Evaluating Lightness Differences under Different Neutral Backgrounds

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Abstract

An experiment was conducted to investigate the crispening effect on lightness differences. The experiment was divided into two parts using surface and CRT colours including 22 and 24 neutral lightness differences, respectively. Each pair was assessed against three to five neutral backgrounds. The results show that there is a clear crispening effect.

Introduction

The crispening effect is the change of perception of colour differences caused by the change of background colours. In 1964, Kaneko[1] found that a grey background enhances the sensitivity of the observer to lightness differences between grey samples of about the same luminance factors as that of background. This influence of background lightness on the perception lightness difference was also found in later studies.[2,3] The experimental results reported by Chou et al.[4] also shows a cirspening effect, i.e. a V-shape curve in the plot of $\Delta E^*_{ab}/\Delta V$ against L*. The experimental data set was used to verify the lightness scale in the new CIE colour-difference formula CIEDE2000.[5] The lowest point of this V-shape curve is located at L* of 50; all pairs were assessed against a mid-grey background with a L* of 50. This shape indicates the existence of crispening effect in the mid-grey background and the lowest point of the curve corresponds to the lightness of the background. Cui et al[6] carried out a colour-difference experiment to investigate various parametric effects on a CRT. They found that there is a strong crsipening effect. However, it was heavily affected by the setting of viewing parameters for each stimulus displayed. For example, the cirspening effect disappears when there is a black frame surrounding each stimulus. This experiment extended the earlier Cui et al's study to investigate crispening effect by assessing neutral lightness differences against 3 to 5 different neutral backgrounds using surface and CRT samples.

Experimental

An experiment was carried out to investigate the crispening effect based upon surface and CRT samples. These were subdivided into three and five phases, respectively. Each phase used a different neutral background. Each phase is expressed by two characters: the first character denotes surface (P) or CRT (C) samples while the second represents the lightness of background [white (W), light (L), mid-grey (M), dark (D) or black (B)]. The CIELAB values of each background are listed in Table 1. Fourteen glossy and eight matt neutral lightness-difference pairs were selected for surface colour experiment while twenty-four neutral lightness-difference pairs were generated using a CRT display. All CRT colours, had no black frame and no dividing line between a pair of samples. The pairs were selected to have a ΔL* value about 2.5 for each pair from L* = 0 to 100. For each pair, the $|\Delta L^*/\Delta E^*_{ab}|$ value was larger than 0.9.

Table 1 The CIELAB values of the backgrounds

Background	Surface sample				CRT samples			
	Phase	L*	a*	b*	*Phase*	L*	a*	b*
Black	-	–	–	–	CB	0.20	-0.02	-0.02
Dark Grey	PD	20.19	-0.04	-1.22	CD	20.72	-1.48	1.10
Mid-Grey	PM	50.46	-0.09	-0.03	CM	49.34	0.66	-0.34
Light Grey	-	–	–	–	CL	72.11	0.14	-0.11
White	PW	90.27	-0.11	2.17	CW	94.76	0.05	0.25

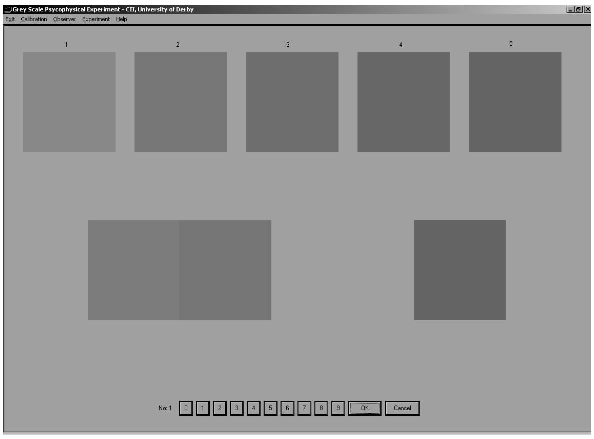


Figure 1 Sample arrangement in the grey scale experiment

The grey scale method[7,8] was employed in the psychophysical experiment. The sample arrangement of grey scale method in the experiment is illustrated in Figure 1. Each sample had about 10° viewing field subtended to observers' eyes in the real experiment. The CIELAB L*a*b* values for each grade in the grey scale and standard under CIE D65/10 are given in Tables 2 and 3 for surface and CRT experiments, respectively. Each observer was asked to provide the visual results in terms of grade value between one and five. The grade values were then transformed to visual differences (ΔV) by fitting a polynomial equation between the ΔE^*_{ab} and grade values in Tables 2 and 3.

