Use and application of the PAD scale in the study of colour emotion

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ABSTRACT

This study concerns the affective impact of the colour and appearance of materials in the self reported emotional responses of groups of observers. A comparison will be made between the use of the Pleasure Arousal Dominance (PAD) Scale and the more commonly used Colour Emotion Scale (Nobbs, 1997 and 2004 and Ou, 2004). This paper reports on the development and use of the PAD Scale for assessing observer response to single colours in controlled conditions. An aim of the study reported here is the assessment of the usefulness of the PAD Scale in studies of Colour Emotion.

Keywords: Colour, Colour Emotion, PAD Scale, Pleasure Arousal Dominance Scale.

1 INTRODUCTION

The effective use of colour in materials, objects, and products enhances reflectivity, visibility, contrast, and legibility. Colour can also be used to entice people, enhance an idea, twist a message, or express a feeling or emotion relating to anything from a product to an environment, an individual, a website or advertising (Triedman and Cullen, 2002, and Lee and Qian, 2005). Much human behaviour is controlled by responses to the five senses, either singly or in combination. To the consumer, the appearance, the feel, the smell, the sound, and the taste of a product or an environment are used to assess quality, both consciously and subconsciously, and so affect product choice (Pointer, 2004-2005). Colour and appearance is the first point of contact for the consumer, this will imply a level of quality, which will or will not then lead them to try a product. It is the affective use of colour in this way that this project will study. This is an important subject area as the results are relevant in many areas of life; colour is used in practically everything we come into contact with. The combination of colour, shape, perception, and psychology is a very powerful one (Guthrie, 2005), so when the influence of these factors is understood, it will enable use of this effect to its fullest extent.

The primary aim of this study is a comparison between the PAD Scale and the Colour Emotion Scale. The secondary aims are to investigate the effects that the following factors (underlined) have on the emotional reaction perceived by an observer: Knowledge background – using observers with and without a background in Colour Science; Culture – Using a group of observers from the UK and also a group from outside the UK; Situation – Approaching real life versus controlled laboratory viewing.

The PAD Scale was originally developed by Mehrabian and Russell (1974) and is designed for use in the study of environmental psychology. The scale takes its name from the three factors that Mehrabian and Russell suggest underlie all emotions. These being Pleasure, Arousal and Dominance:

Pleasure – how much happiness a person feels;

Arousal – the amount of stimulation that is generated in a person by the surroundings;

Dominance – how 'in control' a person feels in relation to the surroundings.

The following examples show PAD Scale definitions of various emotion terms (underlined), where scores on each PAD Scale range from -1 to +1: angry (-0.51, 0.59, 0.25 = highly unPleasant, highly Aroused, and moderately Dominant); bored (-0.65, -0.62, -0.33 = highly unPleasant, highly unAroused, and moderately submissive (the inverse of Dominant) (Mehrabian 1995-2005).

The PAD Scale has been widely used in consumer research. There are several advantages to using the PAD Scale. It is well researched, so the word pairs that are used should be well chosen, and (as much as is possible) the opposites of each other. PAD Scale word pairs should cover all emotions, so will give a wider understanding of the affect of colour on emotions without having to select one word pair (or more) for each emotion that would be studied (as would have to happen with the Colour Emotional Scale). Also, there are many different emotional scales in use (Nobbs, 1997 and 2004, Ou, 2004 and Sato, 2004 amongst others), and only one PAD Scale, so this aspect will be useful for continuity and will also make it easier to compare results from one study to another. This is not easily possible with emotional scales, even if only slightly different words are used. As well as the above given advantages, perhaps the main advantage that the PAD Scale offers over the Colour Emotion Scales is that there is a strong likelihood that some Colour Emotion Scales measure word association instead of emotion (for example: warm/cool, elegant/inelegant and healthy/unhealthy), whereas the PAD Scale is more likely to measure true emotion, which is after all, the aim of studies within Colour Emotion.

Although there is debate regarding the suggestion that the three factors that underlie all emotions are Pleasure, Arousal and Dominance; there is a large body of research regarding the different uses to which the PAD questionnaire has been put and critique regarding this. Even if it is an oversimplification to consider just three basic factors, it does at least make it possible to test, and makes the situation approachable for experimental investigation.

Many of the studies considering the use of the PAD Scale have shown that the pleasure, arousal and dominance constructs are sufficient to define all emotions (Holbrook and Batra, 1987 and Mehrabian, 1995). An important consideration, however, is that the PAD Scale is only sufficient to describe other emotions from the basic pleasure, arousal and dominance set when the stimuli selected for the study cover the area to be studied fully. Mehrabian acknowledges the difficulty in doing this.

"*The difficulty to develop broad based and emotionally balanced samples of stimuli may explain the temptation for other investigators to delete the dominance factor and to rely only on the pleasure and arousal factors, or rotations thereof, to describe emotions*"(Mehrabian, 1974).

The PAD Scale has been extensively used in consumer research, including studies that have looked at the affect of colour on consumer behaviour. A recent study in this area (M. Brengman and M. Geuens, 2003), considered the affect of colour and found that for the sample group in question, the main factors were pleasure, tension, excitement and dominance. It was also found that the PAD scores had adequate reliability and validity, although the dominance factor was weak. This observation was a result of factor analysis, and found that the dominance factor had low validity and reliability compared with the results generated for the pleasure and arousal factors. The study (M. Brengman and M. Geuens, 2003) suggested that the dominance factor might be ignored completely as some previous researchers have done (Van Kenhove and Desrumaux, 1997). This supports the suggestion (Russell and Pratt, 1980) that the dominance factor is not applicable in environments that are being assessed for their affective response. There is also evidence that suggests that the applicability of the dominance factor depends on the type of environment setting used (Foxall, 1997). This may explain why the studies in question, and others, have found that the information concerning the dominance factor is less reliable than that concerning the pleasure and arousal factors. It is not unlikely that the reason that these studies have found the dominance construct to be weak is because the sample set used did not sufficiently cover the area under study, as Mehrabian and Russell noted (see the quotation in the previous paragraph). Therefore, as Mehrabian and Russell intended, to ensure that a study of all three emotion factors (pleasure, arousal and dominance) is relevant and useful, it is a matter of applying them as a tool in the correct way to the appropriate design of experiment.

In the study by Brengman et al (2003), the PAD Scale was validated for capturing the emotional responses of observers to store interior colours. Unlike previous studies in this subject area, the study used a range of colour stimuli that attempted to cover a large region of colour space including a range of luminance and chroma, which many other studies have either not covered or have covered insufficiently.

2 METHOD

2.1 Colour Selection

The colours used for the test material have (as much as is practical) a good and even coverage of colour space with as little as possible correlation between the lightness, intensity of colour sensations, and hue. The initial steps for selecting the colours to be used involved downloading the co-ordinates of a list of real colours from the Munsell Colour Order System and converting these values into L* a* b* and L* C* hº values.

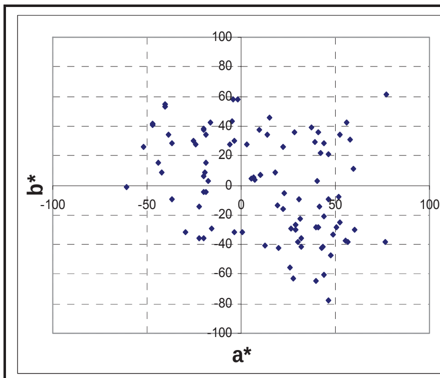

Figure 1: a* versus b* of colour set

Using the L* C* hº values, the boundaries for the x, y gamut and the luminance range of the method of reproducing the colours were identified. Colours outside of these boundaries were then removed from the colour list. The reproducible set of colours was then split into sections. Five colours were then selected randomly from each section in order to give a reduced set of ninety colour samples (see Figure 1: a* versus b* of colour set).

