Are Chroma-Tolerances Dependent on Hue?

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Abstract

CIE94 is the latest recommendation on color-difference formulas made by the International Commission on Illumination. The strongest trend incorporated by this formula is a linear dependence for chroma-tolerances with chroma. A potential hue-angle dependence for chroma-tolerances, as proposed by Dr. Kim at the University of Leeds, could have been masked in previous experiments. We have tested this potential hue-angle dependence through a new experiment, where chroma-tolerances have been measured with a CRT device by 12 observers, using a constant level of L*= 40, two chroma values of C*=20 and 40, and 12 hue-angles at 30° intervals for each one of these chroma values. Our results support the existence of a hue-angle dependence for chroma-tolerances, and agree with Kim's model proposed for this dependence. However, from the experimental data set employed by the CIE TC1-47 for the development of the forthcoming CIEDE2000 formula, we have found that the hue-angle dependence for chroma-tolerances for reported here is not a consistent effect.

Introduction

In the predicting of the magnitude of visually perceived color-differences, it is generally accepted[1] that a significant improvement upon the CIE 1976 recommended formulas (CIELAB and CIELUV) has been achieved by the so-called "advanced color-difference formulas" (e.g. JPC7, CMC, BFD, CIE94, CIEDE2000)[2]. The common structure for all these formulas is given by the next equation:

$$\Delta E=\left[\left(\frac{\Delta L^*}{K_L W_L}\right)^2+\left(\frac{\Delta C^*}{K_C W_C}\right)^2+\left(\frac{\Delta H^*}{K_H W_H}\right)^2+ + R_T\left(\frac{\Delta C^*}{K_C W_C}\right)^2\left(\frac{\Delta H^*}{K_H W_H}\right)^2\right]^{\frac{1}{2}} \quad (1)$$

where ΔL^* ΔC^* and ΔH^* are computed from CIELAB, the weighting functions are designated by W, the parametric factors are designated by K, and the factor R_T is only non-null for the BFD formula.

It should be noted that while the W_H functions proposed by JPC79, CMC and BFD include a dependence of both chroma and hue, the W_C functions proposed by all these formulas are dependent only on chroma. That is, while CIELAB hue-differences are dependent on hue for these three formulas (but not for CIE94), CIELAB chroma-differences are not considered dependent on hue. In any case, we might also assume a dependence of W_C with hue, and, in fact, such a relationship has been recently suggested by the LCD[3] color-difference formula as follows:

$$W_C=\left(1+0.045\cdot C^*\right)\cdot W_{CH} \quad (2)$$

where

$$W_{CH}=1+0.07\sin(h°)-0.16\cos(2h°+250)- -0.05\cos(3h°)-0.03\cos(4h°) \quad (3)$$

unless $C^*_{stand}\leq 4$ when $W_{CH}=1$.

Bearing in mind that the dependence of W_C with chroma is the strongest and most robust correction to CIELAB incorporated by all advanced color-difference formulas, we might also conclude that perhaps the dependence of W_C with hue is a minor effect, which has been masked by the strong dependence on chroma during the development of recent color-difference formulas.

From the previous arguments, we deem it useful to perform a new experiment to test the potential dependence of W_C with hue, as suggested by the LCD formula. Chroma suprathreshold color-difference tolerances were estimated by 12 observers using CRT generated stimuli.

Experimental Device and Procedure

A Samsung SyncMatester 900 p monitor 19" full square type, was used in these experiments. The monitor was controlled by video card GD5426/28 and Pentium II CPU. The monitor was calibrated and characterized according to previous works in our laboratory.[4]

Color measurements for calibration, were made by a PhotoResearch spectroradiometer SpectraScan PR-704. The calibration was repeated several times during the time the experimental period, revealing differences smaller than the instrument sensitivity.

The spectroradiometer was positioned at the place occupied by the real observers during the experiments and focused at the center of the samples.