Table 2. CIELAB values of the surface grey scale samples.

Grade	1	2	3	4	5	Standard
L*	53.59	46.71	43.23	40.21	38.71	38.23
a*	-0.24	-0.13	-0.79	-0.42	0.07	0.02
b*	-0.43	-0.54	-0.21	-0.23	-0.18	-0.17
ΔE^*_{ab}	15.36	8.49	5.07	2.03	0.48	
ΔL*	15.36	8.48	5.00	1.98	0.48	

Table 3. CIELAB values of the CRT grey scale samples

Grade	1	2	3	4	5(Standard)
L*	53.01	46.2	42.64	39.66	38.05
a*	0.50	0.26	-0.26	0.19	0.78
b*	-0.39	-0.36	-0.31	-0.03	-0.33
ΔE^*_{ab}	14.97	8.17	4.71	1.75	0.00
ΔL*	14.96	8.15	4.59	1.62	0.00

Data Analysis

The PF/3 value calculated by eq. 1 was used to indicate the disagreement between two data sets in terms of percentage errors. For no errors, PF/3=0. A 20 PF/3 units means a 20% disagreement between two data sets.

$$PF/3=100(\gamma - 1 + V_{AB} + CV/100)/3 \qquad (1)$$

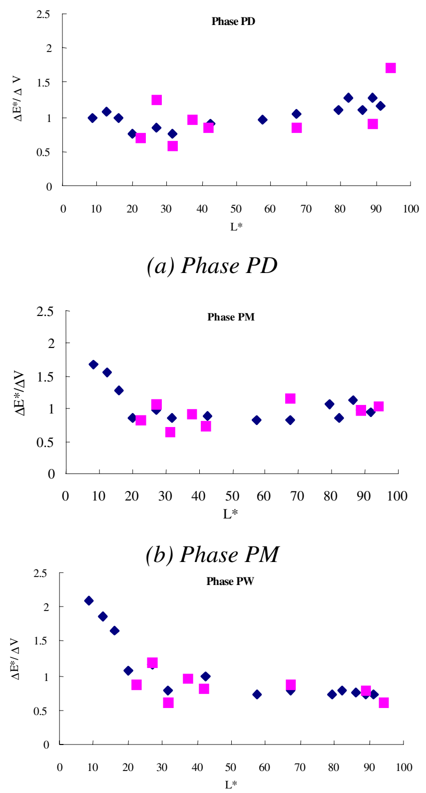
where CV and γ were proposed by Coates et al,[9] and V_{AB} derived by Schultz.[10]

Fourteen and eight observers took part in the surface and CRT experiments with total observing sessions of 17 and 21 respectively. (Some observers assessed more than once in both experiments.) Observer repeatability was evaluated by calculating PF/3 value between each observer's first and repeated ΔV results. These values were then averaged to represent the typical observer repeatability. Only CRT experimental results were used because each pair was only assessed once by the majority of observers in the surface experiment. Observer accuracy was also calculated between each individual observer's and the mean visual results. The observer repeatability and accuracy results for each phase in terms of the mean and maximum PF/3 values are summarised in Table 4.

The results indicate that observers performed more accurately for assessing CRT colours than surface colours by a factor of 1.5. This might be caused by observers improving their performance by gaining more experience the surface experiment was conducted prior to CRT experiment), by specular reflections from the glossy surfaces and by providing better controlled viewing conditions adopting automated and user-friendly computer software. Observer repeatability with an average of 16 PF/3 units is slightly better than that of observer accuracy (18 PF/3 units).