Table 1 reports the correlation between the colour parameters for the reproducible colour set, showing that the objective of negligible correlation was achieved.

Table 1: Correlation of reproducible set of colours

	L*	a*	b*
L*	1.000	-0.237	0.093
a*	-0.237	1.000	-0.356
b*	0.093	-0.356	1.000

2.2 Sample preparation

The co-ordinates of the chosen colours were converted into sRGB values and the test panels printed using a Hewlett Packard inkjet printer. The printed samples created were measured, and the values (target and actual) were entered into a simple printer characterisation model to start characterising the printer. The model was based on the amount of light reflected in three wavelength bands and included factors for dot-gain. Several cycles of this were necessary in order to generate prints of the required colours.

2.3 Focus groups and questionairre design

Several focus groups (with colour knowledgeable, colour naïve, British, and non-British observers) were run in order to generate words that observers would use to describe a range of different colours and surface finishes so that these might be considered for inclusion into the PAD questionnaire. It was decided however, not to include any of the words generated from the focus groups as the emotional content of the words used was limited, making them unsuitable for inclusion into the questionnaire.

2.4 Observer tests

The observers consisted of two groups, those from inside (colour experienced) and outside (colour naive) of the department. There was also a non-british group as it has been shown that culture affects the perceived emotion. All observers have normal colour vision (as assessed by the Ishihara Test). The order of presentation of samples and emotion scales was randomised for each observer.

The semantic difference method of self-reporting was used to obtain sensory data describing the emotional response of observers to coloured panels. During an experiment, an observer looked at a coloured panel under controlled conditions and selected a point on a seven point bipolar scale between the word pairs, stated by the PAD Scale, that they felt best describes their impressions of that colour. See Table 2 for the PAD Scale word pairs. Like and dislike were also added in order to judge the observer preference for each colour.

Table 2: PAD Scale word pairs

Dominant	Submissive	Frenzied	Sluggish
Satisfying	Unsatisfying	Exiting	Calming
Stimulating	Relaxing	Controlling	Controlled
Jittery	Dull	Autonomous	Guided
Hopeful	Despairing	Influential	Influenced
Happy	Unhappy	Arousing	Un-arousing
Pleased	Annoyed	Important	Awed
In control	Cared for	Contented	Melancholic
Wide awake	Sleepy	Relaxing	Boring

As described in the previous paragraph, each word pair used was on a 7 point scale. This is a bipolar scale. However, when designing a questionnaire it is usually considered to be better to use a unipolar scale as a bipolar scale necessitates finding opposites to the words being used, and it is often difficult to do this successfully (Chambers and Baker-Wolf, 1996). In this case, however, a well researched and widely used scale is used so in this instance a bipolar scale is considered to be suitable.

It is generally suggested that ratings scales should not usually have less than 5 categories. The discrimination and reliability of the results is often assumed to increase with an increased number of segments. However, beyond 9 segments this increase is only slight and the noise that is generated is not sufficient to make up for the increase in discrimination (Chambers and Baker-Wolf, 1996). For these reasons, a 7 point scale was considered to be the most appropriate for giving a good level of discrimination, without generating noise that would detract from the results.

Affect of viewing conditions on the observer reported emotion was also investigated. Judgements on coloured cards were made in the following three settings; i) Using a viewing cabinet with neutral grey background and D65 light, viewers requested not to touch the samples. The viewing cabinet will be placed in a darkened room; ii) In a room illuminated with D65 lamps (replacing the usual light sources), samples placed an a table covered by a neutral grey piece of card, viewers requested not to touch the samples; iii) In a room illuminated with D65 lamps (replacing the usual light sources), samples placed on a natural wood surface table and viewers allowed to touch and move the samples.

2.5 Analysis of results

After defining the emotions from the word pair answers, the results will be analysed in order to create predictive equations. These may then be used to predict the most likely emotional response to the appearance of coloured materials. Factor analysis will also be used to understand which variables have the greatest effect on the emotional response to the colour and in what way this is affected.

2.6 Current status of work

The colour selection and initial sample creation steps have been completed. The printer characterisation is progressing and is expected to be completed shortly. The observer tests will start as soon as the printer characterisation is completed.

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Colour Emotion and Area Proportion

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ABSTRACT

This study investigates the effects of area proportion on colour emotion using psychophysical methods. The results suggest that the effect was significant only for colour combinations having great difference in colour emotion values between the constituent colours, especially for the "heavy-light" scale.

Keywords: Colour emotion, colour semantics, colour meaning, area proportion

1 INTRODUCTION

Colour emotion has been used in recent years for an intensively studied research area which uses quantitative approaches to investigate the relationship between colour and semantic words (while some of the words were in fact real emotion terms, such as "exciting" and "calming"). A number of studies in this area have been carried out for single colours [1-3] and for two-colour combinations [4-6]. For the latter, the results were based on stimuli with equal-sized colours, and have been thought to be insufficient for practical use in design work. Therefore, the present study used a number of colour combinations as the stimuli, each consisting of three colour chips with different sizes, in order to see whether different proportion lead to different colour emotion scores for the same constituent colours.

2 METHODS

The aim of the study is to investigate any influences of area proportion on colour emotion. To achieve this, visual assessments of three colour emotion scales, i.e. "warm-cool", "heavy-light" and "active-passive", were conducted using the method of categorical judgement [7].

2.1 Colour Stimuli

Thirty colour combinations (each containing three constituent colours), generated randomly by 35 colours, were used as the stimuli in the experiment. As shown in Table 1, these 35 colours were selected to cover a large gamut in CIELAB space. For each of the 30 colour schemes, 7 area ratios were set up in determining sizes of each constituent colour, including (4:1:4), (3:1:3), (2:1:2), (1:1:1), (1:2:1), (1:3:1) and (1:4:1). An illustration of these area ratios is shown in Figure 1. This resulted in 30 x 7 = 210 stimuli for each participant to view in the experiment.

Table 1 CIELAB specifications of the colour samples

	L^*	C^*_{ab}	h_{ab}
1	35.2	52.2	53
2	57.7	58.8	24
3	80.2	62.4	357
4	35.4	35.5	320
5	35.4	21.6	330
6	35.4	32.0	358
7	35.2	46.3	49
8	80.4	22.7	13
9	80.3	25.7	5
10	80.2	30.5	342
11	80.2	21.9	357
12	80.3	19.5	12
13	57.7	22.5	18
14	57.7	27.5	356
15	57.7	17.1	344
16	35.2	24.6	15
17	35.5	26.8	327
18	35.4	22.3	357
19	80.3	16.0	357
20	80.3	10.6	353
21	80.6	6.9	4
22	57.6	11.1	8
23	57.6	13.0	3
24	57.7	16.4	346
25	57.6	10.2	357
26	57.8	8.3	7
27	35.3	10.9	13
28	35.3	14.0	357
29	35.2	8.2	347
30	35.3	9.6	14
31	11.8	1.6	0
32	35.5	3.3	356
33	57.7	4.2	357
34	80.3	5.0	357
35	100.7	1.0	359

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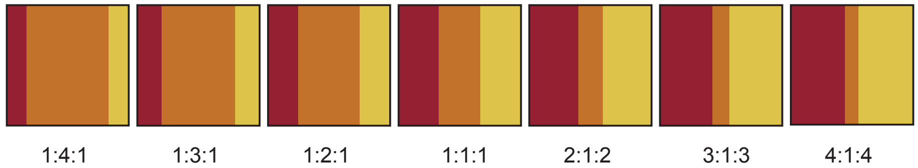


Figure 1 Seven area ratios were used in the experiment

2.2 Experimental Set-up

The experiment was conducted using a calibrated cathode ray tube (CRT) display in a darkened room. Fifteen participants, all Chinese students at the University of Leeds, including 7 males and 8 females, took part in the experiment.

