Colour Size Effect

Gábor Kutas, Katalin Gócza, Peter Bodrogi, and János Schanda
Colour and Multimedia Laboratory
Department of Image Processing and Neurocomputing, University of Veszprém
Veszprém, Hungary

Abstract

The size of the colour stimulus has an effect on colour perception. To investigate this in detail, an experiment was conducted with the help of a PDP monitor (to display a large colour stimulus) and a CRT monitor (to display the same colour stimulus but of smaller size). Observers viewed a large and corresponding slightly different small colour stimuli several times, immediately after each other. They had to decide whether their colour perception was the same. All stimuli were measured in-situ by the aid of a spectro-radiometer. Aim of this work was to get a reliable visual dataset for the colour size effect for this colour point.

Introduction

Colour perception is affected by several different factors. One of these factors is the size of the colour stimulus, or, more precisely the viewing angle, under which the stimulus appears. One could consider a physiological reason, e.g. the spatial distribution of the S, M and L cones or the existence of the yellow spot (macula lutea) but the so-called *colour size effect* takes place also in retinal regions where the ratio of the number of cones is approximately uniform.

Investigations on small visual field (less than 10°) go back to the 19th century. In 1893, Hering found that yellow seemed more reddish as the visual angle was decreased.[1] Repeating his experiment in 1947, Hering's conclusions were confirmed[2]. Latter experiments showed that, as visual angle is reduced, more green needs to be added to the mixture to match the original yellow stimulus. This phenomenon was observed within the range of 1° to 5° of viewing angle. Conversely, if the stimulus size is increased[3] observers add more red to the matching to identify it as identical to the original yellow stimulus. This trend takes effect up to 25 degrees of viewing angle. It is also common that as visual angle becomes excessively small (1'-5'), due to the inhomogeneous density of the three cone types at the fovea, colour stimuli seem to loose some of their colour components until they become completely achromatic.[4-6] Recently, as colour is more and more instrumental in transmitting information e.g. in traffic, new experiments have been performed on the topic of small visual field under several illumination levels,[7] including colour identification.[8]

In art, however, the phenomenon of different perception of different large sizes of the same paint is also known. Burnham reported in 1951 that there is an increase in excitation purity when the field size is increased from 2° to 22° and this increase is smaller when the area changes from 22° to 77° by generating the same luminance of the stimuli and the background.[9]

Furthermore, in architectural practice it is common that the small colour sample used to select the covering paint for interior and exterior surfaces does not exactly predict the colour perception of the finished large surface. Experiments related to this were performed in recent times including large visual angles and outdoor observations.[10,11]

The introduction of *large screen monitors*, head mounted displays and virtual reality systems made necessary the study of self-luminous stimuli, too. Latter stimuli have been examined systematically[12,13] where hue and chroma shifts were detected, when the visual angle increased from 10° to 120°. In certain cases $\Delta E_{ab}*$ set by observers exceeded 10 units.[13]

The aim of the present work is to investigate this colour size effect more in detail. Uniform self-luminant images were studied in controlled laboratory experiments. To find out more about the colour size-effect, a new experimental method was developed and tested employing a large 42" Panasonic PDP monitor and a 21" Hewlett Packard CRT monitor. As a starting point, it was decided to experiment with only one dedicated colour stimulus, in case of which shifts were already detected.[13] Our aim was to set up a reliable psycho-physical database on the colour size effect with accurate spectral measurements of all stimuli.

Experiment

Physical Characterisation of the Stimuli

All stimuli were displayed on a computer controlled Hewlett Packard P1100 21" CRT display and on a 42" (diagonal) Panasonic TH-42PHD5EX high-definition plasma display panel (HD-PDP). On the basis of previous visual experiments on the HP CRT monitor, it proved to be an excellent colour display. Light output from the r, g, b channels was perfectly additive thus it was reasonable to use a simple monitor characterisation model. The characterisation of the CRT monitor was done by measuring uniform colour patches on a mid-grey background in the same size as they appeared later during the experiment. Reflections from the mid-grey surround of a colour patch did not influence the luminance measured in the middle of the small colour patch significantly. The resolution of the device was 800×600. It was controlled by a PC containing an S3 Trio graphics card. The white point was set to 9300K.

