Unique Hues of Large Stimuli: The "Colour Size Effect"

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Abstract

From architectural practice it is known that the perceived colour of large painted facades viewed outdoors at a distance from the house differs from the perceived colour of a small colour card placed directly onto it to perceptually match its colour. Authors believe that the explanation may be – at least partially – the so-called "colour size effect". To study this, laboratory experiments have been carried out with controlled viewing conditions. Significant shifts of three (red, yellow and green) of the four unique hues were found on uniform self-luminant stimuli of a colour CRT monitor when the stimulus size changed from 10° to 120°. The mean overall hue difference was $\Delta H^* = 2$. The extent of the colour size effect varied among the 7 observers. Hue differences of the painted facades had a similar order of magnitude as the hue differences in the present study.

Introduction

From architectural practice[1] it is known that the perceived colour of large painted facades viewed from a distance differs from the perceived colour of a small colour card placed *directly onto it* to perceptually match its colour (the so-called *inherent* colour[1]). This implies that the colour sample chosen by the designer does not predict the facade's colour perception. These differences have been determined experimentally[1]. In these psycho-physical experiments the basic method (among other methods) was the following. The observer stood in front of the facade holding an NCS colour atlas and selecting a small colour in the atlas matching the large facade's perception. The perceived colour of the facade had less blackness than its inherent colour (average difference: 11 NCS units, statistically significant). The perceived colour of yellowish brown, red, yellowish green, and blue facades had more chromaticness than the inherent colour (average difference: 4 NCS units, statistically significant). The perceived colour had more whiteness than the inherent colour (average difference: 7 NCS units, statistically significant) except red. Finally, the often significant hue differences between the perceived colour of the facade and its inherent colour depended much on the kind of the inherent colour, e. g. yellowish red shifted toward unique red.

Above findings have been explained by several different factors[1] related to the nature of these outdoor observations. The illumination of the facades (blue sky, overcast sky, or different phases of daylight, with or without haze) may differ significantly from that of the colour sample (daylight simulator). The level of illumination may be different (e. g. 1000 lx for the sample and 20000 lx for the outdoor facade observation). Chromatic adaptation (or colour constancy) may be incomplete. The different levels of illumination may cause differences in perceived colourfulness and hue shifts may come into play (Bezold-Brücke effect). The proximal field and the surround may also be different for the facades (soil, paving, vegetation, other buildings) and small colour samples (white paper).

The authors of the present work believe that the above experimental findings may also be related to another effect if the facade is close enough to the observer. In this case the retinal image corresponding to the approximately *uniform* colour stimulus (e. g. the coloured facade) is *large*. Its colour appearance may depend on the spatial variation of the retinal properties (e. g. cone densities) within the large surface and the specific viewing condition significantly influenced by the large uniform surface itself. There may be an extremely high colour impact of the large uniform colour stimulus. This is also apparent in cinemas, in virtual reality systems, and in head mounted displays. Authors tend to call this phenomenon *"colour size effect"*. The aim of the present work was to study this effect in the laboratory under precisely controlled and measurable viewing conditions, in addition to the field experiments[1]. As a starting point, it was decided to study the difference between each unique hue (red, yellow, green, and blue) on a uniform self-luminant 10° image and on a uniform self-luminant 120° image. The experiment was constructed to exclude the change of any viewing condition parameter but the image size.

Method

A viewing booth prepared from black paper was mounted onto the front of a computer-controlled 20" CRT monitor standing in a dark room. The white point of the monitor was set to 6500K. The only light source of the room was the monitor. It had excellent image rendering properties: uniform colour patches with the same digital *rgb* counts all over their virtual surface in the computer's video memory had uniform light output all over their real surface, as well. Light output from the *r*, *g*, *b* CRT colour channels was perfectly additive thus all displayed colour stimuli were predictable by using a simple monitor characterisation model. The monitor was characterised by measuring full-screen colour patches only because in the experiment just full-screen colour patches (subtending 120°) were displayed. The 10° condition was obtained by covering the monitor with black paper except a 10° square in the middle.