The most luminous color producible on the monitor is x=0.312; y=0.329; Y=86.9 cd/m^2 for CIE 1964 and 10° observer. The colors used in the experiment were calculated in CIELAB relative to this white point Our work was made at 24 standard centers of C* = 20 ,40 and L* = 40 with h_{ab} = 0°, 30°, 60°, 90°, 120°, 150°, 180°, 210°, 240°, 270°, 300° and 330°.

The chroma tolerances were estimated following the experimental configuration designated as "relative experiment" by Montag et al[5]. The configuration for this experiment is show in figure 1.

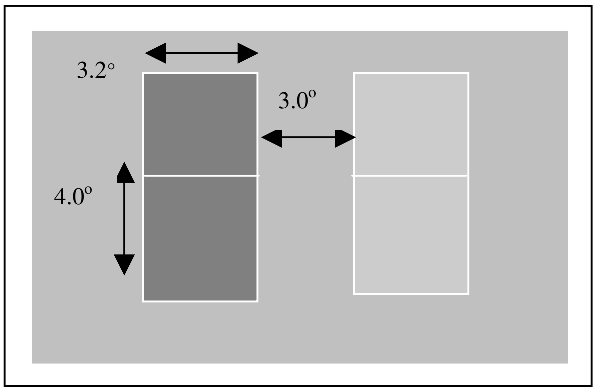

Figure 1

An achromatic test pair next to an anchor pair were presented on a background with luminance L* = 49.8, and coordinates a* = 0.47, b* = 1.12, surrounded by a field with the same coordinates as those of the experimental reference white. The test pairs were presented on the right. A one-pixel black line, subtending 0.02°, surrounded each of the anchor pair and test pair colors with a one-pixel black line between the members of each pair. The stimuli were presented in dark room.

The ΔE^*_{ab} of the anchor pairs was 1.56 (Top L* = 40.3, a*=1.46, b*=1.05 and bottom L* = 40.1, a*=2.13, b*=2.50) with ΔH^*_{ab} = 0.44, ΔC^*_{ab} = 1.48, ΔL* = 0.2), the chroma difference in the anchor pair being 95%, at least, of the total color difference.

The RGB values stimuli were determined from the calibration by a program developed in Borland C^{++} in a range around each color center varying only in CIELAB chroma by ± 4 or 5 units (depending on the color center) in steps of 0.1. These RGB values were then quantized in 8-bits, and the CIELAB values due to quantization, the 80 to 100 target values would be reduced to about 30 to 40 values (depending on the color center).

For the centers corresponding to C* = 40 and h_{ab} = 180°, 210° and 240° the number of stimuli obtained around these centers was insufficient, and, therefore, although they were calculated, they were not considered for our study.

Twelve color-normal subjects, ranging from 23 to 42 years of age, took part in the experiment. At the beginning of each session, a test pair composed by the analysed center and a stimulus with the same RGB values was presented next to the anchor pair.

The observer task was to use the computer mouse to vary the chroma of the stimulus in order to set up a color difference considered just larger than that of the anchor pair. This was done for stimuli presenting a higher (+ΔC*) and a lower chroma (-ΔC*) than that of the center. The positions of the center and the stimulus in the test pair (up or down in the test pair) were random. Before each experimental session, the observer adapted to darkness during 2 minutes.

Results

Figures 2 and 3 show for C* = 20 y C* = 40, respectively, the chroma tolerances found for the 12 hue angles and Kim's[3] work predictions. In the figures

$$\Delta C^* = \left(\left(+\Delta C^*\right) + \left(-\Delta C^*\right)\right)/2 \qquad (4)$$

The hue angle tolerances ΔH* with the hue angles variations are also included, according to CIE Technical Committee 1-47[6], as well as CIE94 predictions.