The PDP display also turned out to be suitable for this experiment. Measuring the luminance uniformity of a full-screen colour patch (the light pink "original colour", see Section 2.2) on the entire surface in nine points resulted in an average luminance of 28.8 cd/m^2 (STD=1.4). The addressable surface of the PDP to display colour information is 92×56cm, which is large enough to create a completely immersive visual sensation at close viewing distance (similar to e.g. large wall surfaces, except that it is self-luminous). Colorimetric characterization of the plasma monitor and more technical data is described in another paper of these proceedings.[14] The resolution of the display was 1024×768. It was controlled by a PC containing an integrated Intel 8245G graphics controller. The white point was set to "cool", which actually resulted in 9481K. To prevent the observers from being affected by the disturbing size of the pixels due to the short viewing distance, a diffusion filter was placed on the PDP screen.

A Photo Research PR-705 spectro-radiometer was used to measure the absolute spectral power distributions of the colour patches displayed on both devices during the whole experiment. The instrument was used with 2° measuring field. Its specifications are listed in Table 1.

Table 1. Specifications of the PR-705 spectro-radiometer (manufacturer's data).

Spectral range	380 – 780 nm
Angle of view	2°
Spectral accuracy	±2 nm
Luminance accuracy (Standard illuminant A)	±2%
Chromaticity accuracy (Standard illuminant A)	x ±.0015 y ±.001

Psycho-Physical Method

The experimental set-up is illustrated on Figure 1. The two monitors were placed on a table next to each other. The angle included by the planes of the screens of the displays was 100°. A black separator was placed between them fully separating the screens of the monitors while still enabling the observation of the depicted colour patches at the desired distance. When observers were required to look at either the CRT or the PDP, the separator completely excluded the other monitor from their field of view.

The experimental method was as follows. The observer sat in front of the displays. To achieve the proper viewing distances (i.e. visual angles), observers had to lean towards either screen right next to the separator until the other monitor disappeared from their field of view. The viewing distance in case of the CRT was 55cm and the displayed 180-pixel-side-length square appeared under 10° of visual angle. For the PDP, the close distance (~20cm) provided a viewing angle of about 130°.

The experiment was based on the method of constant stimuli i.e. subjects were presented a set of fixed stimuli (this will be called in the future "comparison stimuli") and the task was to evaluate these stimuli without any adjustments according to a dedicated rule. In the present work, observers were requested to compare two stimuli of different visual angles. The idea was that the observer was shown a full-screen uniform colour surface having the same colour during the whole experiment (the light pink "*original colour*" – see Table 2.) on the large screen PDP. Several fixed-size (10°) colour stimuli ("comparison colours") of different colours chosen from the neighbourhood of the "original colour" in CIELAB space (including the "original colour" itself) were displayed on the CRT device to compare them with the original colour. The question asked from the observers was:" Do these two stimuli on the two monitors have the same perceived colour?" All stimuli on the CRT were surrounded by a mid-grey background. The 18 "comparison colours" were located around the original stimulus within an approximately **six** CIELAB-unit radius at constant L^* level i.e. only the chroma and the hue deviated from the original colour (see Table 2). For every CIELAB calculation, the measured CIE tristimulus values of the full-screen white of the CRT monitor were used.

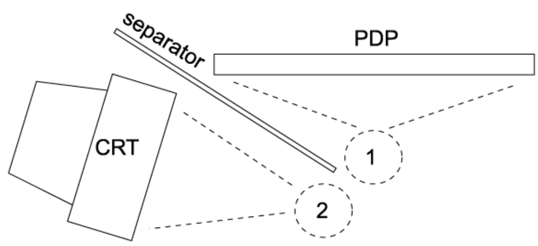

Figure 1. Top view of the experimental set-up. Numbers denote the observer's head position when observing the PDP (1) or the CRT (2) monitor.

