Chroma Scaling and Crispening

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Abstract

A chroma scaling psychophysics experiment was conducted using a CRT in a dark surround. The experiment consisted of constant hue and lightness IPT step ramps on a uniform background. Each hue step ramp was displayed on an achromatic, a medium and a high chroma background. The results clearly show that chroma scaling is dependent on the chroma of the background. For the medium chroma backgrounds a modest crispening effect is evident. The results also show that chroma scaling on achromatic and high chroma backgrounds differ considerably. The data for the achromatic backgrounds are used to compare C*, C and C_F chroma metrics. Additional comparisons using several of the phases of the LUTCHI data demonstrate that C and C_F are clearly better than C* and that C has an intercept of roughly 0.1 for a linear fit between normalized scale and metric data. In comparison, C_F provides a good fit to the chroma scaling data and an intercept closer to 0.

Introduction

Chroma, along with lightness and hue, is one of the fundamental perceptual attributes for color and can be defined as "the colorfulness of an area judged in proportion to the brightness of a similarly illuminated area that appears white or highly transmitting."[1] The CIECAM97s color appearance model provides a chroma attribute, C, for quantifying the chroma of a given color.[2] It has been noted that this scale appears to expand the chroma significantly for near neutral colors. This expansion is relative to the Munsell Book of Color[3] and CIELAB.[4]

It has been hypothesized that this difference is due to differences in viewing conditions between the LUTCHI[5] data set and the Munsell Book of Color[6]. The author hypothesized that perhaps the scaling on a gray background might introduce chroma crispening for the near neutrals. It has also been hypothesized that the differences may be a result of whether the scale is constructed from small color-difference data, large color-difference data or Munsell data.[7] The question of chroma scaling has been an ongoing topic of discussion for CIE TC8-01.[8] The author has also previously used simultaneous equisection to explore lightness scaling and crispening.[9] Therefore a simultaneous equisection or chroma partitioning experiment was conducted to provide additional data for assessing the CIECAM97s chroma scale.

In addition to C, Fairchild has proposed a modified CIECAM97s chroma scaling for consideration.[10] This chroma scale, notated C_F in this paper is simply C raised to the power of 1.41 and multiplied by 0.2129 or in terms of the full equation for computing C:

$$C_F = 0.7487 s^{0.973} \left(\frac{J}{100} \right)^{0.945n} \left(1.64 - 0.29^{n} \right)^{1.41} \quad (1)$$

The multiplicative scaling factor and exponent were derived by optimizing a linear fit to the Munsell chroma data. This chroma scale will be compared to both C* and C in the discussion section.

Some of the phases of the LUTCHI magnitude estimation experiments were conducted using stimuli on a uniform gray background. This scaling on gray could result in crispening for the near neutral colors. Crispening has been defined as "the increase in perceived magnitude of color differences when the background is similar in color to the stimuli themselves".[11] An example of chroma crispening can be seen when two low chroma colors are shown on a gray and then on a highly chromatic background. The computed chroma difference is the same for both backgrounds but the perceived chroma difference is clearly larger on the gray background. Stated another way "chroma differences are perceived best if the chroma of the surround is between that of the samples compared".[12] It may also be useful to consider crispening as occurring for a single stimulus but it is the variation of a perceptual attribute as it approaches a match with the background. There are also lateral adaptation or simultaneous contrast effects that should be considered but in this case crispening will be used as specifically referring to the increase or decrease in chroma relative to the chroma of the background. Previous research[13] has shown that the chroma of a stimulus is affected by the chroma of the background. However, it is useful to further investigate this topic and explore possible implications for the CIECAM97s chroma scale.

Methodology

A simultaneous equisection experiment was performed to quickly gather chroma-scaling data for six different hue angles. This experiment was conducted using a D65 approximately sRGB[14] CRT in a dark surround. A Tcl/Tk program was used to provide a user interface in which observers could increase and decrease the chroma of six test patches arranged between achromatic and high chroma anchors. An example screen from the experiment is shown in Figure 1. The achromatic anchor is furthest to the left and the high chroma anchor is furthest to the right.

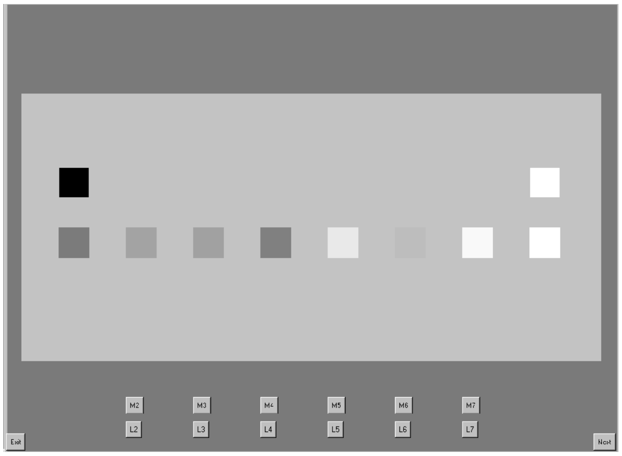

Figure 1. Example screen for the chroma partitioning experiment.