For the case of the 120° image, the observer was asked to put her/his head into the viewing booth and view the uniform full screen from 10 cm binocularly and imagine to become immersed into the environment of e. g. a large cinema screen. The concept of unique hues was shortly explained. Then the observer had to change the *hue* of the uniform screen by using the "+" key (to go counter-clockwise around the hue circle) and the "–" key (to go clockwise) on the keyboard until one of the four unique hues was found. Then the key corresponding to the initial letter of the unique hue name was pressed and the *r*, *g*, *b* digital colour counts of the uniform image were saved automatically.

The program was designed to provide a *constant* CIELAB L^* and C^* in each of four CIELAB h intervals that were expected to contain each of the four unique hues. Three series of observations have been carried out with different constant L^*, C^* values listed in Table 1. The first series contained stimuli of medium colourfulness. The most colourful stimuli in the monitor's gamut have been displayed in the 2nd and 3rd series, with a slight change of the L^* and/or C^* values between the two series. In each series the 120° condition was observed first. Each of our 7 observers with normal colour vision was asked to find each unique hue 15 times in this order: R, Y, G, B, R, Y, G, B, ... Then the monitor screen was covered inside the booth with the black sheet except the 10° square and the observer was asked to find the unique hues on a 10° image from 50 cm binocularly. Otherwise, the task of the observer was similar to the 120° condition. Thus the number of observations was: 3 series times 2 image sizes times 7 observers times 4 unique hues times 15 repetitions = 2520.

Results and Discussion

Table 1 contains the mean and standard deviation values calculated from all 105 observations (7 observers x 15 repetitions) as well as the two-tailed significance p of a paired samples T-test comparing the mean h_{10° and the mean h_{120° values (i .e. the CIELAB hue angle values of the 10º and 120º conditions). For the sake of comparison, Table 2 contains the main results of a recent unique hue experiment,[2] and the data of the monitor used in the present experiment. All values have been calculated by using the 2º observer. The data in Tables 1-2 are depicted in Figure 1.

Following can be seen from Tables 1-2 and Figure 1. The unique hue ranges of all observations were broader (Δh=40-70) than in the Kuehni experiment (Δh=10-20)[2] because the monitor's basic colours (see Table 2) may have influenced some of the observers who were male informatics students and frequent CRT monitor users. Sometimes they might have considered the CRT basic colours as unique although they were given a clear perceptual definition of the concept of unique hue at the beginning.

For unique green, this tendency is clearly visible in Figure 1: the observers' mean findings are close to the hue angle of the green monitor primary, especially for the case of the more saturated series 2 and 3. A similar tendency can be seen for the monitor's basic cyan and yellow colours. But the moderate SD values indicate an acceptable level of repeatability and inter-observer agreement. Therefore the present dataset may be a point of departure to evaluate the colour size effect.

For unique red, observers found greater hue angle values for the 120º condition than for 10º. This was significant (at the 5% level) in series 1 and 2.

Table 1. Means(M), standard deviations(SD), and ranges of h_{10° and h_{120° for the three series(S). Significance p of paired T-tests (df=104). Asterisks indicate a significant difference between h_{10° and h_{120°. CIELAB colour difference ΔE_{ab}* between the 10º and 120º conditions

S	UH	L^*	C^*	M h_{10°	SD h_{10°	Range h_{10°	M h_{120°	SD h_{120°	Range h_{120°	p	ΔEab* (10º-120º)
1	R	50	30	10	15	333-46	13	15	344-55	0.05*	1.6
	Y	50	30	97	15	61-131	97	13	72-133	0.82	0.2
	G	50	30	155	11	123-180	156	11	122-181	0.55	0.5
	B	50	30	227	17	189-269	227	15	192-272	0.79	0.2
2	R	64	60	19	12	352-47	22	12	0-41	0.03*	2.5
	Y	76	60	95	11	71-117	95	12	73-124	0.81	0.3
	G	85	75	142	13	115-164	144	12	120-164	0.15	2.1
	B	70	46	228	12	203-253	230	13	203-257	0.31	1.2
3	R	56	55	24	15	352-57	26	12	358-56	0.12	1.7
	Y	81	70	98	6	83-111	95	8	80-122	0.00*	4.3
	G	80	75	143	10	119-163	140	11	117-164	0.03*	3.2
	B	63	42	229	11	204-254	231	12	203-261	0.35	1.1

