Investigation of Complementary Colour Harmony in CIELAB Colour Space

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ABSTRACT

This study is concerned with one aspect of colour harmony, the complementary relationships between colours. The relationships are most usually represented in colour wheels or hue circles such that opposite colours are assumed to be complementary. However, there is a lack of consistency if different colour wheels are compared. The primary focus of this work is to determine for each hue the optimal complementary hue using psychophysical experiments. The aim is to be able to define the complementary relationships between hues and ultimately to be able to produce a colour wheel that is specifically designed to represent these relationships. Experiments were conducted to ascertain the complementary relationships between hues. The null hypothesis was that opposite colours in CIELAB space would be optimally complementary, producing a maximal colour contrast. However, the experimental data showed systematic deviations from this hypothesis around the colour wheel. The results suggest that opposite relationships in CIELAB colour space do not accurately predict for complementary relationships. Of course, there are many different colour spaces from which we could attempt to predict complementary relationships. The results also indicated a curious asymmetry that merits further study.

INTRODUCTION

Applied researchers, colourists and artists (notably Munsell, Itten, and Ostwald) have long been interested in defining - and finding rules for - colour harmony [1-3]. This study is concerned with one aspect of colour harmony; that is, the complementary relationships between colours. Such relationships are most usually represented in colour wheels or hue circles and in such structures colours that are opposite to each other in the colour wheel are assumed to be complementary producing a maximal colour contrast [4-6]. However, there is a lack of consistency if different colour wheels are compared. For example, in colour wheels that represent colorant mixing, yellow is placed opposite to purple and orange is placed opposite to blue.

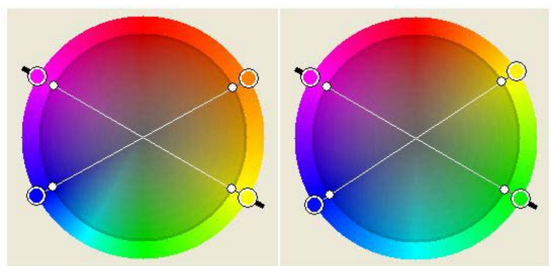

Figure 1: Colorant mixing (left) and visual (right) colour wheel show inconsistent complementary relationships.

In colour wheels that represent visual relationships, on the other hand, yellow is placed opposite to blue and green is placed opposite to purple (see Figure 1).

We may also consider colour spaces based upon properties of human vision such as CIELAB. In the CIELAB colour space yellow and blue are opposite each other (consistent with the right-hand part of Figure 1) and red and green are opposite each other (consistent with the left-hand part of Figure 1). We suggest that neither the colorant mixing wheels or the visual mixing wheels - nor indeed CIELAB – were specifically designed to represent complementary hue relationships. The primary focus of this work is to determine the optimal complementary for each hue using psychophysical experiments by asking observers to find a colour in a maximal contrast with another one. The aim is to be able to define the complementary relationships between hues and ultimately to be able to produce a colour wheel that is specifically designed to represent these relationships.

EXPERIMENTAL METHOD

A psychophysical experiment was carried out to investigate the complementary colour relationships for two-colour combinations. A "LACIE ELECTRON 19 blue IV" CRT with a