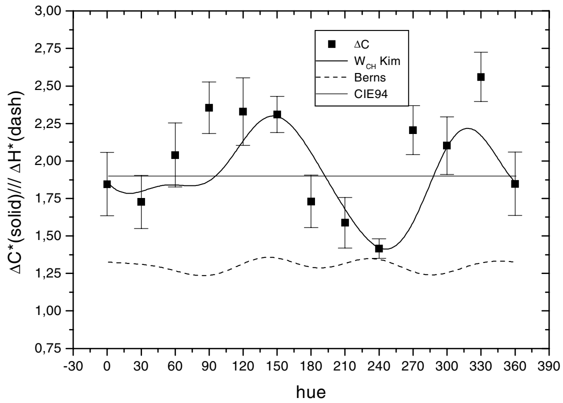

Figure 2

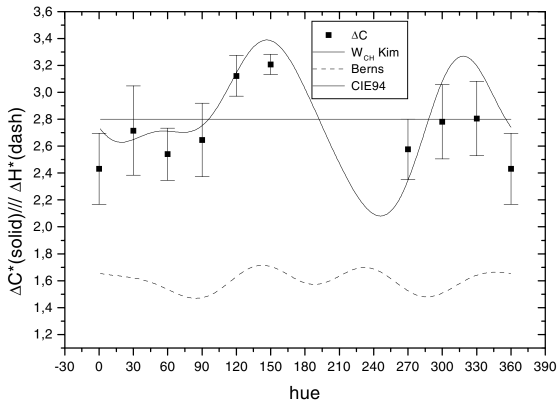

Figure 3

These figures show that there is apparently an important dependence of chroma tolerance on hue angle. Thus, for C* = 20, chroma tolerance changes in chroma from 2.354 for h_{ab} = 90° up to 1.447 for h_{ab} = 240°, with a 1.63 factor. These results appear to agree strongly with the model proposed by Kim[3], which shows that chroma tolerance (for C* = 20) changes with hue angle from 2.3 (h_{ab} = 146°) up to 1.4 (h_{ab} = 245 °), with a 1.64 factor.

This variation is much stronger than that of the hue tolerance ΔH* with the hue angle[6], which for C* = 20 (figure 2) ranges between 1.23 (h_{ab} = 84°) and 1.36 (h_{ab}=141°) with a 1.10 factor.

It should be mentioned that the maximum ΔC* appears in our results at h_{ab} = 90°, as contrasted with values close to 150° in Kim's[3] results. Nevertheless, as we can see in figure 2, values corresponding to 90° and 150°

angles are very similar (2.354 and 2.318, respectively), whereas the minimum values are coincidental.

When we consider the results corresponding to C* = 40, a variation of chroma with hue angle appears too, as we expected, now with a 1.32 factor and variations from 3,207 for h_{ab} = 150° up to 2.432 for h_{ab} = 0°. This variation is higher than that of hue tolerance ΔH* with hue angle, which ranges between 1.47 (h_{ab} = 84°) and 1.72 (h_{ab} = 141°) for C* = 40 (figure 3), with a 1.17 factor.

Difference found in factor value in relation to results corresponding to C* = 20 and to Kim's[3] model, may be owed to the fact that we did not have results available in interval (150°-270°), where minimum values appear for Kim's[3] model and for our results corresponding to C*=20. However, just as in the proposed model, maximum values appeared close to 145° hue angle, although now lower, being 3.201 in our results and 4.6 for this model.

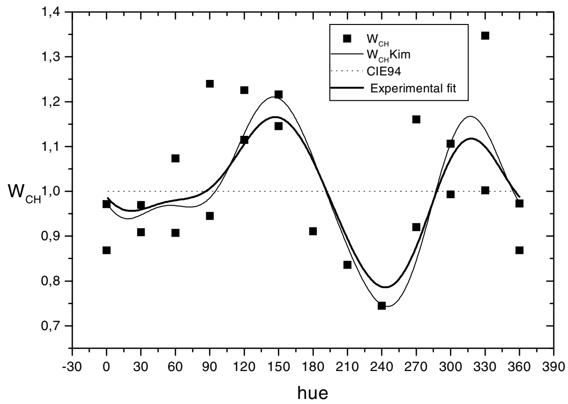

Figure 4

Because our results at first appeared to agree strongly with the model proposed by Kim[3], we tried to fit W_{CH} in the same way.

