Affecting Colour Appearance by Surround Field and Stimuli Sizes

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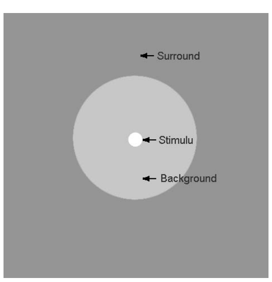
Abstract

This study investigates the effects of the size of stimuli, the size and the luminance lever of the surround field on colour appearance under various viewing conditions. Ten phases of psychophysical experiments were conducted to obtain visual data assessed by a panel of 10-15 observers. The viewing conditions investigated include three different sizes of stimuli, two sizes of surround field, three viewing distances, two luminance level of surround. It was found that the colourfulness was increased for large surround fields (or small display fields), and a lightness and colourfulness increase for large viewing angle of stimuli, especially for dark colours. The results were used to reveal colour appearance under different viewing conditions. The visual results were also used to test the CIE colour appearance model, CIECAM02. In general, so far CIECAM02 gave a satisfactory prediction.

INTRODUCTION

In the real world, human observe colour stimuli in a complex environment. They perceive colours against a surround field. Surround arguably is the most important factor for determining the viewing conditions when study colour appearance. Unfortunately there are two definitions of surrounds according to CIECAM02[1] and ISO 3664:2000[2].

CIECAM02 is the colour appearance model recently recommended by CIE. Colour appearance model plays a key role in achieving successful colour image reproduction across different media under distinct viewing conditions. In order to apply the model correctly, there is a need to understand viewing parameters defined in CIECAM02. As shown in Fig. 1, three key viewing fields are defined by the following:



- *Adapting field:* everything in the visual field outside of the stimulus.
- *Background:* a roughly 10 degree region immediately surrounding to the stimulus.
- *Surround:* the field outside the background[3].

Figure 1: *The region of fields used in colour appearance models (adapted from Hunt[4] p.739)*

In CIECAM02, There are three categories of surround ratios, i.e. $S_R \geq 0.2$, $S_R<0.2$ and $S_R= 0$, corresponding to three types of surround, *average*, *dim* and *dark*, respectively. S_R is a ratio of the luminance value of the reference white in the surround area (denoted as L_{SW}) to that in the display area (L_{DW}).

However, the definition of *surround* in ISO 3664:2000 is "the area adjacent to the border of an image which, upon viewing the image, may affect the local state of adaptation of the eye." Both definitions should be used carefully according to different contents. Note that the ISO 3664:2000 and CIECAM02 are used for complex image and colour patch, respectively.

In this study, particularly interest was paid to the investigation of surround conditions. A viewing field can be divided into two areas: '*display'* and '*surround'*. In the CIECAM02 model, it only considers the surround conditions according to the luminance level ratio (see the definition of S_R above). It does not consider the size of surround field. It should be noted that a larger the surround field is, a smaller display field will be. This is also dependent on the viewing distance. A longer the viewing distance is, the smaller display field (or the larger surround field) will be.

The aim of this study was to investigate the effects of sizes of stimuli and surround fields (sizes and the luminance levels) on colour appearance, to study the contribution of surround field to the perceived match under different viewing conditions, and to test the colour appearance model, CIECAM02, using the experimental data sets accumulated.

EXPERIMENTAL CONDITIONS

A CRT monitor with a 24-bit graphic card was used to display colour stimuli. It was adjusted to a correlated colour temperature of 6500K with a luminance of the CRT's white point of 67 cd/m^2. The CRT monitor was carefully characterised using the GOG (gain-offset-gamma) model.[5]

Experimental Set-up

A viewing environment was arranged using a CRT monitor surrounded by a paper cardboard, as shown in Figure 2. Two surround conditions were under investigation. Note that a black cardboard was used in a *'dark'* surround condition (dark room) and a white cardboard in an *'average'* surround condition. The white cardboard was selected to have similar colorimetric values to the wall colour of the experimental room.