Table 4. Summary of observer variations for each phase in terms of PF/3 values

Repeatability			Accuracy		
Phase	Mean	Maximum	Phase	Mean	Maximum
CB	18.3	35.3	CB	15.5	20.0
CD	16.2	20.5	CD	20.7	28.5
CM	14.9	25.6	CM	18.6	30.5
CL	14.5	25.8	CL	18.6	26.4
CW	16.6	25.9	CW	18.5	29.8
Mean	16.1		Mean	18.4	
			PD	31.9	52.0
			PM	30.6	42.6
			PW	31.1	49.1
			Mean	31.2	



(a) Phase PD

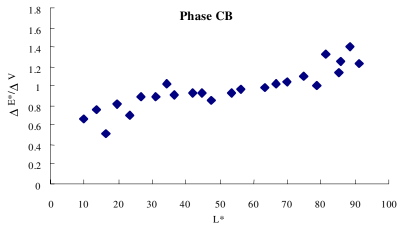
(b) Phase PM

(c) Phase PW

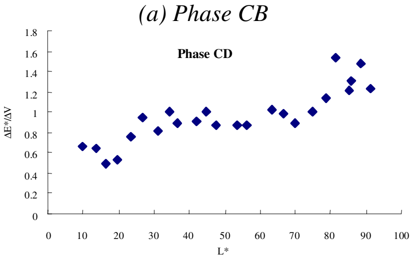
Figure 2. The ΔE^*_{ab} /ΔV values plotted against L values for three surface experimental phases*

Results

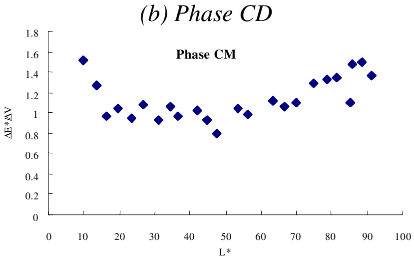
Following the method used by Cui et al,[6] the crispening effect was investigated by plotting ΔE^*_{ab} /ΔV of each phase against L* for each phase. These plots are given in Figures 2 and 3 for the surface and CRT experimental phases, respectively. If CIELAB L* scale predicts well to the visual results, all ΔE^*_{ab}/ΔV values should close to a constant and all data points will be located along a horizontal line in Figures 2 and 3. Figure 2 also shows a reasonably good agreement between glossy and matt pairs plotted using diamond and square symbols respectively. Note that matt sample pairs did not cover the dark region.



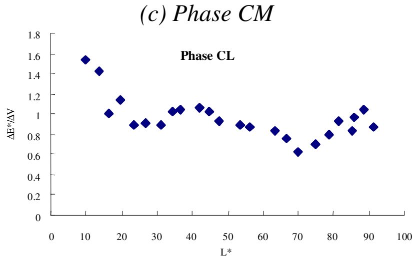
(a) Phase CB



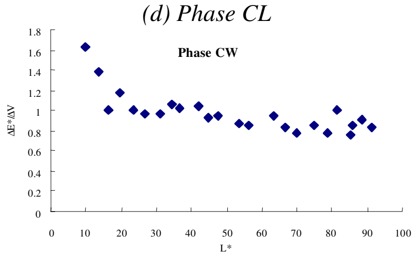
(b) Phase CD



(c) Phase CM



(d) Phase CL



(e) Phase CW

Figure 3. The ΔE^*_{ab} /ΔV values plotted against L values for five CRT experimental phases.*

There is a trend in each diagram that the smallest $\Delta E^*_{ab}/\Delta V$ value in each phase roughly corresponds to the lightness of background. This agrees with those found by Chou et al and Cui et al for their mid-grey background conditions. All data sets of results confirm that there is a crispening effect. The most obvious effect occurs for the dark sample pairs. For the PW Phase, $\Delta E^*_{ab}/\Delta V$ rises to over 2 indicating very small visual differences. For the same pairs for the PD Phase, $\Delta E^*_{ab}/\Delta V$ about 1 indicating that the visual differences were twice as large on the dark background. For the CRT experiments, the $\Delta E^*_{ab}/\Delta V$ values from the dark pairs decreased from about 1.5 for the CW Phase to about 0.6 for the CD and CB Phases. For the pairs of medium lightness (L* about 50), the lowest $\Delta E^*_{ab}/\Delta V$ might be expected for the M background, no such effect is apparent. This could be due to a similar effect occurring for the grey scale/pairs, and the effects cancelling out. The fact that similar effects were found for physical samples and for CRT colours adds confidence to these findings.