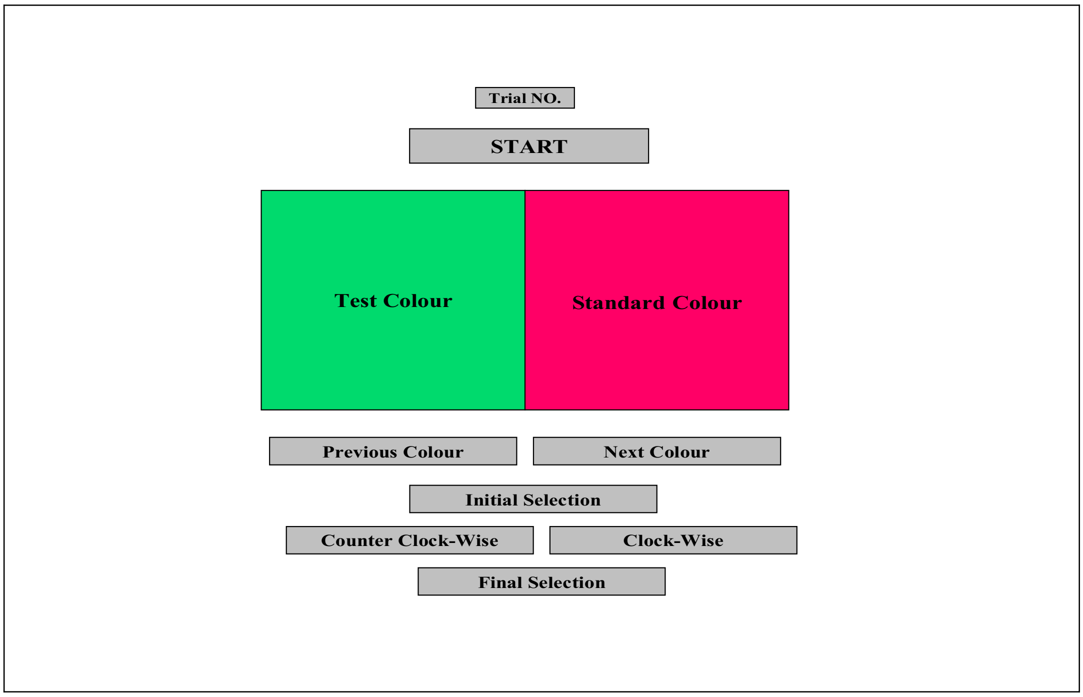

Figure 2 : The user interface used in the experiment

27.5cm × 37cm screen was used to display the colour patches. The stimuli were rectangles that measured 9.4 cm × 19.5 cm and contained two adjacent colours, whose common edge was vertical, displayed on a mid-grey background and viewed in a darkened room. All observers were asked to sit at a distance of 70 cm from the CRT. Measurements of the CRT were made using a Minolta CS-1000 telespectroradiometer and were used with the GOG model [8] to characterise the display so that colours of specific CIE coordinates could be displayed. The brightness and the contrast of the monitor were fixed at 81.3 and 80.0, respectively. Certain properties of the display unit (lack of channel independence and lack of spatial independence) were measured. The CIE colour difference between a measured white and the white predicted by an additive mix of the three primaries was 1.57. The colour difference between a white patch displayed on a black background and on a white background was 1.4. The measured values are typical for high-quality display devices.

In the psychophysical experiment (Figure 2) one of the colour patches was fixed (standard hue) and the hue of the other (test hue) could be varied by observers who were asked to vary the test hue until it was in maximal (hue) contrast to the standard hue. A total of twenty standard colours (evenly distributed around the hue circle at 18 degree intervals) were displayed randomly in turn. For each standard hue (H) the observers were asked to move around the whole colour circle in an unlimited range between 0 to 360 degrees (in steps of 18 degrees) in order to find the colour pair producing maximal colour contrast. The observer signified that they had found the optimal contrast by clicking on a button the screen and were then asked to fine-tune their selection by adjusting the test hue by intervals of 3.6 degrees. The reason for this two-part procedure was to enable the observers to freely choose any hue as the complementary colour (first part of the procedure) and yet do so with a fine level of precision (second part of the procedure).

Ten observers (including six females and four males with normal colour vision and different nationality in the age of 24 to 48) took part in the experiment. The lightness and chroma of all colours were fixed at L* = 52 and C* = 30. It was noted, of course, that not all CIELAB coordinates can be displayed on the RGB monitor because it has a limited gamut [7]. It was necessary to find a Lightness plane and a Chroma value that would result in the complete hue circle being within the gamut of the monitor. A MATLAB programme was written to find the largest hue circle (defined by an L* value and a C* values) that would be within the gamut of the display device and this is how the L* = 52 and C* = 30 parameters were arrived at. Figure 3 demonstrates the optimal hue circle with C* =30 (green circle) in comparison to that of C* = 34 (red circle) which is outside the gamut and C* = 25 (blue circle) which is inside the gamut. (The distortion in the shape of the hue circle with C* equal to 34 is due to producing the RGB values outside the range 0-255.)