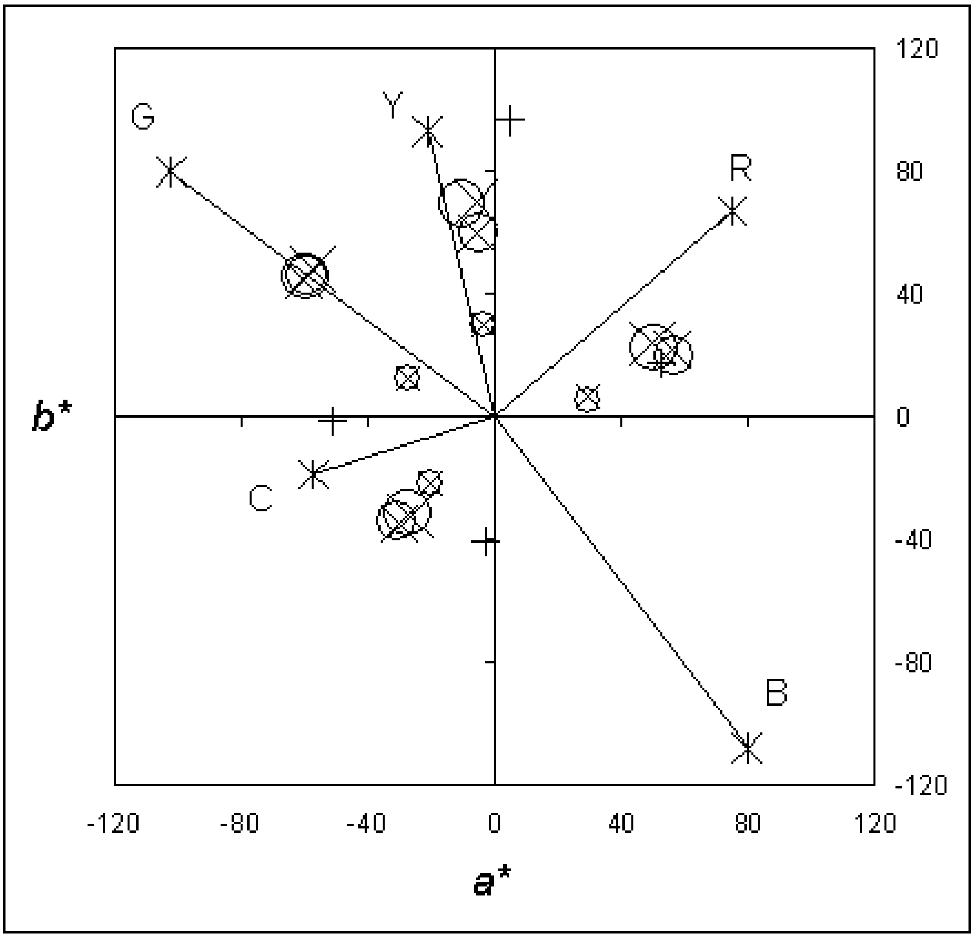

Figure 1. Data of Tables 1-2. Circles (crosses) depict the mean values of the 10º (120º) viewing condition. Series 1 (2,3): small (medium, large) circles and crosses. Plus signs depict the mean unique hues of the Kuehni experiment[2]. Stars indicate 5 basic peak colours of the monitor used in the present experiment: red(R), yellow(Y), green(G), cyan(C), and blue(B)

