Y, and Z are tristimulus values calculated from the provided chromaticity coordinates and a luminance value of 20. The tristimulus values were normalized for the chromaticity of the reference. The X values were adjusted according to the following formula:

$$X_{ad} = 1.05\ X - 0.05\ Z, \tag{2}$$

where X_{ad} is the adjusted X tristimulus value. Linear chromatic vectors were added to the reference luminance values so that the ratio between the calculated value and the reference value matched as closely as possible the experimental ratio. Assuming that the HKE is due to the effect of adding a portion of the chromatic vector to the luminosity to

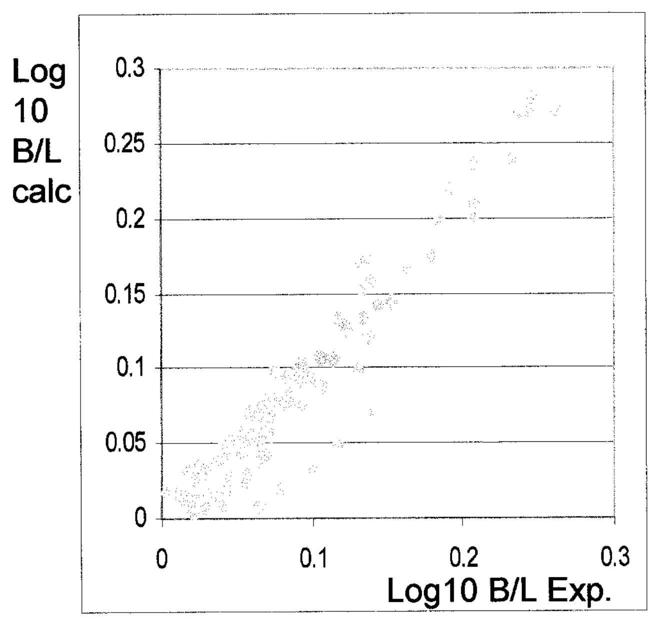

FIG. 1. Scatter diagram of the calculated vs. the experimental B/L ratios of the Sanders–Wyszecki data.

result in the apparent brightness, adjustments in the chromatic vectors were made only on a quadrant basis.

The following formula was found to be optimal:

$$Y_A = Y_C + 0.23\ |a| \quad \text{if } b \text{ is positive,}$$

$$Y_A = Y_C + 0.20\ (a^2 + b^2)^{1/2} \quad \text{if } a \text{ is negative and } b \text{ is negative,}$$

$$Y_A = Y_C + 0.30\ |a| \quad \text{if } a \text{ is positive and } b \text{ is negative,} \tag{3}$$

where Y_A is the luminance of the reference having the same apparent brightness as the chromatic stimulus and Y_C is the luminance of the chromatic stimulus. The correlation coefficient between the log10 of the calculated and experimental ratios (as used by Nayatani) is 0.95. The scatter diagram is shown in Fig. 1. The only group of colors where the correlation is relatively poor is that of dominant wavelength 450 nm. If it is removed, the correlation coefficient increases to 0.97. Reduced correlation was obtained when using cube roots or any other power applied to the chromatic vectors. Correlation was also reduced when applying vectors at the neurophysiologically supported α, β level of color processing.[8] When using the Sanders–Wyszecki analytical formula based on chromaticity coordinates, the correlation coefficient is 0.92.

An optimized formula fitted to the Wyszecki tile HKE data[3] requires not only a higher added amount of chromatic vector (explainable on basis of the adaptation conditions) but also a somewhat different vector composition.

DISCUSSION

This result supports the idea that the HKE is caused by the operation of the opponent-color system. The output of opponent-color cells appears to contain a component that is, depending on the circumstances, perceived as brightness. In the transition to opponent-color signals, cone responses are generally believed to be undergoing a nonlinear transformation. It is interesting to note that based on these calculations the nonlinear transformation appears to occur after the opponent color system makes its contribution to perceived brightness.

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Euclidean Color Spaces with Logarithmic Compression: A Comment on Knud Thomsen's Note

I have a comment concerning the NOTE by Knud Thomsen on pages 64–65 of the first issue of *Color Research and Application* (volume 25) of the year 2000.

In the Note by Knud Thomsen, "A Euclidean Color Space in High Agreement with the CIE94 Color Difference Formula," the author introduce a logarithmic transformation of the CIE C* coordinates as an approximation to the hyperbolic weights of the CIE94 system. He presents this as a new approach to generating a more nearly uniform color space with a color difference metric that is nearly identical to CIE94. Such a transform has already been presented twice in the literature[1,2] and once in a new national standard.[3] It seems that the reviewer and the author both failed to find these somewhat obscure though recent references in the literature. It is interesting to note that the author here arrived at a very similar form to that of Ref. 1, while following a very different path to get there.

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2. Rohner E, Rich DC. Eine angenähert gleichförmige Metrik für industrielle Farbtoleranzen von Körperfarben. Die Farbe, 1996;42:207–220.
3. DIN 6176 Farbemetrik. This standard documents the new formula DIN99 (1999).

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