Figure 2 shows the experimental layout, indicating that a medium grey with a lightness value of 50 was used as the background. Three word pairs, "warm-cool", "heavy-light" and "active-passive", were used in the experiment as these have been found to be the main underlying factors of colour emotion [1-2, 8]. Each word pair was presented on a seven-category scale, e.g. "very warm", "warm", "a little warm", "uncertain", "a little cool", "cool" and "very cool".

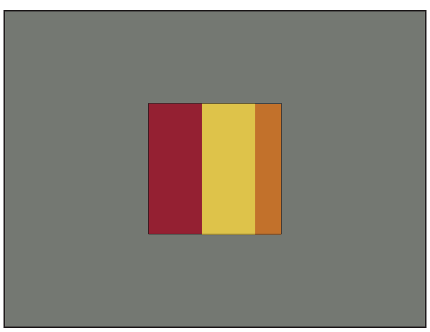


Figure 2 Experimental layout

2.3 Research Hypotheses

The present study hypothesises that the psychophysical models for single-colour emotion [2] and for colour-pair emotion [4] developed recently by the co-authors can well predict visual results obtained from the current experiment, with consideration of area proportion. The single-colour models under test included "warm-cool" (WC), "heavy-light" (HL) and "active-passive" (AP), as shown in the following:

$$\mathrm{WC} = -0.5 + 0.02\,(C^*_{ab})^{1.07}\cos(h_{ab} - 50°) \quad (1)$$

$$\mathrm{HL} = -2.1 + 0.05\,(100 - L^*) \quad (2)$$

$$\mathrm{AP} = -1.1 + 0.03\,[(C^*_{ab})^2 + (L^* - 50)^2]^{1/2} \quad (3)$$

where L^*, C^*_{ab} and h_{ab} are the three colour-appearance attributes lightness, chroma and hue angle, respectively, in CIELAB system [9].

The colour-pair model under test is shown in the following:

$$E = (E_1 + E_2)/2 \quad (4)$$

where E represents the colour emotion value for an entire colour pair; E_1 and E_2 represent colour emotion values for the two constituent colours in that pair, and can be determined using Equations (1) to (3).

Note that the present study uses three-colour combinations as the stimuli. It was thus assumed that Equation (4) can be extended to the following, given that the three constituent colours share the same size:

$$E = (E_1 + E_2 + E_3)/3 \quad (5)$$

The study further assumes that in a colour combination, the contribution of each constituent colour to the emotion value of an entire combination is proportional to the size of that colour area. Accordingly, Equation (5) was modified into:

$$E = (a_1E_1 + a_2E_2 + a_3E_3)/(a_1 + a_2 + a_3) \quad (6)$$

where E represents the colour emotion value for an entire colour combination; E_1, E_2 and E_3 represent colour emotion values for the three constituent colours in that combination, and can be determined using Equations (1) to (3); a_1, a_2 and a_3 represent the area for each of the three colours.

3 RESULTS

To see whether the hypotheses described above really worked for the present study, the colour emotion values predicted by Equations (5) and (6) were calculated using the experimental data, in which the colour emotion value for each constituent colour was determined by Equations (1) to (3). Predictive performance of each equation was measured using the Pearson product-moment correlation coefficient (r) between the visual results and the values predicted using the equation in question.

The results are shown in Tables 2(a) and (b) for Equations (5) and (6), respectively, indicating good predictive performance for both equations, with a mean correlation coefficient of 0.86 for Equation (5) and 0.87 for Equation (6). Note that Equation (5) is a simple "average" model and that Equation (6) considers area proportion by adding proportion values into the model as the weighting. Therefore, the two figures (i.e. 0.86 and 0.87) suggest that area proportion had little impact on colour emotion.

In addition, Table 2(a) shows that the correlation coefficients for each area ratio are virtually equal (e.g. 0.86 for 1:4:1, 0.87 for 1:3:1, etc). This also suggests that there the effect of area proportion was insignificant.

To find out why there was little impact of area proportion, we looked into every single colour combination used in the experiment, with an assumption that the significance of area proportion was perhaps related to colour emotion difference between constituent colours within each colour scheme.

First, a measure of colour emotion difference (ΔCE) for each colour scheme was established, as shown in the following:

$$\Delta CE = \left| E_2 - \left(E_1 + E_3 \right) / 2 \right| \tag{7}$$

where E_2 represents the colour emotion value for the colour at the middle of a colour combination; E_1 and E_3 are colour emotion values for those on the two sides within that combination.

Figures 3(a) to (c) show colour emotion difference values plotted against the predictive performance of Equation (6), in terms of correlation coefficients (r) between the predicted values and the visual results for various area ratios within each colour scheme. Since Equation (6) was based on area proportion, the r values shown here can represent the effects of area proportion; the higher the r value, the more significant the effects of area proportion.

The diagrams show that colour combinations with high ΔCE values tend to have high r values, thus having great influence of area proportion. This tendency was found to be significant especially for the "heavy-light" scale, indicating that the impact of area proportion was most significant for this word pair.

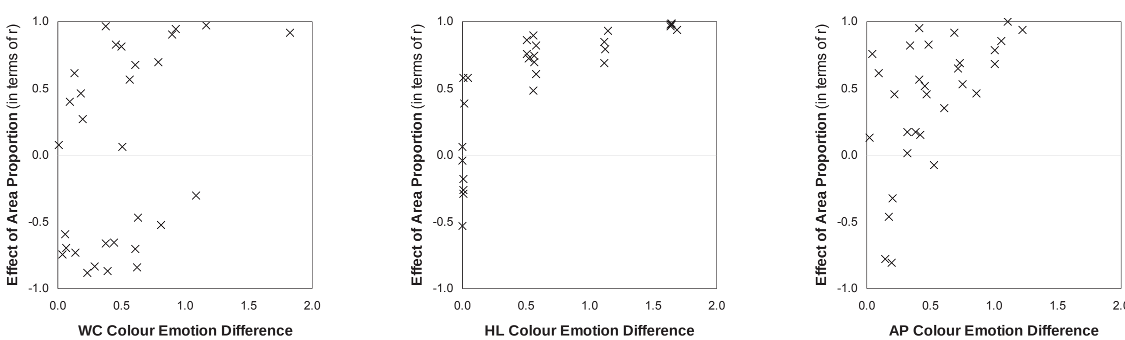
Table 2 Predictive performance (in correlation coefficient) of (a) Equation 5 and (b) Equation 6

(a)

	1:4:1	1:3:1	1:2:1	1:1:1	2:1:2	3:1:3	4:1:4	All
WC	0.84	0.85	0.85	0.87	0.87	0.88	0.87	**0.86**
HL	0.91	0.94	0.93	0.95	0.94	0.93	0.95	**0.93**
AP	0.82	0.83	0.83	0.81	0.77	0.76	0.76	**0.80**
Mean	0.86	0.87	0.87	0.88	0.86	0.86	0.86	**0.86**

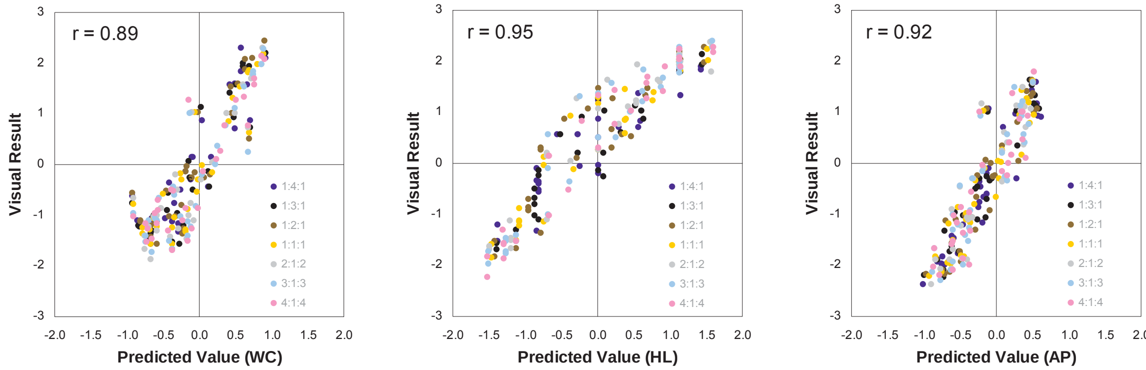
(b)

	1:4:1	1:3:1	1:2:1	1:1:1	2:1:2	3:1:3	4:1:4	All
WC	0.89	0.88	0.88	0.87	0.85	0.85	0.83	**0.87**
HL	0.92	0.93	0.92	0.95	0.96	0.96	0.97	**0.95**
AP	0.81	0.82	0.82	0.81	0.79	0.79	0.79	**0.80**
Mean	0.88	0.88	0.87	0.88	0.86	0.87	0.86	**0.87**



(a) (b) (c)

Figure 3 The effects of area proportion (in terms of Pearson r) plotted against colour emotion difference between constituent colours in each colour combination for scales (a) warm-cool, (b) heavy-light and (c) active-passive.