White point and black point anchors were also provided and three different backgrounds were used for each of the hue angles. A middle-gray background surrounded these backgrounds and provided a constant middle gray reference region for observers. The observers viewed the screen from roughly 60 cm. This resulted in test patches subtending about 2 degrees with approximate 2-degree separation between the patches. The chroma of the intermediate patches was randomized, as was the order of background presentation. Six color normal observers participated in the experiment.

The chroma increment and decrement values were computed by uniformly subdividing the chroma range for the CRT primaries and secondaries in the IPT space.[15,16] Thirty-two increments were pre-computed for each of the hue angles. These increments connected the primary or secondary with the corresponding zero chroma IPT value. This resulted in different lightness anchors for each of the hue angles. The corresponding lightness value was also used as the achromatic background for that hue angle. The intermediate chroma background was taken as roughly two-thirds of the maximum chroma for that hue angle as computed using IPT. The IPT space was used due to its hue constancy and as an independent color space not derived from the LUTCHI or Munsell data sets. The hue angle specific achromatic anchor and background is a compromise between confounding lightness and chroma differences and a constant achromatic anchor for all hue angles.

Results

The averaged chroma scaling results for four of the hue angles are shown in Figures 2 through 5. The x-axis is the normalized measured IPT chroma value and the y-axis is the normalized chroma scale or partition. Note that the measured IPT chroma value can be converted to any given color space but it is used here to separate the analysis of basic trends from the comparison of chroma scales used and proposed for use with CIECAM97s. The three backgrounds are shown for each plot where the achromatic background is shown as a solid line, the medium chroma background is shown as a dotted line and the high chroma background is a solid line with a square symbol.

The results shown in Figures 2 through 5 clearly show that the chroma of the background affects the chroma of a stimulus. The high chroma background tends to expand the chroma such that a smaller chroma difference for a high chroma color is more evident. The medium chroma background falls on or between these two curves. Qualitatively, the sigmoidal inflection appears less defined than that seen for lightness crispening. This may be due in part to the fact that many observers reported that chroma partitioning was a more difficult task than lightness partitioning.

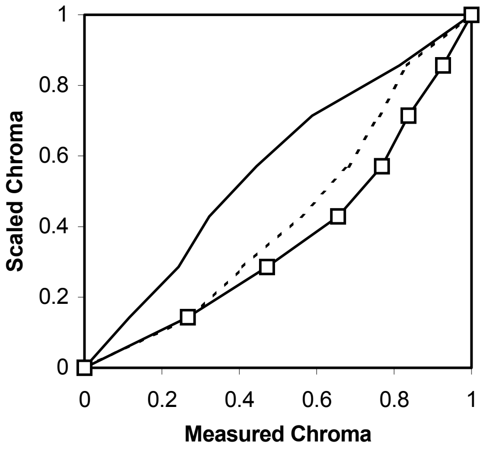

Figure 2. Results for red hue angle.

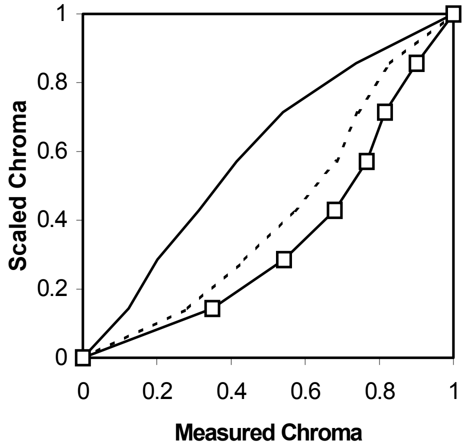

Figure 3. Results for yellow hue angle.

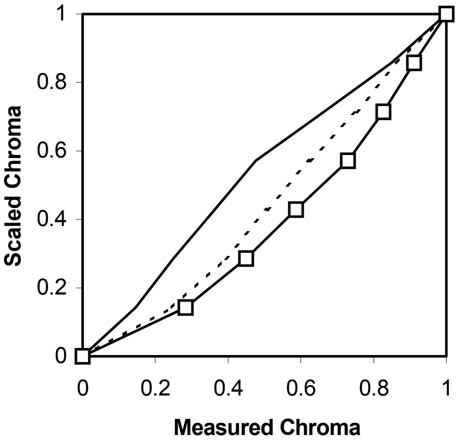

Figure 4. Results for green hue angle.