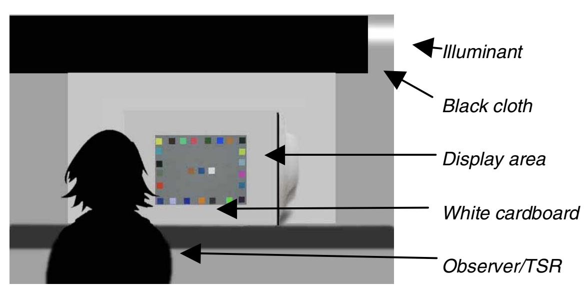


Figure 2: *The experimental set up.*

The luminance of the CRT peak white was taken as the device white (L_{DW}). The average surround condition was simulated with a D65 simulator hung from the ceiling. A black cloth was used to avoid observers from seeing the light source directly (as shown in Figure 2).

Psychophysical Experimental Setting

Ten phases of psychophysical experiments were conducted to obtain visual data by 10-15 observers using the magnitude estimation method. Each colour was assessed in terms of lightness, colourfulness and hue.

Forty colour patches were carefully selected to cover a wide colour gamut and lightness range. Each was displayed in the centre of the CRT monitor and was measured using a Minolta CS1000 tele-spectroradiometer (TSR) to obtain tristimulus values. Figure 2 shows the viewing pattern used in the experiment which was similar to the one used in the LUTCHI[6] experiment. It included a test colour, a reference white and a reference colourfulness patch. Table 1 summarises the viewing conditions in each phase.

The name of each phase is composed of four parts. The first part describes viewing distance with 300, 30 and 70, corresponding to 300cm, 30cm and 70cm, respectively.

The second part expresses the surround condition, i.e. D and A corresponds to dark and average surround conditions, respectively.

The third part states the background colour, G corresponding to grey colour.

The fourth part shows the viewing angle of stimuli and display field by the number of degree separated with a hyphen. For example, 30DG2-34 denotes that a 2° stimulus is viewed against a grey background on a 34° display field at a 30cm distance under dark surround condition. Note that the viewing angles of surround field plus the display field represent the full viewing field. Thus the angular subtenses of the display field also represent that of the surround field.

In Phases 1-6, the physical sizes of colour patches were varied from 8cm×8cm to 1cm×1cm for investigating the effects of the sizes of stimuli. The colour patches with the same physical size had different viewing angles at different viewing distances.

In Phases 1-8, the size of display field (or surround field) was fixed, but its angular subtense was changed according to the viewing distance: 300cm, 30cm and 70cm. For further investigating the effects of surround field sizes, the size of the display field was changed in Phases 9-10 with the same viewing distance as Phases 7-8 (70cm). Figure 3 illustrates large and small display fields used in the experiment which had 34° (left) and 12° (right) angular subtense, respectively. Note that test colours were located in the middle of the display area, with a constant 2° field in Phases 3, 4, 7 and 9.

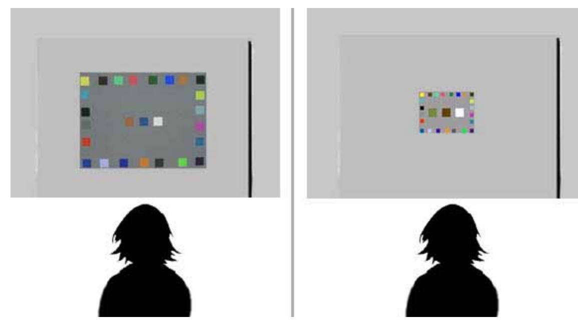


Figure 3: *The two display sizes used in Phases 7-10.*

In Phases 7-10, dark and average surround conditions were investigated. Note that in Phases 8 and 10, under the average surround condition, the luminance level (76cd/m^2)of surround field was much higher than that (0.1 cd/m^2) in Phases 7 and 9 under a dark surround condition. Comparing with the difference in luminance level of display field between the pairs of phases (see Table 1). This can be used to reveal the appearance change due to the luminance of surround.