Figure 4 shows experimental data (ΔC*/(1 + 0.045*20) and ΔC*/(1 + 0.045*40)) next to a graph corresponding to W_{CH}, obtained starting from a statistical fit made with our results and given by the equation:

$$W_{CH} = 1 + 0.07\sin(h°) - 0.132\cos(2h° + 250) -$$

$$-0.04\cos(3h°) - 0.015\cos(4h°) \qquad (5)$$

where h° is hue angle expressed in degrees.

To complete our work, we deemed it useful to perform the same analysis with other experimental datasets. Recently, it became possible to use a dataset called COM[7], composed by different datasets compiled by the CIE for deriving or testing colour difference equations, and employed for developing the new CIEDE2000 formula.[6] From these results we chose for our study only stimuli pairs having a chroma difference of 90% or higher of the total color difference between them (ΔC*≥0.9·ΔE). After this selection, the number of pair diminished to 437, or 1045 if we take into account the weighting factor.[7]

Figure 5 shows, only for this pair selection, the chroma tolerance normalized to chroma by (1 + 0.045·C*) versus the hue angle.

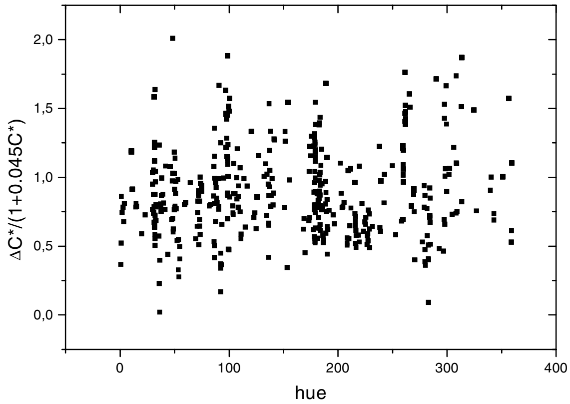

Figure 5

From the experimental dataset used by the CIE TC1-47 for developing the forthcoming CIEDE2000 formula, we have found that the hue-angle dependence for chroma-tolerances reported here was not a consistent effect.

Conclusions

In this work we have determined chroma tolerances (ΔC*) for 24 centers with values C* = 20 and 40, L*= 40 and 12 hue angles, in 30° intervals. The experimental results seem to show a dependence on chroma tolerance with hue angle, giving higher factors than those which appear for hue tolerance with the hue angle proposed by Berns[6]. On the other hand, our results agree with the model proposed by Kim[3], having similar factors.

According to our results normalized to chroma by (1+0.045·C*), we found a fit equation given by

$$W_{CH} = 1 + 0.07\sin(h°) - 0.132\cos(2h° + 250) -$$

$$-0.04\cos(3h°) - 0.015\cos(4h°) \qquad (5)$$

If we include the COM dataset in our study, selecting only the pairs having a color difference mainly in chroma (ΔC* ≥ 0.9·ΔE*), we do not clearly find this dependence.

The fact that for our experimental results we had found a clear dependence on chroma tolerance with the hue angle (for low and middle chromas) and this dependence had not appeared so clearly for the COM dataset, leaves us with the need to obtain new experimental datasets for chroma tolerances of C* values higher than the employed ones.

Acknowledgements

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Biography

María del Mar Pérez is Ph. D. in Physics (Optics) in 1994 (University of Granada, Spain). Associate Professor at the Optics Department at the University of Granada. She has published more than 20 articles on Colorimetry and Applied Colorimetry in several journals (Applied Optics, Color Research and Application, Soil Science, JAOSC, Die Farbe…). Currently she is heading International Research Projects sponsored by the Spanish Agency of International Cooperation (AECI) and the Spanish Science and Technology Ministry.