18 observations consisted of 18 *sequences*. In a particular sequence the following two stimuli appeared: the original colour on the PDP (for 2 seconds) and, after that, a "comparison" colour under 10° of visual angle (for 5 seconds) on the CRT monitor. These two colours were displayed after each other five times. To allow the observer to change the head position and to focus on the other screen, a 5-second interval with a uniform full-screen mid-grey was between them on both displays. While on either monitor (CRT or PDP) a colour patch appeared on the other monitor a full-screen grey was shown. During the repetitions, subjects were requested to consider the perceived colour difference between the full-screen original colour on the PDP and the "comparison colour" on the CRT. At the end of the fifth appearance of the comparison stimulus, observers made their judgements. A beeping signal marked the request for evaluating the perceived colour difference between the alternating stimuli. Pressing key 'i' denoted complete correspondence and button 'n' denoted a difference between the two perceptions (the keys i/n are abbreviations for Hungarian yes/no). After the observer pressed one of the buttons, the next sequence started automatically with the next comparison stimulus of the 18, until each of them were shown to the observer 10 times. (The observation of 10 x 18 comparison colours was partitioned to three *series* of 60 observations). The order of the comparison stimuli within the whole observation was randomly generated. The five repetitions in a sequence were necessary to prevent memory artefacts.[15] To make control data sets and to make

the observers get acquainted with the concept, several pilot experiments had been conducted completed with numerous physical measurements before and after.

Table 2. Mean CIELAB and luminance values of the light pink original colour displayed on the PDP (mean of 4 different measurements a day between each) and comparison colours on CRT (mean of 18, during one experimental series). Also the luminance values of the displayed achromatic greys are listed displayed during the head position phases.

	L^*	a^*	b^*	lum. [cd/m^2]
original colour (mean)	75	16.23	10.77	29.97
STD	0.28	0.15	0.48	0.27

	L^*	lum. [cd/m^2]
comparison colours (18)	75.39	30.28
STD	0.14	0.13
mid-grey (PDP)	74.69	29.59
mid-grey (CRT)	74.62	29.52

Each observation was conducted in a completely dark room where the only light source was the monitor. The whole psycho-physical experiment was controlled by well-timed computer programs prepared particularly for this purpose. Since two computers were used simultaneously without any inter-computer communication, to maintain timing, observers handled two keyboards at the same time. In case of every observer, the three series were followed by an *in-situ* spectral measurement of all displayed stimuli.

Three persons (2 females, 1 male) of normal colour vision aged between 20 and 30 took part in the experiment.

Results and Discussion

Although, an inverse monitor characterization model was used to generate the DAC values of the set of comparison colours around the original colour, at the final evaluation, results of the direct in-situ spectral measurements were used for all comparison colours. These measurements were done by setting up the spectro-radiometer in place of the subjects on a tripod.

Since the displayed original colour stimulus was stable enough for each of the three observers (see Table 2), their answers could be handled as answers for the same situation. In Figure 2, *in-situ measured* comparison colours are plotted in a CIELAB a^*-b^* graph, showing the number of cases in which observers perceived them to be the same as the perceived colour of the original colour. Legend is as follows: small circles mean “yes” answers between 0 and 4, large circles mean “yes” answers between 5 and 7 and black dots mean 8-10 “yes” answers from 10 comparisons. The rings around black dots denote 10 “yes” answers from 10 comparisons. Large crosses mark the measured original colour for each of the three observers. Following can be seen from Figure 2: observers generally perceived the full-screen original colour to have less chroma than the 10° display of colorimetrically identical stimuli since they saw matches with comparison colours of less chroma. The average of the comparison colours weighted by the number of “yes” answers (only those comparison colours for which the number of “yes” answers exceeded five) is a^*=13.26 and b^*=8.86. The CIELAB colour difference between this average and the original colour is ΔE_{ab}^*=3.66 (see Table 3).

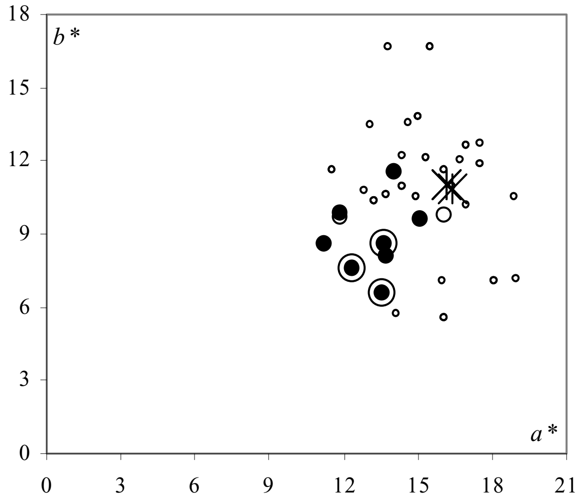

Figure 2. In-situ measured values of the comparison colours for each of the 3 observers in a CIELAB a-b* diagram. (Notation is explained in the text.) Stars indicate the light pink original colour (from 3 slightly different spectral measurements for the three observers). See also Table 3.*

The result of this experiment corroborates the result of a previous experiment[13] where observers set more chroma in the large field to perceptually match the small field. Since in those experiments only one (CRT) display was used, observers changed between the small and the large stimuli themselves. It was based on the psycho-physical *method of adjustment,*[13] and therefore, there was no limited observation time of the large colour patch. This may have caused an increased chromatic adaptation effect resulting for certain observers in a ΔE_{ab}^*=20 unit difference between the small and the large stimulus perceived to match.[13] In this work, precise timing was used to exclude this effect.