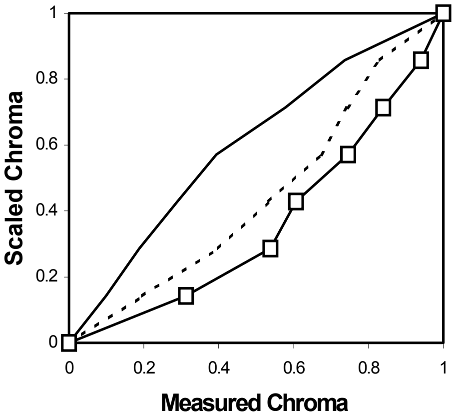

Figure 5. Results for blue hue angle.

The results for the red angle clearly show crispening and multiple observers commented that the red hue angle was one of the easiest to scale. The medium chroma background follows the high chroma scaling for near neutrals and then transitions to the achromatic background scaling for the most chromatic colors. Similar trends can be seen for the yellow, green and blue hue angles where the medium chroma background tends to fall between the achromatic and high chroma backgrounds. The results for cyan and magenta, not shown for brevity, are roughly the same as the results for the other hue angles. It is interesting to note that there is some degree of variation in the specific shape of the curves for the different hue angles but additional testing is required to determine if the differences are statistically significant. Given that the absolute magnitude of the maximum chroma will vary by hue angle, some degree of hue dependency seems likely.

Discussion

While the achromatic backgrounds shows some degree of crispening it does not seem to be as great as that seen for lightness crispening or as large as the chroma expansion in CIECAM97s C. There are at least three factors to be considered. One is that the sampling for the chroma partition may have been too large to get clear results for the first step in the scale. A second factor is the confounding effect of lightness variation across the step ramps. While IPT is useful for an independently derived constant-hue space, it does not provide corrections for visual phenomena such as the Helmholtz-Kolrausch effect.[17] Third, the chromatic backgrounds resulted in simultaneous contrast effects that tended to make the achromatic anchor appear non-neutral. This was most apparent for the maximum chroma backgrounds but was also likely a factor for the medium chroma backgrounds. Regardless, the data for the chroma scaling on an achromatic backgrounds can be used to test the C*, C and C_F chroma metrics. In Figures 6 through 8, the scaled chroma is shown versus CIELAB C*, CIECAM97s C and C_F, the revised CIECAM97s chroma scale. Both axes have been normalized to the range 0 to 1 for each of the hue angles. A linear fit is provided for each figure, along with the R^2 value and the fitted linear equation.

Figure 6 shows that C* provides a reasonable fit to the results with an intercept close to 0 and a slope close to 1. In comparison figure 7 shows that C has a slightly better fit to the data than C* but a large intercept and a lower slope. This implies that while C provides a better fit over the available scale data, there will be considerable error for the first part of the scale. Figure 8 shows that C_F provides both a slightly better fit than C* or C and a much smaller intercept.

This trend in the data can also be seen in the LUTCHI data[18] as well. For example, the mean phase colorfulness data for reflectance samples viewed under 252 cd/m^2 can be plotted versus the three chroma metrics. This corresponds to R-HL phase 3 data from the LUTCHI database. This is shown in Figures 9 through 11 where the LUTCHI nlmean.gh colorfulness data is plotted versus C*, C and CF and a linear fit is provided for each. The C fit is considerably better than the C* fit but the C* fit has a slope closer to 1 and an intercept closer to 0. In comparison, C_F has a better fit than C* and comparable to C and also has an intercept closer to 0 than C. This suggests that C_F is a better fit for the smallest chroma steps. Similar trends were evident in phase 1 of the R-textile data and phase 3 of the CRT data.

Given that the chroma scale has a known origin of zero it would seem important to both minimize the error of the fit and to try to constrain the fit to have a slope as close to one and an intercept as close to 0. It is clear that C* provides the worst fit to the LUTCHI data. However it is less clear that C_F provides a significantly worse fit than C. Further the lack of data would not appear to justify an offset in the scale of roughly 10 percent. The caveats would be that this analysis is not the same as the CV analysis reported previously and should be tested for all other phases of the LUTCHI database as well.