Table 2. Row "K" contains the unique hue results of the Kuehni experiment[2] (mean values and ranges of male observers) for illuminant C. Row "M" contains the monitor's (used in the present work) 5 basic colours: the RGB peak primaries, the peak yellow (row Y) and the peak cyan (row C)

		*L**	*C**	*h*(º)	*h* range
K	R	41	55	19	13-27
	Y	81	97	87	83-98
	G	52	51	182	172-194
	B	41	41	266	255-268
M	R	60	101	42	-
	Y	97	95	77	-
	G	84	129	142	-
	B	32	134	306	-
	C	88	60	198	-

For unique yellow, there was no significant difference between the two sizes in series 1 and 2. But, in series 3, where the stimulus was very colourful(L^*=81, C^*=70), a significant hue change occurred. This indicates the influence of colourfulness on the extent of the colour size effect. Observers considered h=98º as unique for the 10º stimulus size and h=95º for the 120º stimulus size. This hue shift corresponds to a colour shift of ΔE_{ab}^*=4.3 (as indicated in the last column of Table 1) towards the mean unique colour of the Kuehni experiment[2].

For unique green, a significant difference between the two sizes occurred for the case of the 3rd series only: h=143º for the small stimulus and h=140º for the large stimulus. In the 3rd series the stimulus was somewhat darker (L^*=80) than in the 2nd series (L^*=85) but the two stimuli had the same chroma. This indicates the influence of lightness on the extent of the colour size effect. For unique blue no colour size effect was found.

It may be interesting to examine the results of the individual observers separately. The example of the 1st series of unique red is shown in Figure 2.

In this series the difference between $h_{10°}$ and $h_{120°}$ was significant for unique red as indicated by an asterisk in column "*p*" of Table 1. As can be seen from Figure 2, observer No. 4 contradicts the tendency. In addition, some observers obtained a small hue angle difference between the small stimulus size and the large stimulus size while other observers obtained a large difference. Observers have been classified based on the mean absolute value of the mean hue angle difference (Δh) between the two stimulus sizes. Latter value is listed in Table 3 for the 7 observers.

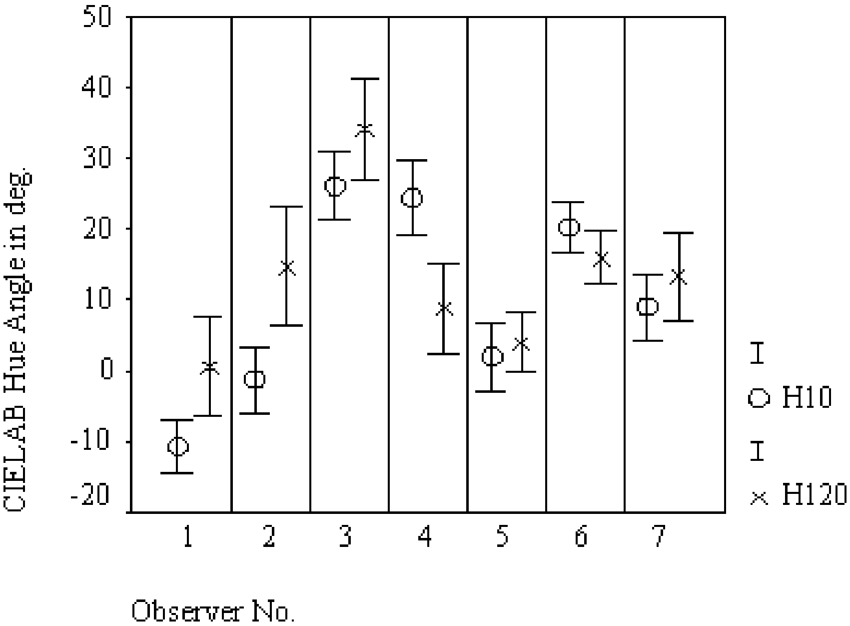

Figure 2.Unique red as seen by the individual observers for the small ($h_{10°}$) and the large($h_{120°}$) image sizes. 1st series

As can be seen from Table 3, observer No. 4 had the highest Δh value. It was this observer who contradicted the tendency of $h_{120°}$ being greater than $h_{10°}$ in Figure 2. The other observers did not deviate so much from the average. The standard deviation of Δh was 0.8 in the dataset of Table 3.