(a) (b) (c)

Figure 4 Predictive performance of Equations 8, 2 and 9, based on Equation 6, for scales (a) warm-cool, (b) heavy-light and (c) active-passive, respectively.

As shown in Tables 2(a) and (b), the predictive performance of psychophysical models "warm-cool" and "active-passive" was not as good as that of "heavy-light". Modified models of these two scales were then developed, as shown in the following:

$$\text{WC'} = -0.22 + 0.15\,(C^*_{ab})^{0.6}\cos(h_{ab} - 20°) \quad (8)$$

$$\text{AP'} = -1.43 + 0.03\{(C^*_{ab})^2 + [(L^* - 40)/0.85]^2\}^{1/2} \quad (9)$$

where L^*, C^*_{ab} and h_{ab} are the three colour-appearance attributes lightness, chroma and hue angle, respectively, in CIELAB system.

Predictive performance of the models (based on Equation 6) are shown in Figures 4(a) to (c), with a correlation coefficient of 0.89 for "warm-cool", 0.95 for "heavy-light" and 0.92 for "active-passive".

4 CONCLUSIONS

The study investigates the effect of area proportion on three-colour emotions for scales "warm-cool", "heavy-light" and "active-passive". The results show that such effect was perhaps only significant for colour combinations with a high ΔCE value, in particular for the "heavy-light" scale. To verify these findings, it is necessary to carry out further research with a wider range of colour samples and perhaps a wider range of area ratios for each colour combination to be studied.

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The role of the colour training into the development of the industrial offer

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KEYWORDS: colour training for industry, colour knowledge, industrial world, creation process

ABSTRACT

Within several institutions such as big industrial groups and universities, colour knowledge and know-how training exist but are not teach the same way. Actually, several stakes have to be considered as far as the teachings of what is the colour material and how to use it is concerned.

1. INTRODUCTION

In the first time, we will try to understand how the colour design notion could be considered as a know-how isolated from every notion of productivity and mass broadcast, as a very artistic practice which theories open mind to new creation possibilities.
Then, we will consider the colour trainings in professional areas where colour classes are given and we will try to identify their main stakes.
At the end, we will focus on the understanding of political stakes of the colour training in industrial areas, questioning ourselves permanently.

2. COLOUR TEACHING : TOWARDS A PROJECT ISSUE

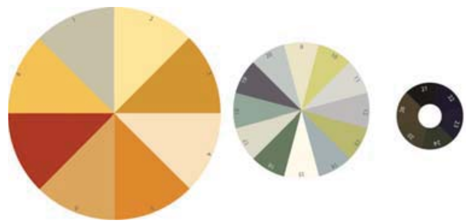
A colour training, in a design school opens the mind towards another way to apprehend the material itself as well as the creation process. The shape leaves its place to colour and the using notion leaves the place to the pure percept.
Colour feeds by its plurality the formal and technical research as colour is a multiple material, a material which can wear the object, protect it and give it an existence in the world.

2.1 From the percept to the concept

The student who has to carry out a project with a colour issue will have to interrogate the notions of materials and colour and make **modelization**s.

By this way, the colour modelization makes it possible to reuse tangible information coming from its perception (for example colours of stones from traditional buildings) in order to put it in a new context and create a new product.
The colour, once isolated from its former function, will begin a material for creation.

1 et 2 : Students work, Piquecos' chromatic chart, France, Preliminary studies.



3 : Students work, Piquecos' chromatic chart, France, Modelization of colours for frontages

This creation coming from a thinking based on colour and material will then integrated into a conception process linked to the designer's requests.
The very fact of having interrogated the material and having carried out a specific analysis and then a modelization will provide credibility to the creation act.
Thanks to this process, a designer trained to colour achieves much more easily to consider the "decoration" issue (of which colour is one of the key components) not like a pejorative aspect of design, but like a necessary condition for the very existence of the object.

For Alessandro Mendini, the « modern designer » is different from the one of the industrial period, he is more female, he thinks space as a cosy and warm cloth, and he prefers the word "live" (abitare) to the word "project" (projettare). [1]
This contemporaneous designer he describes is the designer who thinks colour and for him, colour is "clothing" or "makeup", it has a decorative value.
"We come back to the idea of colour as a language, an alphabet: it becomes a signs system which takes part of the three main components of an object, that is to say the shape, the colour and the decoration".[2]
Those quotes coming from a book written for the Sikkens brand testify of a successful collaboration between an artist and an painting manufacturer, in order to promote products but also to create new range of products, enriched and created by the designer.

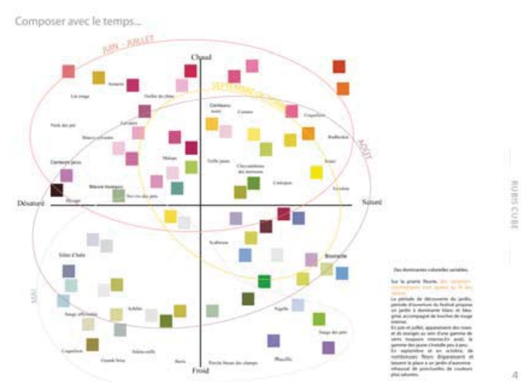
2.2 Colour modelization

Taking into account the industrial reality, the notion of range of products which is at the very heart of colour conception is also an important notion to teach as no industrial object works like a unique object. They form part of a « collection ».

At the Professional University Institute of Applied Arts in Montauban, where classes about colour theories are given as well as classes about project practices, the colour is teach as a mean to have access to the expertise of the project based on colour and material.
The industrial sector as well as the colour jobs are of course present in order to make it possible for the students to be both in a poïetical position (they question the knowledge and the know-how at the same time) and in the position of future professionals of colour, from the perception to the conception and from the conception to the realization.

So students learn to talk about colour but also to communicate about and with the colour : that is why they use colour codification systems created by industrials (ACC, NCS, RAL…) and create project communication tools.

Then, the colour map, a tool as many others, makes it possible to wonder about the colour systems issue.
From Newton to Chevreul, experts created colour systems to make it express itself. From JP Lenclos to Kobayashi, colour, thanks to the colour systems, offers new readings of socio-cultural spaces, of their codes and symbols.



5 : Colour map, hue classification by chromatic areas.

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3. THE SENSIBILISATION OF INDUSTRIAL WORLD TO COLOUR ISSUES

In the industrial world, the colour training has more commercial objectives: it has to promote products, but it is not the unique objective.