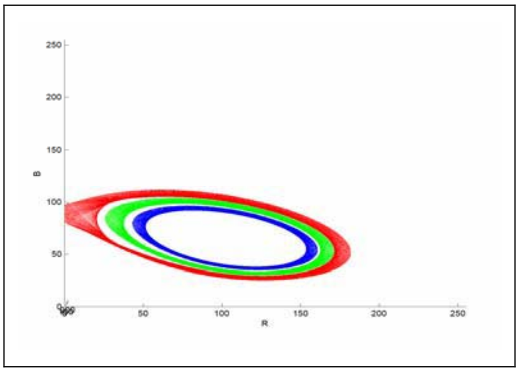

Figure 3a: Optimal Chroma Circle in comparison to the Monitor Gamut in R value vs. B value diagram

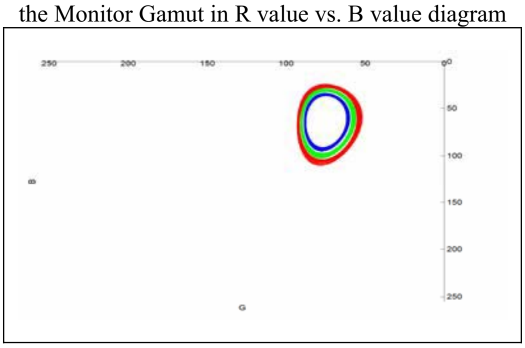

Figure 3b: Optimal Chroma Circle in comparison to the Monitor Gamut in G value vs. B value diagram

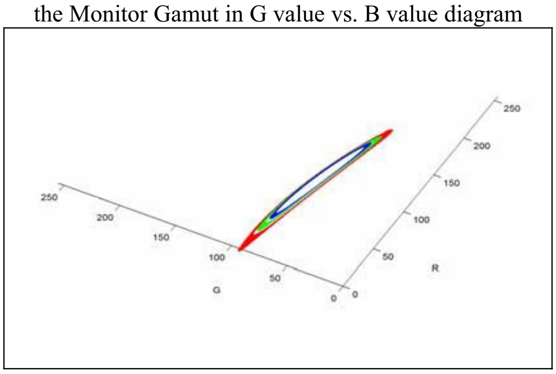

Figure 3c: Optimal Chroma Circle in comparison to the Monitor Gamut in R value vs. G value diagram

RESULTS

In Figure 4 the difference between the hue angle of the observers' preferred complementary hue from that of the CIELAB predicted values (the predicted hue for each standard hue H is 180-H) has been plotted. Note that if the deviations were all zero it would indicate that opposite colours in CIELAB space are optimally complementary. As shown in Figure 4, in some ranges of the standard hue (e.g. 306-72 and 162-252 degrees) the observers' colour selection was reasonably close to that predicted by opposite relations in CIELAB space (ΔE is less than 10). However, in the range of 90-150 and 260-300 degrees (corresponding to yellowish greens and blues) there are large differences between the selected and predicted colours. These departures appear to be significant and as demonstrated in Figure 5, the CIELAB colour difference between the predicted and the selected hues are greater than 10 CIELAB units. Notice that the change in sign of the differences that is seen in Figure 4 at around 180 degrees is simply a consequence of the way ΔH is calculated. The results would seem to indicate that opposite relationships in CIELAB do not accurately predict complementary relationships (at least not for all hues).

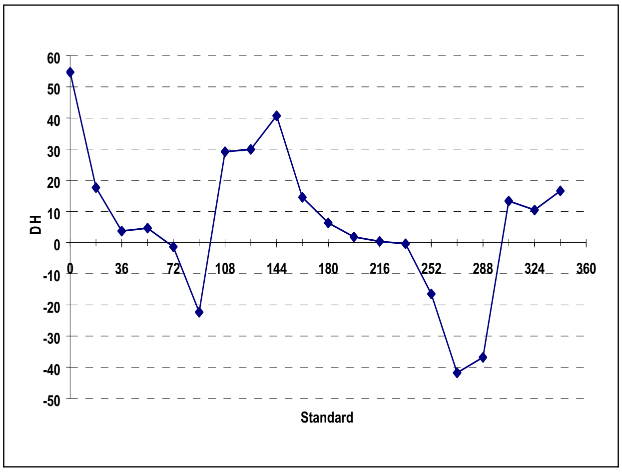

Figure 4: The Angle Difference between the selected test hue and the predicted test hue for each standard colour

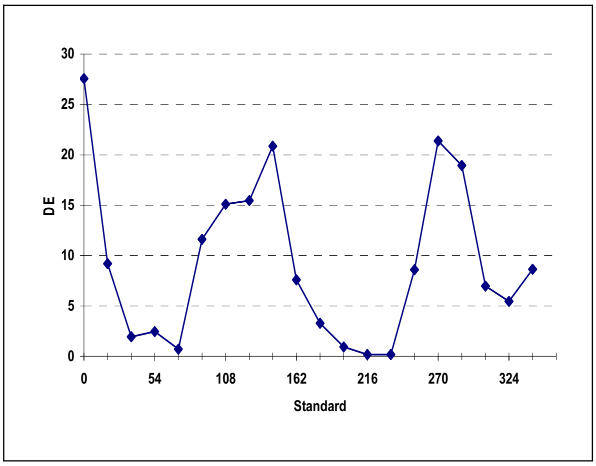

Figure 5: CIELAB Colour Difference between the selected and the opposite colours for each standard hue