Table 1: Summary of the viewing conditions in 10 experimental phases

Phase(Name)	Distance	Size of display field	Angular subtense of display field	Size of test colour	Angular subtense of test colour	Surround condition	Luminance of Display field
	(cm)	(cm)		(cm)		L_{SW}(cd/m^2)	L_{DW}(cd/m^2)
1 (300 DG 0.2-8)	300	39×29	8°	1×1	0.2°	Dark (0.1)	64
2 (300 DG 0.4-8)	300	39×29	8°	2×2	0.4°	Dark (0.1)	64
3 (300 DG 2-8)	300	39×29	8°	8×8	2°	Dark (0.1)	64
4 (30 DG 2-58)	30	39×29	58°	1×1	2°	Dark (0.1)	64
5 (30 DG 5-58)	30	39×29	58°	2×2	5°	Dark (0.1)	64
6 (30 DG 15-58)	30	39×29	58°	8×8	15°	Dark (0.1)	64
7 (70 DG 2-34)	70	39×29	34°	2×2	2°	Dark (0.1)	64
8 (70 AG 2-34)	70	39×29	34°	2×2	2°	Average (76)	69
9 (70 DG 2-12)	70	17×12	12°	2×2	2°	Dark (0.1)	64
10 (70 AG 2-12)	70	17×12	12°	2×2	2°	Average (76)	69

RESULTS AND DISCUSSION

Observer Variation

The magnitude estimation data were collected and the coefficient of variation (CV) was used to indicate the agreement between any two sets of data. For the three colour appearance attributes studied, CV values were calculated between each individual observer's results and the mean results, and between observer's results with two repeats, to represent the performance of observer accuracy and repeatability, respectively. For perfect agreement, the CV value should be zero. A CV of 30 roughly means 30% variation between two datasets. The results show that the mean CV values for observer repeatability and accuracy are 11, 17, 5 and 17, 27, 9 for lightness, colourfulness and hue, respectively. The results are reasonable agreed with those obtained by Luo et al.[6]

Effects of size of stimuli

Comparisons were made between visual results of different phases to reveal colour appearance effects. The results from each phase were plotted against each other. The intercept and gradient were calculated from two sets of results.

In Phases 1-6, two viewing distance, long (8° display field) and short (58° display field) were used; the angular subtenses of stimuli were changed for investigating how the stimuli affect the colour appearance by varying size.

In long viewing distance condition (Phases 1-3), they had different viewing field of stimuli, but had the same viewing conditions on an 8° display field, 300cm viewing distance, dark surround and grey background. It was found that the lightness increased for a larger viewing field, especially for darker colours. Colours appeared less colourful for small angular stimuli (see Fig.4). The differences between the mean visual results with the pairs of phases in colourfulness scale were calculated. It shows that in the comparison between 300DG 2-8 with 300DG 0.2-8 and between 300DG 2-8 with 300DG 0.4-8, there is a small but consistent colourfulness reduction for the darker colours with J (in the CIECAM02 J, a_M, b_M colour space) below 30. Hue did not show significant changes by these factors.

In short viewing distance section (Phases 4-6) which had a 58° display field, 30cm viewing distance, dark surround and grey background, the lightness and hue attributes did not change significantly. As shown in Fig.5, a slightly reduction (around 5%) in colourfulness for small angular test colours was also appeared.

Effects of size of surround field

For investigating the effects of field of surround (or display field), comparisons were made between pairs which keep the angular subtense of the test colour at 2° for long, short and middle distances. In Phase 3 (300DG 2-8), Phase 4 (30DG 2-58), Phase 7 (70DG 2-34) and Phase 9 (70DG 2-12), the viewing field of display was changed from 8° to 58°, 34° and 12°, respectively. But they had the same viewing conditions on 2° stimuli, dark surround condition and grey background. Note that in Phases 7 and 9, the viewing distance was fixed at 70cm; the display size was changed and the viewing fields were 34° and 12°, respectively. The differences between these two phases were small in lightness, colourfulness and hue.

As the results shown in Fig.6, the lightness slightly increased for small display field (8°) than those for 12°, 34°and 58° display areas, particularly for dark colours. There was an increase of colourfulness in 8° (small) display field (or large surround field). Considering the scatter of results in comparison between 34° (Phase 7) with 58° (Phase 4), and 12° (Phase 9), with 58°(Phase 4), the differences in colourfulness were unlikely significant. For hue, no significant difference was found for all the comparisons.