3.1 To promote the knowledge in order to promote the product « colour »

The benefits that result from a colour training are necessary in every area of the industrial creation and the building sector.
Nevertheless, step by step, numerous stakes appear as colour training makes it possible to question, on a regular basis, the creation process as well as the production one and gives the opportunity to discover constant innovation in this area.
If a painting manufacturer wishes to train the painters who use its products it is, of course, to value the qualities of their products, but also to provide him with the keys of more thought and more qualitative harmony creations.
And when it deals with internal training, persons in charge of the industrial product promotion will be able to sell, thanks to the colour training, a product which aesthetical features are known and are communicable.
Usually, the colour training should also sensitize industrial professionals to a sensible and an artistic knowledge, a knowledge which is often far from their day-to-day preoccupations.
The colour training has also to give sense to an harmony, to the space transformation through colour use and to every percept linked to the colour material.
Last but not least, colour training should entail perpetual interrogations about creation process set up for economic and marketing reasons.

Tools that make it possible to set up a reflection about colour in industrial sectors are first, tools of experimentation of the colour phenomenon (experiments of the coloured prism, of colours mix), but also tools to put projects in situation, tools for coloured spaces simulations which make the trainees compose with colours in fake spaces.
Obviously, their creations will have to be described and explained, which make it possible to theorize a phenomenon that is difficult to link to an objective knowledge.
Every parameter in relation with colour could be used (physiological, physical, psychological, sensitive, aesthetical…) in order to produce objective arguments to justify the use of the chosen colour and its aspect.

6 : Farer, closer : analyse of the impact of distance on the hue perception.

7 : Compose with colour : example of an harmony in camaïeu

3.2 Ethic and political involvment

Colour is a phenomenon so linked to our perceptions that it is sometimes difficult to consider it objectively and to make distinction between our tastes and objective knowledge.
And when a creative, a colourist, enters into an industry it is of course to bring its knowledge and its trainers skills but not only :

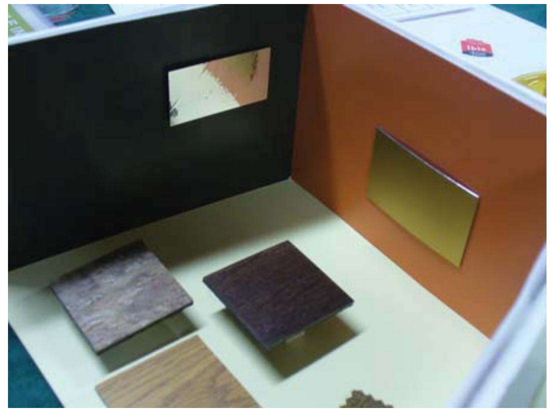
The commercial and the prescriptor, waited by their superiors on competitive results, want always to sell a product without wondering themselves about the validity of this product from an aesthetical point of view as well as from a technological, ecological and durability points of view. So they will suggest very often a "broken white" to hide a lack of expertise by a neutral chromatic answer.
This consensual response, which aims at preventing visual aggressions, will lead to the development of a urban space completely asepticized.

Then, thousands of litters of setting coats sold every year by industrials will have an impact, not only on the urban landscape but also on traditional practices and, sometimes, on the environment.
Think about the impact of what we produce on the visible world it is also think about our role in the society.
The theorical approach of colour which gives a sense to our culture an its specificities, as well as the practical approach, which will confront ourselves to our sensibility but also to our culture of colour, can and should entail interrogations.
Colour is a material with infinite features and the industrial, after a colour training, could question the stakes in relation with this material.

So, a company that wonders about its products and their political validity is a company that positions itself towards research and development: the search for a better living, to take into account, beyond the market, the people's expectations, motor of change.
Thus, the research in human sciences and in the arts and urban and architectural innovation has an important role to play in enterprises.

Its first role is to file information about traditional material and colour, in artisanal and local practices, in order to restore them in the coming future.
Then, it should position itself in relation with the new technologies without forgetting that every material is a material that we see, that we touch, a material that contributes to build our daily environment.

8 : Colour training for industrials



9 Exercice of interior space simulation with industrials (colour and materials samples).

CONCLUSION

To be sensible to the material, to the object itself which is at the very heart of the industry, is to be sensible to the reality of what is manufactured. But to be sensible to the material is also to see beyond the matter, in another light, the colour material, a transitory material.

Though, to offer colour training to many manufacturers, is to offer them the possibility to question perpetually their raw materials.
As far as the pedagogy itself is concerned, it is, obviously, the basis of the relation with trained people: once again, colour creates links and set up a relation to the others, a relation to the world which is specific to the colour itself .

As Giacomo Balla means, « today we would like to abolish (…) every neutral, pleasant, faked, fantasist, half-dark or humiliating hue. (…) Thus, future clothes will be… happy. Coloured fabrics and iridescent filling with enthusiasm. Use muscular coloured, very violet, very turquoise, very green, very yellow, orange, vermilion.
If the government does not decide to wear out its passeist clothes of fear and indecision, we will double, multiplicate by hundred the red of our flag"[3]

We should inspire ourselves from this futuristic utopia in order to make the key players of our time to innovate and question the past, for a future leading to renewal.

[3] Giacomo Balla, *the unneutral wearing*, futuristic manifest, Milan 1914.

Warm and cold colours

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ABSTRACT

A group of 12 observers evaluated the perceived warm and cold appearance of 130 colours, chosen to represent the NSC colour solid, in independent trials. Results show that subjective colour temperature changes abruptly passing from hues below to hues above 120°, and the same brusque change appears around 330° in the CIELAB colour system; saturated colours are warmer; very dark and very light colours are cold. These results and the mathematical model then derived agree well with previous studies and supply detailed data on the boundaries in the colour solid separating the cold from the warm colours.

Keywords: subjective colour temperature; warm and cold colours; cross-sensorial perception.

1 INTRODUCTION

The distinction between warm and cold colours is very old, rooted in the colour language itself[1] and of great perceptual importance. Although largely used, a precise definition of which are the warm and the cold colours is seldom given, the reported reason being that the distinction is evident to all people. The reference to the experience of thermal sensations with warm and cold objects of specific colours seems irrelevant to explain the distinction. The characterisation of colours according to their perceived temperature is always found in research using the semantic differential[2,3], and it almost always appears as an independent factor in factorial analysis[4].

This research is directed to experimentally specify, in a standard colour system and in a controlled situation, which colours are perceived as warm and which as cold.

2 METHOD

An accurate choice of 130 colours (Figure 1) has been made by splitting the whole set of colours listed in the NCS Colour Atlas[5] and described inside the CIELAB system, in eight horizontal layers as a function of their lightness (from $L^* = 20$ to $L^* = 99$).

The whole colours solid was moreover vertically divided in 10 equispaced sectors roughly corresponding to the five main hues (Y, R, P, B, G) and their intermediates.

Ten colours were taken from the first ($20 < L^* < 30$), the second ($30 < L^* < 40$) and the last layer ($90 < L^* < 99$), one for each hue sector, at a short distance from the achromatic axis. From the other five layers ten colours were taken at a relatively short distance from the achromatic axis (Figure 1a) and more ten at a larger distance (Figure 1b).

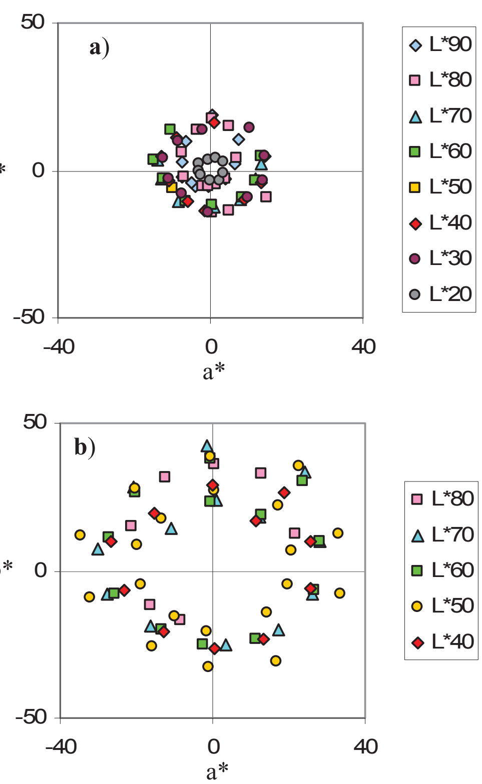

Figure 1. The less chromatic colours used in the experiment are plotted in **a)**, while the more chromatic colours are plotted in **b)**.