For example, when the standard hue was 144 degrees the average contrasting hue chosen by the observers was 4.7; when the standard hue was 324 the average contrasting hue was 139.32. This is illustrated in Figure 6 where sRGB values have been calculated for these four colours and within the constraints of colour management should demonstrate the colour relationships. As shown in the Figure 6, one of the pair selections is consistent with the mixing colour wheel complementary relationship (144 and 4.7: green and pinkish red) and the other is consistent with the visual colour wheel relationship (324 and 154: green and purple). Figures 7 and 8 illustrate some additional pairs that also seem to support this dichotomous behaviour.

Figure 6 : The selected test colours for standard colour of 144 and its opposite colour (324)

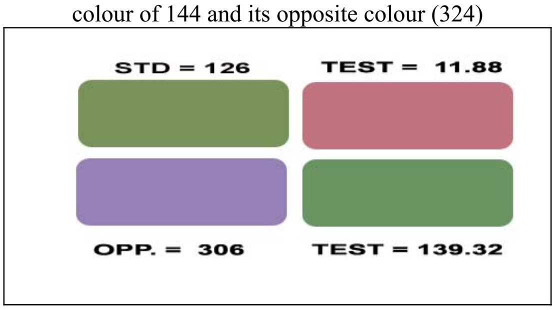

Figure 7 : The selected test colours for standard colour of 126 and its opposite colour (306)

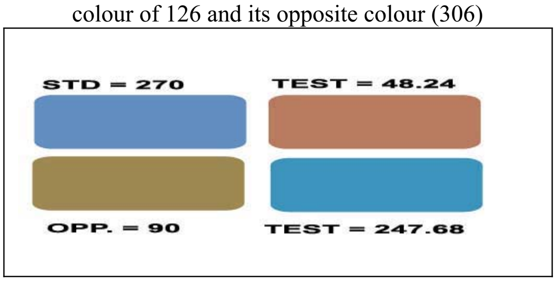

Figure 8 : The selected test colours for standard colour of 270 and its opposite colour (90)

However, the results need to be treated with caution because they also reveal an unusual asymmetry which is difficult to explain. For instance, in simple terms, when asked to find a colour that maximally contrasted with pinkish red observers consistently selected blue; however, when asked to do the same for that blue, observers consistently selected yellowish orange (Figure 9).

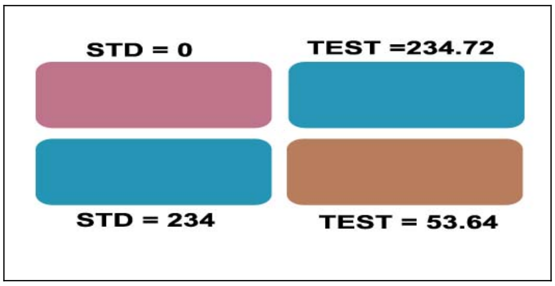

Figure 9 : Test colour selection for the same colour and different orientation

Having paid attention to the initial and final selections of the observers, there was generally an agreement between the observers' choices.

CONCLUSION

Experiments were conducted to ascertain the complementary relationships between hues (subject to the constraint of equal lightness and chroma). The null hypothesis was that opposite colours in CIELAB space would be optimally complementary which produce a maximal colour contrast between colours. However, the experimental data showed strong and consistent deviations from this hypothesis and the agreement of the observers do not support the hypothesis. Interestingly, the deviations gave some indication of a symmetric pattern in some parts of the colour circle. A curious asymmetry was revealed in the results. A weakness of the study is that the observers were instructed to select a test colour that maximally contrasted with the standard colour and we have assumed that this will provide information on complementary relationships. The reason that the words "complementary" and/or "harmony" were not used explicitly in the observer instructions was that these words have technical meanings (in the case of complementary) and various meanings (in the case of harmony) whereas most observers, we argue, understand what contrast means. However, it is possible that the asymmetrical results obtained are an artefact of syntax and understanding and further studies need to be carried to investigate this.

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