Performance of Colour Difference Formulae

Six colour-difference formulae (CIELAB, BFD, CMC, LCD, CIE94, CIEDE2000) were tested using the current experimental data. Figure 4 shows the lightness weighting functions of these formulae. It can be seen that the shapes of these functions are quite different, i.e. CIEDE2000 is a V-shape function; CMC and BFD functions have the lowest part of the curve in the dark region; the LCD function is similar to the BFD and CMC functions for L*>50 with a horizontal line for L*<50; only a horizontal line for both CIELAB and CIE94 functions. All formulae were developed to fit some experimental data with background at an L* of about 50. This implies that there are inconsistencies between different experimental data sets, especially in dark region.

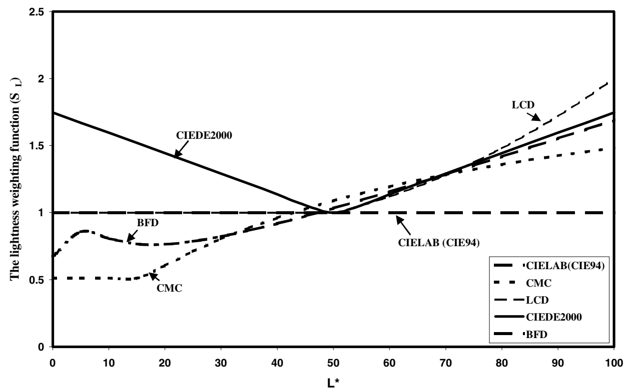


Figure 4. The lightness weighting functions for CIELAB (CIE94), CMC, LCD, BFD and CIEDE2000.

The performance of each formula is summarised in Table 5 in terms of PF/3 values. The results show that CIEDE2000 performed the best for the mid-grey background for both media amongst all colour difference formulae. This is easy to understand because its V-shape function (see Figure 4) agrees well with the data points in Phases PM and CM (see Figures 2 and 3). For testing formulae using the surface experimental data, CIEDE2000 again outperforms the other five formulae. However, all formulae gave the worst for the white background results (see Phase PW in Figure 2).

This is due to the fact that the shape for each formula in Figure 4 is quite different from the visual data. The performances of six formulae tested by the CRT experimental data were similar except for CMC which gave the worst results.

Table. 5(a) Testing colour difference equations' performance in terms of PF/3 (surface samples).

Phase	PD	PM	PW	Mean
CIE94	21.1	22.9	36.4	26.8
CMC	31.8	52.2	72.3	52.1
CIELAB	21.2	23.1	36.4	26.9
LCD	15.6	32.7	53.7	34.0
BFD	19.0	36.1	55.2	36.8
CIEDE2000	18.3	20.4	36.8	25.1

Table. 5(b) Testing colour difference equations' performance in terms of PF/3 (CRT samples).

Phase	CB	CD	CM	CL	CW	Mean
CIE94	21.8	33.6	16.1	17.5	15.7	20.9
CMC	19.3	18.0	34.6	49.7	48.3	34.0
CIELAB	21.7	33.6	16.2	17.7	15.9	21.0
LCD	13.3	23.1	14.1	30.4	30.2	22.2
BFD	13.9	22.0	19.0	33.4	32.4	24.1
CIEDE2000	23.5	35.6	12.8	19.2	19.3	22.1

Conclusion

The present experimental results are consistent with the existence of a crispening effect for lightness differences. The visual difference is increased when the lightness of a sample pair is close to the lightness of background. All trends can be described as a variant of V shape curve in the plot of ΔE^*_{ab} /ΔV against L*. The V shapes are varied along the L* axis according to the lightness of background used in each phase. The lowest point of V shape is occurred close to the lightness (L*) of background where the visual sensitivity was enhanced most. This systematic effect will be formulated for lightness difference predication.

The effect is most marked for very dark and very light backgrounds. Similar effects were found for physical samples and CRT colours. The CIEDE2000 colour difference formula generally gave better fits than other formulae for the physical samples. For the CRT phases there was little difference between the results for the different formulae, expect that CMC gave particularly poor results.

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Biography

Kai Man Ho Raymond received his BSc degree in Textile Chemistry from the Polytechnic University at Hong Kong in 2000 and a MSc in Colour Imaging from University of Derby in 2001. Currently, he is studying his PhD in University of Derby, his work is focused on the development of colour difference formulae for predicting parametric effects, including background colours, degree of gloss, size of colour differences. He is a member of the Society of Dyers and Colourists.