The coloured area (21° x 17° at a viewing distance of 70 cm) was displayed at the centre of a 39.5 × 29.5 cm screen of a CRT 19' monitor (Barco Reference Calibrator V); the left and upper sides were surrounded by black and the other two lower and right sides by white background (0.1 and 80 cd/m^2 respectively). To mask possible after images, a 1-sec full screen chessboard with 1 × 1 cm light and dark grey squares (54.9 and 7.0 cd/m^2, respectively) was presented before each stimulus, with the offset of the mask coinciding with the onset of the stimulus.

3 PROCEDURE

Twelve observers volunteered in the experiment, the two authors who made a series of 5 complete trials, and a group of ten university students who went only once through the whole procedure. In a first run the task consisted in evaluating in a Likert scale (from 1 to 7) how much warm was the observed colour. In a second run the observers had to evaluate the cold instead of the warm appearance. The evaluation order was inverted for half observers. There was no time limit. Given the length of the task, observers were allowed a rest any time they liked.

3 RESULTS

The separate assessments of the cold and warm colour appearance were highly consistent (Pearson correlation $r = 0.96$, $p < 0.0001$).

Therefore the two evaluations were transformed into a unique value between 100 and -100, with positive numbers for the warm colours and negative for the cold ones. Results are shown in Figure 2.

Results show that the warm-cold dimension characterizes two well distinct groups of colours as a function of their hue: there is a well clear-cut change in the evaluations around 120° and 330° hue angles. The interval between these two angles contains the cold colours while all the other colours appear mostly warm.

More chromatic colours appear significantly warmer, and less chromatic colours appears significantly cooler (this effect can make cold the colours belonging to 'warm' hues).

Saturated greens are the least cold in the group of the cold colours (Figure 3), but still they appear cold, while some desaturated reddish colours (from magenta to yellow-green) appear not only less warm but also positively cold (Figure 4).

There is no statistical difference in the perceived temperature as a function of the lightness (L*), as it appears in Figure 5. Nevertheless very dark colours, under L* = 35, are always cold, and this is true also for the very light ones; only in the range 35 < L* < 85 colours can appear warm.

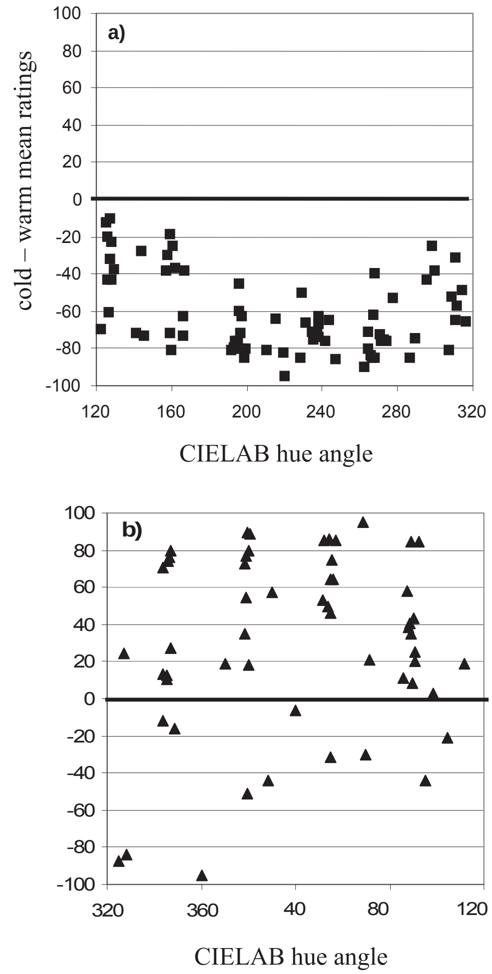

Figure 2. Mean ratings of the cold (negative, **a)** – warm (positive, **b)** appearance of the various colours as a function of their hue angle in CIELAB.

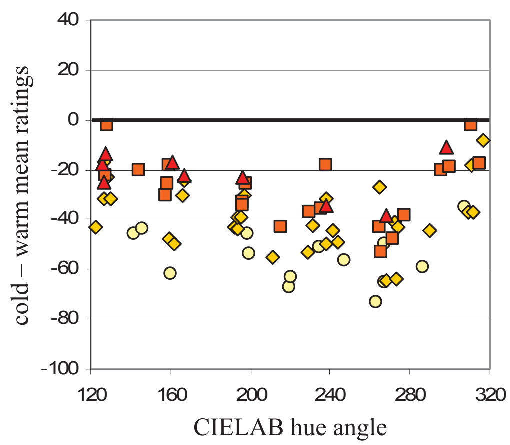

Figure 3. Mean ratings of the cold colours as a function of their chroma (circle = C* < 10; diamond = 10 < C* < 20; square = 20 < C* < 30; triangle = C* > 30) and hue angle in CIELAB.

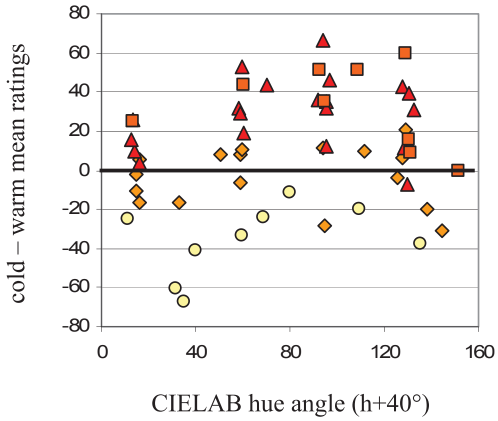

Figure 4. Mean ratings of the warm colours as a function of their chroma (circle = $C^* < 10$; diamond = $10 < C^* < 20$; square = $20 < C^* < 30$; triangle = $C^* > 30$) and hue angle in CIELAB.

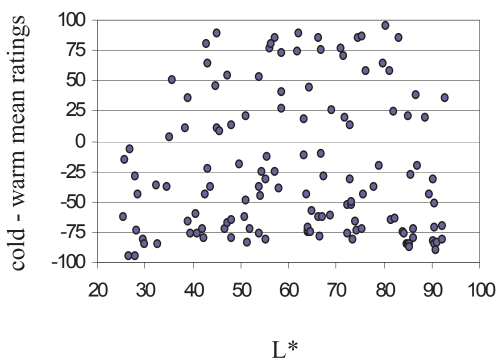

Figure 5. Mean ratings of the warm and cold colours as a function of their lightness.

5 TOWARDS A MODEL

This study was focused on the determination of the regions of the colour solid which characterise the warm and the cold colours, respectively. Factorial analysis in previous research[3,6,7] showed that one factor in judging colour appearance is always the warm / cold dimension, almost always saturated by the semantic scale 'warm-cold', and for this reason we limited our inquiry to his dimension. The observers' task was to give, in two separate runs, a direct measure of each colour aspects, i.e. the warm and the cold appearance of the selected colours. In other recent works the study was extended to a number of semantic scales, and the colour dimensions derived by a factorial analysis were colour activity, colour weight, and colour heat in one research[6], and colour activity, potency and warm-cold in another research[9]. Another recent work[8] compared the performance of three groups of observers as regard to a dozen of semantic scales, one of which was warm – cold, where the task consisted in choosing one appropriate adjective for each observed colour.

In general all results seem to agree quite well as regard to the role played by hue, lightness, and saturation in determining the perceived temperature of the colours, and often a mathematical model has been proposed.