It seems that choosing comparison colours only in the environment of about **six** CIELAB units of this "light pink" original colour may be **too small** to predict the total chroma shift since several comparison colours of 10 matching answers are located at the perimeter of the visited environment of the comparison colours (see Fig. 2).

Table 3 contains individual results of the three observers: the number of comparison colours with 5, 6, 7, 8, 9, and 10 yes answers, as well as the weighted averages of the comparison colours and individual CIELAB colour differences between the average and the original colour. Weighted averages are also plotted in Figure 3. As can be seen from Table 3, observers gave more than 5 “yes” answers for only a few comparison colours (compare with Figure 2). Observer No. 3 (KG) gave most “yes” answers during the experiment. The other two observers perceived matches for only two comparison colours (more than 5 times). It is also apparent that only observers GK and KG gave an "always matching" answer i.e. 10 “yes” answers. The weighted average of all three observers follow the overall trend: all observers perceived the full-screen colour patch to exhibit **less chroma** than the small patch. In case of subject AA a shift towards yellow is also observable (see Figure 3).

Table 3. Number of comparison colours with 5, 6, 7, 8, 9, and 10 yes answers. Weighted averages of the comparison colours.

number of “yes”	Number of comparison colours AA	GK	KG	
5	0	0	1	
6	1	0	0	
7	0	0	0	
8	0	0	3	
9	1	0	1	
10	0	2	1	
Weighted averages	AA	GK	KG	overall
*a**	13.21	13.01	13.39	13.26
*b**	10.77	8.08	8.59	8.86
ΔE_{ab}*	3.05	4.35	3.73	3.66

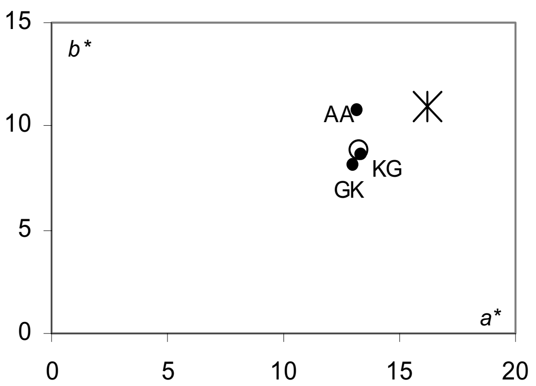

Figure 3. Individual weighted averages of the CIELAB coordinates of comparison colours where observers gave more than 5 yes answers out of 10. (open circle: overall average, filled dots: individual averages, star: original colour)

Conclusion

In this paper the dependence of the perception of the colour stimulus upon the stimulus size at one point in colour space was studied. With the introduction of a new experimental technique, based on the method of constant stimuli, a **significant chroma reduction** was detected when the size of the stimulus was robustly increased.

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Biographies

Gábor Kutas received his M.S. degree in Information Technology from the University of Veszprém in 2002. Recently, he is working on his Ph.D. thesis in the Colour and Multimedia Laboratory of the University of Veszprém. His interest is primarily focused on colour display calibration and psycho-physical colour measurements. He is member of the SID.

Katalin Gócza is a graduate student of the University of Veszprém in the Faculty of Information Technology. She is working on her M.S. thesis in the Colour and Multimedia Laboratory.

Peter Bodrogi received his M.S. degree in Physics from the Eötvös Lóránd University of Budapest in 1993. He received his PhD degree in Information Technology from the University of Veszprém in 1999. Currently he is associate professor at the University of Veszprém. His interest is photometry, colorimetry and lighting technology. He participates in the technical work of the International Commission on Illumination (CIE).

János Schanda graduated in physics at the Lóránd Eötvös University of Budapest, he is at present professor emeritus of the University of Veszprém.