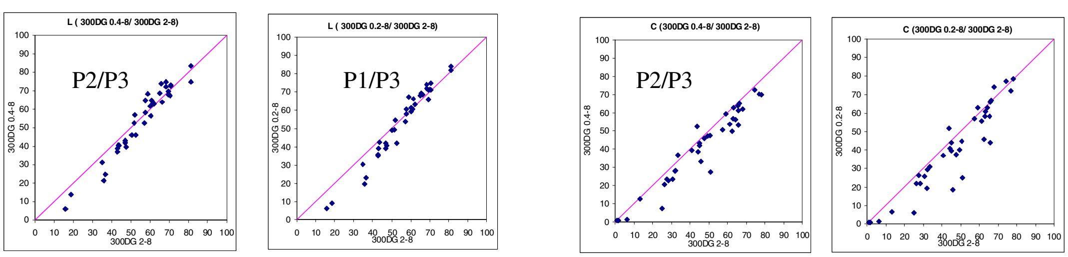


Figure 4: *Comparisons of mean lightness and colourfulness visual results between Phases (denoted as P) with 8° display field.*

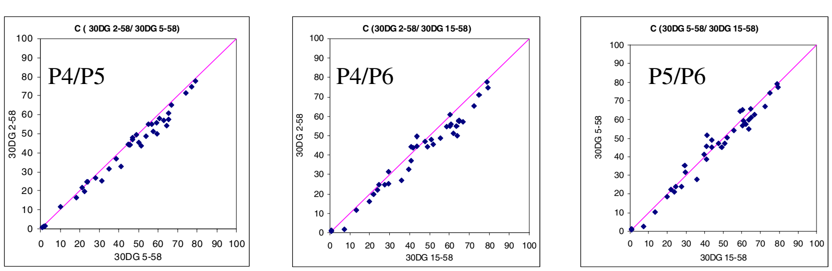


Figure 5: *Comparisons of mean colourfulness visual results between Phases (denoted as P) with 58° display field.*

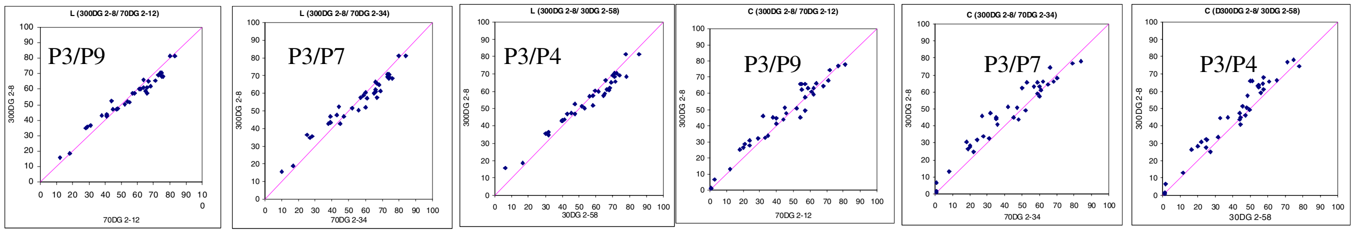


Figure 6: *Comparisons of mean lightness and colourfulness visual results between Phases 3, 4, 7 and 9 with the same 2° stimuli.*

For further investigation, Phases 8 and 10 were conducted under average surround condition. All the viewing conditions were the same as those in Phases 7 and 9, except the dark surround condition. The differences were also small in lightness, colourfulness and hue.

In addition, the ratio of the size of stimuli to the size of display field was calculated. It was 25% for Phase 3 (300 DG 2-8) which had a small display field (8°) but the biggest ratio among ten phases. Note that the smaller viewing angle of stimuli always had the smaller ratio with less colourfulness. These indicate that there was an increase of colourfulness appeared in high ratio of the size of stimuli to the size of display field. Further investigation about this ratio and visual results is required and ongoing.

Effects of luminance level of surround field

In Phases 7-10, comparisons were made between different phases with different luminance levels of surround field. The results from each phase were plotted against each other and the intercept and gradient were calculated from two sets of results. The summary is shown in Table 2.

Table 2 Summary of comparisons of visual data between pairs of Phases 7-10.

X Y	phase phase	7 (70 DG 2-34) 8 (70 AG 2-34)	9(70 DG 2-12) 10(70 AG 2-12)
Lightness	CV	7	8
	gradient	0.93	0.93
	intercept	7.08	7.29
Colourfulness	CV	12	15
	gradient	0.96	0.93
Hue	CV	7	8

The surround luminance effect was investigated by comparing between Phases 7 and 8, and between Phases 9 and 10. The results show a weak trend that dark colours appear lighter in high-level luminance (average surround) than in low-level luminance (dark surround). For colourfulness, the gradients are about 0.95. This indicates a slight colourfulness reduction at the high-level luminance condition.