Some limitations in the comparisons are due to the different number of examined colours (20[6], 218[8], 130 here), the different size of colour patches (7.5 x 7.5 cm[6], 1.0 cm x 1.5 cm[8], 30 x 20 cm here), and the different procedures (pair comparison[6], direct estimation here). Nevertheless the resulting models not only fit well their own data ($R^2 = 0.74$[6], $R^2 = 0.862$[8], $R^2 = 0.898$[here]), but also correlate well one each other.

Colour heat[6]:

$$= -0.5 + 0.02\,(C^*)^{1.07} \cos(h - 50°) \qquad (1)$$

$$WC^{8}_{0° \le h \le 180°}: \qquad (2a)$$

$$= 0.154\,L^* + 39.378\,C^{*\,(0..372)} - 0.303\,h - 113.855$$

$$WC^{8}_{180° \le h \le 360°}: \qquad (2b)$$

$$= 0.355\,L^* + 23.476\,C^{*\,(0.429)} - 0.159(360° - h) - 105.71$$

Our model for the $W_{arm}C_{old}$ dimension:

$$= -40 + 20/a \log(C^*) \cos(h - 40°) \qquad (3)$$

where $a_{0° \le (h+40°) \le 160°} = 2$; $a_{160° \le (h+40°) \le 360°} = 0.3$

First of all lightness does not appear in equations (1) and (3), as it results nearly irrelevant in affecting the warm-cold dimension of colour, while it is linearly included in (2a) and (2b), although its influence is not relevant in that work too[7]. Secondly, al the equations (1), (2a) and (2b) perform relatively well ($R^2 = -0.83$) in predicting the present data, but the last equations do still better ($R^2 = -0.855$) if the parameters for the Thailand observers are used instead of those for the Hong Kong subjects (L^*, $x_1 = -0.331$, $x_2 = -0.315$; C^*, $y_1 = 11.2$, $y_2 = 0.016$; h, $z_1 = -0.389$, $z_2 = -0.321$; C^* index, a = 0.621, b=2.05; constant, $c_1 = -44.7$, $c_2 = -12.1$). Moreover equations (2a) and (2b) with a set of specific parameters for the Italian observers (L^*, $x_1 = 0.19$, $x_2 = 0.19$; C^*, $y_1 = 34$, $y_2 = 30$; h, $z_1 = 0.29$, $z_2 = 0.29$; C^* index, a = 0.36, b = 0.35; constant, $c_1 = 111$, $c_2 = -99$) fits our data still better ($R^2 = 0.883$).

4 CONCLUSIONS

This research shows that there is a high correspondence between the warm and the cold evaluations, which were given independently, and that warm hues are clearly distinct from the cold ones. Moreover, in agreement with previous findings[2,3,6,8] chromaticness (or chroma, or still saturation) is another relevant dimension affecting the warm-cold aspect of colours, being the more saturated colours warmer (or less cool). Lightness plays a minor role: at both extremities of the lightness interval colours appear cold, and this effect is more pronounced in the dark region,most probably because colours in these regions are also little chromatic.

In this research all colours were singularly presented in random sequences and therefore neither spatial nor temporal effects were considered. The mathematical model expressed by equation (3), in comparison with similar models, seems to be quite accurate in predicting our data.

Further research is needed to study how spatial and temporal interactions can modify the warm-cold attributes of colours, with the hypothesis that contrast effects will accentuate the differences in apparent temperature here determined in decontextualized colours.

Acknowledgments

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Color preference affected by mode of color appearance

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ABSTRACT

Most of color preference works focus on colors in surface color mode. However, there are several modes in our daily life. To explore the relationship between color preference and mode of color appearance, the experiment I was examined. Thirty-three color chips were chosen from the Munsell notation varying in hues and chromas. The color chips were presented in different color appearance modes. The results showed the brighter and more chromatic colors were more preferred. The subject preferred color in light source color mode to color in the other modes. In experiment II, we investigated the relationship between color preference and the perceived color attributes. The results showed that the preference score increase with increasing perceived chromaticness and decrease with increasing perceived whiteness or blackness. We found that both perceived whiteness and blackness play a role as underlying mechanism on the determination of the color preference on different color appearance modes. Consequently, we suggest that the color preference is dominated not only by physical color attributes, but also by mode of color appearance.

Keywords: Color preference, Color appearance mode, Color appearance mode preference, Color appearance mode index

1 INTRODUCTION

Color preference is a powerful tool to attract a subject's attention and to arouse the desire to consume. Color preference may be influenced by differences in age, gender, geographical region[1] or cognition.[2] Studies on color preference for single color have long focused on the hue effect. Previous studies showed what hues were generally preferred and what hues were not.[2-3] Most of these work have been done with surface color mode samples of moderate size and relatively high color purity. In our daily life, however, colors appear not only as surface color mode, but also as fluorent and luminous color modes.

The color of the object can be perceived in various modes of color appearance depending on the situation. The color appearance mode can be classified into three different modes: object color mode (OB-mode), unnatural object color mode (UN-mode), and light source color mode (LS-mode). According to the Recognized Visual Space of Illumination theory (RVSI), the color appearance modes are related to the recognized illuminance of an environment in which the object is placed.[4] The color appearance mode can be changed by adjusting the intensity of environmental illumination and the luminance of objects.

It would be important to know whether color preference remained static or not when the mode of color appearance had been changed while x-y chromaticity coordinates of the color kept unchanged. Two experiments were conducted for this study. In experiment I, we investigated the relationship between color preference and color appearance mode. Because of the change in amount of chromaticness, blackness, and whiteness for luminance increase of color chips,[4-5] in experiment II we investigated how the perceived color attributes relate to color preference.

2 EXPERIMENT I

2.1 Method

The apparatus was composed of subject's room and test chart's room separated by a wall having a 1^{o} square aperture. Subject's room was 1.3 x 2 x 2 m^3 (W x L x H) which was decorated with wallpaper of about N9 and illuminated by fluorescent lamps. The intensity of the lamps was adjusted by a light controller and the room illuminance was measured by an illuminometer placed on a shelf below the test stimulus at a distance of 44 cm. Many objects such as artificial flowers, dolls, books were put into this room. Color chips to serve as the test stimuli were attached to a rotating wheel placed in test chart's

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room. They were illuminated by fluorescent lamps. The subject sat in subject's room and looked at the aperture from a distance of 1.3 m.

Thirty-three color chips selected from the Munsell Color notation were used as the test stimuli (Table 1). Five subjects participated in this experiment. There were two sections for each subject. First, subjects were asked to answer the degree of color preference for each color by using the scale which was divided into 7 levels, as -3 (dislike) to +3 (like). Second, subjects were asked to judge the color appearance mode. Subjects were instructed to look around and not stare at the color chip. Within each session, 16 or 17 color chips were randomly presented at six experimental conditions to make 96 or 102 determinations. Each subject has done five sessions per condition. The experimental conditions were composed of the combination of 2 subject's room illuminance levels (I_S:50, 500 lx) and 3 test chart's room illuminance levels (I_T:300, 500, 700 lx).

Table 1 Color samples in Munsell Color Notation used in this study.

Hue	5R	5YR	5Y	5GY	5G	10BG	10B	5P	N
Value/ Chroma	5/2	5/2	5/2	5/2	5/2	5/2	5/2	5/2	5
	5/5	5/5	5/5	5/5	5/5	5/5	5/5	5/5	
	5/8	5/8	5/8	5/8	5/8	5/8	5/8	5/8	
	4/14	6/14	8/14	6/10	3/10	4/9	4/10	4/10	

2.2 Results and Discussions

For each color chip, the preference scores for the five subjects were averaged. The scores of 5YR and 10BG are plotted against different chromas in figure 1. Results showed the higher the chroma, the higher the preference score. The same tendency occurred in all conditions. Our result agrees well with previous works. Guilfore,[6] Smets,[7] and Guilford and Smith[8] all stated that subjects preferred vivid colors to grayish colors. However, it was noted that the score of 5G, 10BG, and 5P are lower at fully saturated chromatic color. It is possible that the Munsell value of fully saturated chroma color among these color chips are less than that of chroma 8.