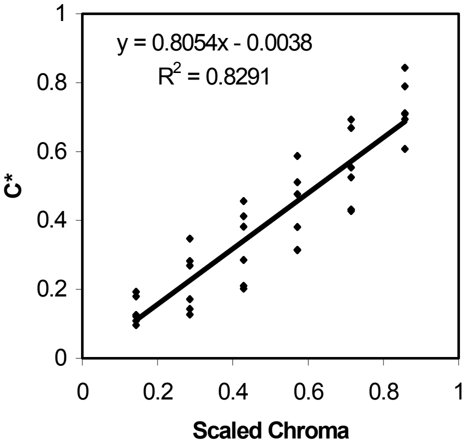

Figure 6. Scaled chroma versus CIELAB C.*

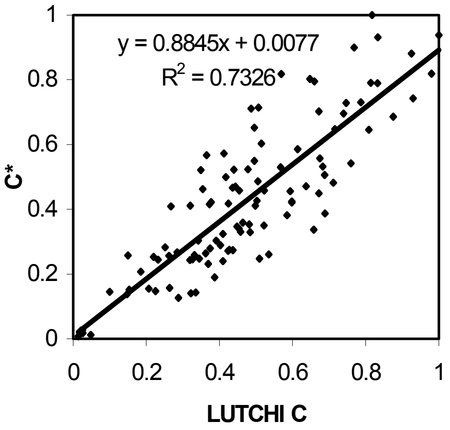

Figure 9. LUTCHI C versus C .*

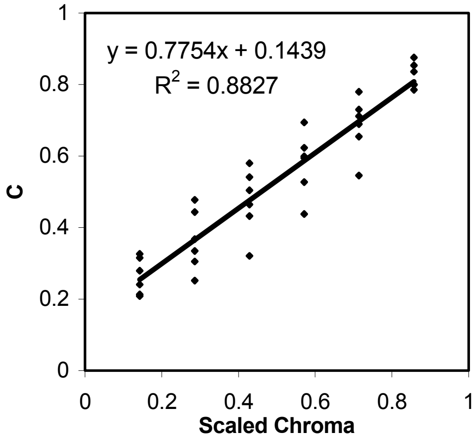

Figure 7. Scaled chroma versus CIECAM97s C.

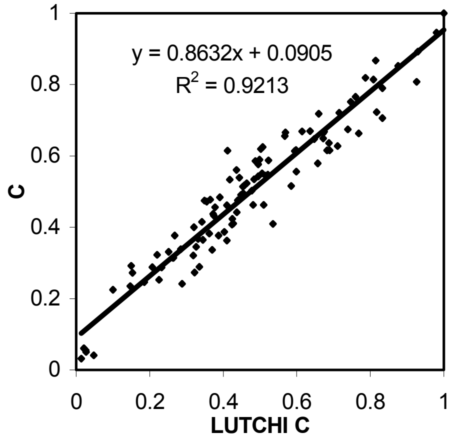

Figure 10. LUTCHI C versus CIECAM97s C.

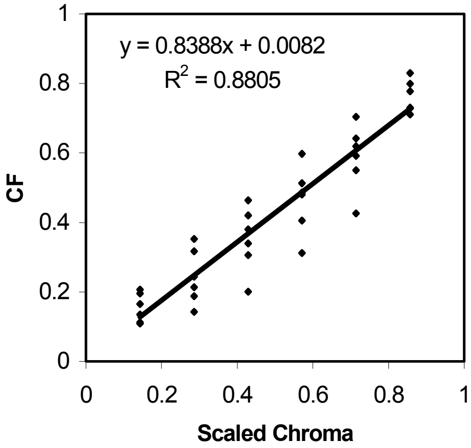

Figure 8. Scaled chroma versus C_F.

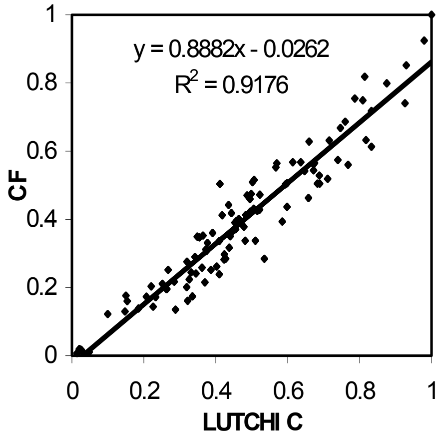

Figure 11. LUTCHI C versus C_F.

Conclusions

Chroma partitioning was used to determine how the chroma of a stimulus varies based on the chroma of the background on which the stimulus is viewed. Six hue angles and backgrounds with three chroma levels were tested. Highly chromatic backgrounds clearly expanded the chroma for near neutrals while achromatic backgrounds tend to expand the chroma for highly chromatic colors. Intermediate chroma backgrounds tended to fall between the highly chromatic and achromatic backgrounds but there are differences with hue angle. The results for the achromatic background chroma scaling are used to compare C*, C and C_F. Additional comparison with several of the phases of the LUTCHI data also suggests that C and CF are better than C* but that C* and C_F have a much smaller initial step. Specifically, C* and C_F have intercepts closer to zero while C has an offset of roughly 0.1 for a linear fit between normalized chroma scale and the metric. Therefore, C_F provides both a reasonable fit to the data and has a intercept closer to zero for the linear fit between normalized chroma and metric.

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