Comparisons of the Mean Visual Result and CIECAM02 Prediction

The CV value was used to indicate the agreement between visual results and CIECAM02 predictions. The results are summarised in Table 3. Note that the viewing parameters used in this study were obtained following the recommendation of CIECAM02, that the chromaticity and luminance value of the monitor peak white should be measured using a TSR. L_A (the luminance value of adapting field) was calculated by Eq. (1).

$$L_A = L_{DW} \times Y_b / 100 \quad where \quad Y_b = L_{background} / L_{DW} \times 100 \qquad (1)$$

Table 3 Summary of comparisons of visual data and CIECAM02 prediction in Phases 1-10.

phase	Yb	La	CV-L	CV-M	CV-H
1 (300 DG 0.2-8)	19.48	11.93	19	27	8
2 (300 DG 0.4-8)	19.48	11.93	19	30	9
3 (300 DG 2-8)	19.48	11.93	19	35	9
4 (30 DG 2-58)	19.48	11.93	18	25	10
5 (30 DG 5-58)	19.48	11.93	17	23	10
6 (30 DG 15-58)	19.48	11.93	18	25	7
7 (70 DG 2-34)	19.39	12.49	15	24	9
8 (70 AG 2-34)	21.70	15.23	14	22	7
9 (70 DG 2-12)	19.39	12.49	16	22	9
10 (70 AG 2-12)	21.70	15.23	14	22	10
Mean			**17**	**28**	**9**
Observers accuracy			**17**	**27**	**9**

Fig.7 shows the comparisons between visual results and CIECAM02 predictions. These phases, Phase 1 (300DG 0.2-8), Phase 2 (300DG 0.4-8), Phase 3 (300DG 2-8), Phase 5 (30DG 5-58) and Phase5 (30DG15-58), have different stimuli viewing angles.

In Fig.8, comparisons were also made between visual results and CIECAM02 predictions in Phase 3 (300DG 2-8), Phase 4 (30DG 2-58), Phase 7 (70DG 2-34) and Phase 9, which keep the 2° stimuli for long, short and middle distances (with different viewing field in surround).

Based on the general trend of these plots, the CIECAM02 prediction shows a good agreement with visual results, i.e. the mean prediction errors are almost the same as the observers accuracy based on a panel of 10 to 15 observers. However, there is a weak trend that lighter colours have higher lightness than visual results. For colourfulness, CIECAM02 prediction shows a trend of reduction except scattering results found in very small viewing angle of stimuli (0.2° and 0.4°). For hue, there is hardly and difference between visual results and CIECAM02 predictions.

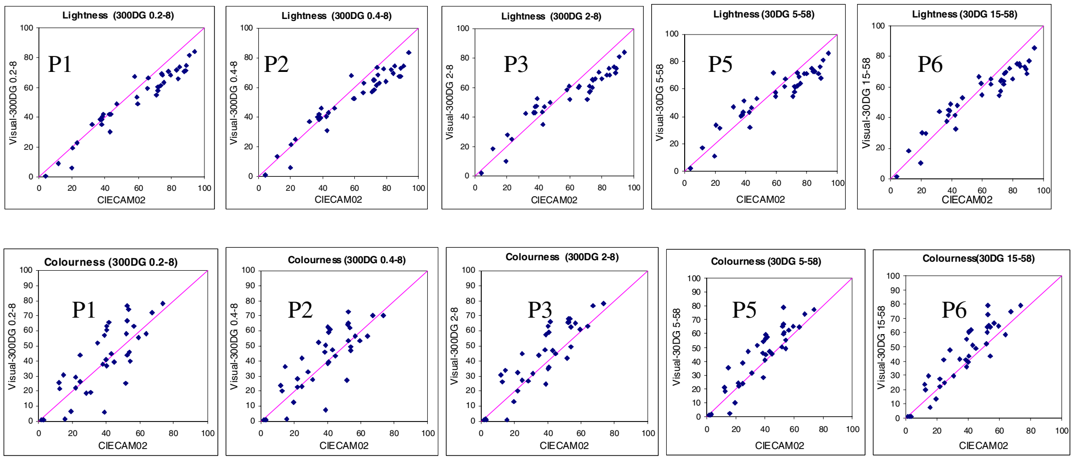


Figure 7: *Comparisons between visual results and CIECAM02 in the phases (denoted as P) having different stimuli sizes.*