Table 3. Mean absolute value of the mean hue angle difference (*Δh*) between the two stimulus sizes, for the 7 observers

Obs. No.	1	2	3	4	5	6	7
Δh	5.2	4.4	5.0	6.5	4.8	3.9	4.3

Finally, 13 typical results from the Anter experiment[1] are presented in the CIELAB a^*-b^* diagram of Figure 3. Anter's original NCS data have been transformed by using the D65 illuminant and the 2º observer. In accordance with the findings formulated by the NCS terminology in the Introduction, the CIELAB lightness and chroma of the facade colour viewed from a distance were usually greater than those of the inherent colour. Above 13 typical results had ΔL^*=8 and ΔL^*=4 in average, the mean colour shift was ΔE^*=10, and the mean hue shift was ΔH^*=3.

In the present experiment, no chroma or lightness change was allowed thus the overall mean colour shift between the 10º stimulus and the 120º stimulus was equal the overall mean hue shift: ΔE^*=ΔH^*=2. As can be seen, the mean ΔH^* value of the present experiment has the same order of magnitude as the mean ΔH^* value of the Anter experiment[1]. But the lightness and chroma shifts were greater than the hue shifts in the Anter experiment. This finding points toward the future laboratory experiments where the lightness and chroma changes between the small and large stimulus size shall be investigated.

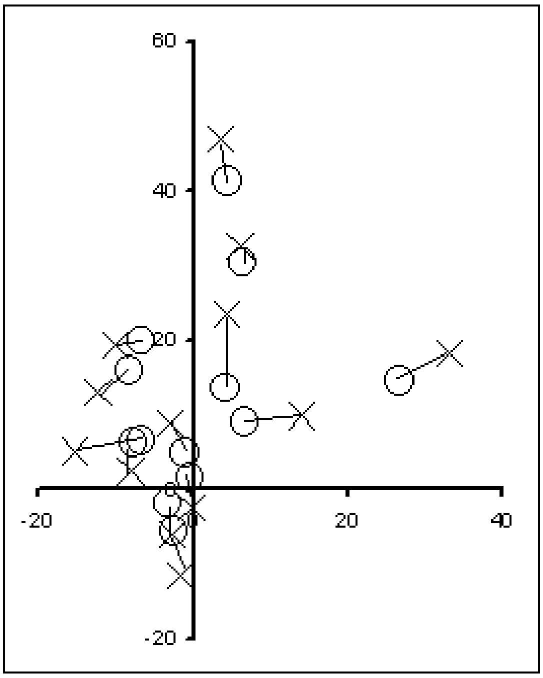

Figure 3. CIELAB a-b* diagram. 13 results from the Anter experiment[1]. Circles: "inherent" colours near the painted facade; crosses: facade colours perceived at a distance from the wall*

Conclusion

In this work the so-called "colour size effect" has been studied. Significant shifts of three (red, yellow and green) of the four unique hues were found on uniform self-luminant stimuli of a colour CRT monitor when the stimulus size changed from 10° to 120°. The mean overall hue difference was $\Delta H^*=2$. The extent of the colour size effect may vary among observers. Present results have been compared with the results of a previous open-air study of coloured building facades[1]. Hue differences of the latter study had a similar order of magnitude as the hue differences of the present study. We need further laboratory experiments with variable chroma and lightness before a general conclusion can be drawn about the colour size effect.

Acknowledgement

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Biography

Peter Bodrogi received his M. S. degree in Physics at the Loránd Eötvös University in Budapest, Hungary. He received his PhD degree at the University of Veszprém, Hungary. Since 1993 he has worked for the Department of Image Processing and Neurocomputing of the University of Veszprém. Currently he is adjunct professor at the Laboratory of Colour and Multimedia in Veszprém.
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