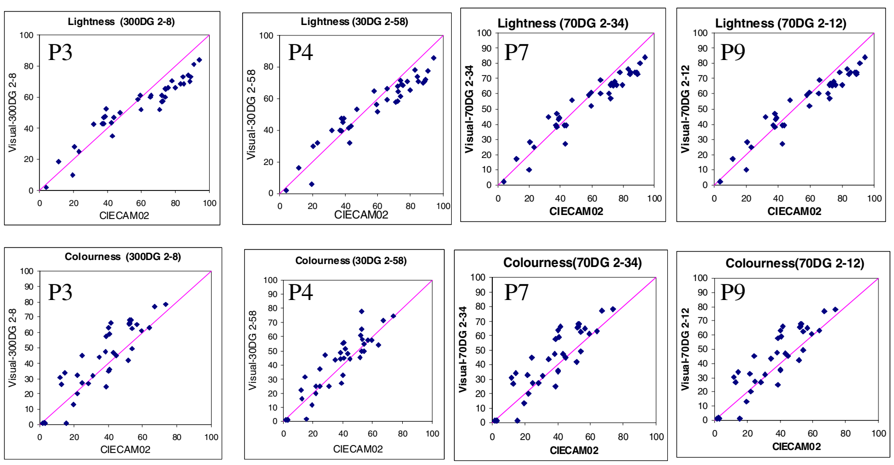


Figure 8: *Comparisons between visual results and CIECAM02 in the phases (denoted as P) having the same 2° stimuli but different surround sizes.*

CONCLUSIONS

The aim of this study was to investigate how surround conditions affect colour appearance by varying the sizes of stimuli, the sizes and the luminance levels of surround field. In general, for hue attribute, differences in colour appearance between each of the comparisons were small. This indicates that perceived hue of colour stimulus does not show significant difference for different parameters investigated.

For the effects of surround field sizes, comparisons were made between phases with the same 2° stimuli, but different viewing field of surround. The results show that the lightness was slightly increased, particularly for dark colours, and the colourfulness was increased for large surround fields (or small display fields). For the effects of surround luminance levels, it was found that a weak trend that dark colours appear lighter and a slight colourfulness reduction in high-level luminance viewing condition.

For the effects of stimuli sizes, comparisons were made between phases with the same viewing distance but different viewing angles of stimuli. The results indicate that the lightness increased for a larger viewing field of stimuli, particularly for dark colours. And colours appeared less colourful for small angular stimuli, especially for the dark colours with J (in the CIECAM02 colour space) below 30.

In general, CIECAM02 prediction shows a reasonable good agreement with visual results. Except a weak trend that lighter colours have higher lightness than visual results, and a trend of colourfulness reduction. Optimal viewing parameters in colour appearance models are under investigation.

REFERENCES

[1] N. Moroney, M. D. Fairchild, R.W.G. Hunt, C Li, M. R. Luo and T. Newman, “The CIECAM02 Color Appearance Model”, The tenth Color Imaging Conference, IS&T and SID, Scottsdale, Arizona, 13-15 November, 2002 23-27.

[2] ISO 3664:2000, “Viewing conditions for graphic technology and photography”.

[3] R. W. G. Hunt, “Measuring Colour”, 3rd Edition, Fountain Press, U. K. (1998).

[4] R. W. G. Hunt, "The Reproduction of Colour", 5th Edition, Fountain Press, U. K. (1995).
[5] R. S. Berns, "Methods for Characterizing CRT displays", Displays, 16:173-182 (1996).
[6] M.R. Luo, Anthony A Clarke and Peter A Rhodes, A. Schappo, S. A. R. Scrivener and Chris J. Tait, "Quantifying Colour Appearance. Part 1. LUTCHI Colour Appearance Data" Color Res. Appl., 16(3) 166-179 (1991).

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