To see the environmental illumination effect and the luminance effect figure 2 was prepared, where the average preference scores are taken along the ordinate and the luminance of color chips along the abscissa. As environmental illumination effect, the scores of I_S50 conditions were higher than that of I_S500 conditions at low luminance, but the scores become close to each other when the luminance was increased. As luminance effect, the subjects preferred the color chip which was brighter. It was noted, however, the score were quite constant in the I_S50 conditions. It is possible to have color preference constancy at low environmental illumination.

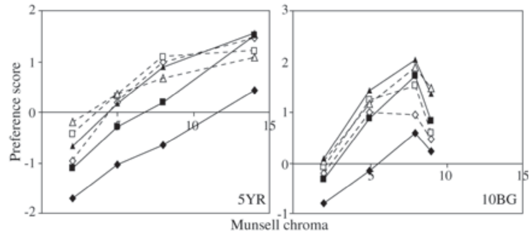

Figure 1 The preference score from average result across all subjects by plotting against chroma for different I_T; 300 (◇), 500 (□), and 700 (△). Filled symbols and solid lines represent data for I_S 500 conditions, whereas open symbols and dashed lines represent data for I_S50 conditions.

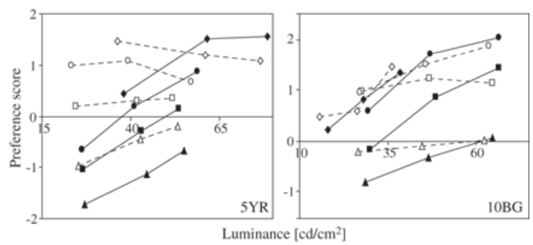

Figure 2 The preference score from average result across all subjects by plotting against chroma for different chromas; 2 (△), 5 (□), 8 (○), and fully saturated chroma (◇). Filled symbols and solid lines represent data for I_S 500 conditions, whereas open symbols and dashed lines represent data for I_S50 conditions.

Next we considered color appearance mode. The raw data accumulated from all subjects were calculated in term of the color appearance mode index (i_{mode}) by following equation:

$$i_{mode} = \frac{a(-1) + b(0) + c(1)}{a + b + c} , \qquad (1)$$

where *a, b,* and *c* are the number of response in OB-mode, UN-mode, and LS-mode, respectively. If $i_{mode} > +0.5$, the color chip was classified in LS-mode, whereas if $i_{mode} < -0.5$, the color chip was classified in OB-mode. If the i_{mode} between -0.5 and +0.5, the color chip was classified in UN-mode.

In figure 3, i_{mode} of all color chips in all conditions were plotted against the preference score. Within each color appearance mode, the preference score increased when the i_{mode} increased. The range of preference score in OB-mode was wider than the other modes; -2.08 to 2.56 in OB-mode, -0.96 to 2.24 in UN-mode, and -0.56 to 2.4 in LS-mode. All color chips in LS-mode and almost in UN-mode dropped in positive side of preference score. This showed the color chips tended to be preferred if they appeared in LS- and UN-mode. It was noted, nevertheless, that the highest and lowest preference scores within each color chip fell in OB-mode (except 5YR, 5Y, and 5GY the highest score fell in the other modes).

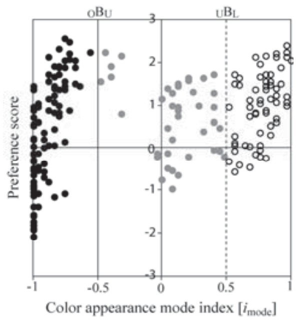

Figure 3 The relationship between preference score and i_{mode} in all color chips. Modes of color appearance are defined by solid dots (OB-mode), gray dots (UN-mode), and open dots (LS-mode). A horizontal solid line in each figure represents the border between OB-mode and UN-mode, whereas a horizontal dashed line represents the border between UN-mode and LS-mode.

3 EXPERIMENT II

Because of the change of color attributes when the color appearance mode had been change,[4-5] in this experiment we investigated the relationship between the perceived color attributes and color preference. The elementary color naming method was used to assess the color attributes of color chips based on the Natural Color System (NCS).

3.1 Method

The apparatus and experimental conditions were the same as the previous experiment. To do elementary color naming four subjects who participated in experiment I were asked to estimate the amount of chromaticness, whiteness, and blackness in the color chip by allocating one hundred points to them.

3.2 Results and Discussions

In figure 4 the preference scores were plotted against perceived chromaticness, whiteness, blackness and saturation. The color appearance modes were drawn with different symbols: OB-mode (solid dot), UN-mode (gray dot) and LS-mode (open dot). The amounts of perceive expressed as average value across all subjects for each color chip in each condition. The preference score and i_{mode} value came from average across same subject in the experiment I. Table 2 showed the correlation coefficient, *r*, of color appearance modes and perceived color attributes. The correlations of perceived chromaticness for OB-mode, UN-mode, and LS-mode were 0.730, 0.798, and 0.812 respectively. As shown in figure 4 (a), the preference score increased with increasing perceived chromaticness, regardless of the color chips. This result corresponded with the results of physical chromaticness from experiment I. This showed that both physical chromaticness and perceived chromaticness have an influence over the color preference. Moreover, the intersection of perceived chromaticness in LS-mode held the higher position than that in other modes. This indicated that the subjects preferred color in light source color mode to the other modes. This result emphasized the influence of color appearance mode effect on color preference.

In addition, it was found that perceived whiteness related to preference score as negative correlation in UN-mode and LS-mode (-0.768 and

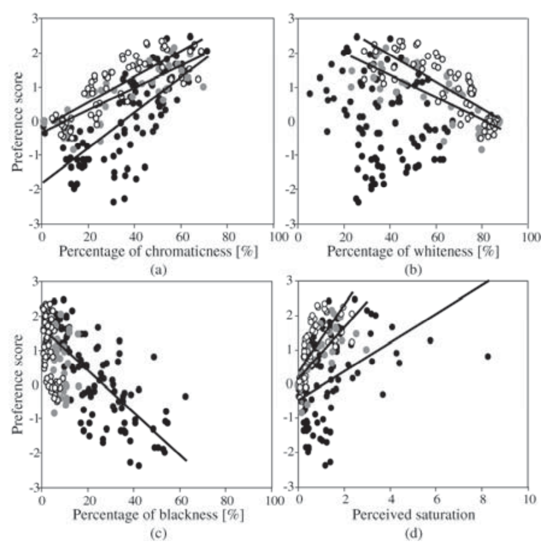

Figure 4 Scatter plot of preference score and color perception attributes; (a) chromaticness, (b) whiteness, (c) blackness, and (d) saturation. Modes of color appearance are defined by solid dots (OB-mode), gray dots (UN-mode), and open dots (LS-mode).

Table 2 The correlation coefficient, *r*, of color appearance modes.

Color appearance mode	Correlation coefficient, *r*			
	Perceived chromaticness	Perceived whiteness	Perceived blackness	Perceived saturation
OB-mode	0.730	-0.194	-0.704	0.441
UN-mode	0.798	-0.768	-0.360	0.664
LS-mode	0.812	-0.793	-0.596	0.676

-0.793) and perceived blackness in OB-mode (-0.704) as shown in Table 2 and figure 4 (b) and (c). This result showed the scores decreased when the perceived whiteness and blackness increased. The reason is that the large amount of chromaticness was replaced with whiteness at LS-mode and with blackness at OB-mode. Thus, the score decreased because percentage of chromaticness decreased. This decrease in chromaticness, when the color chip appeared in LS-mode, corresponded with pervious study by Ikeda *et al*.[4]

Finally, we consider the relationship between color appearance mode and perceived saturation. The perceived saturations were calculated in terms of a ranging from 0 to 10, as given in equation 2:

$$\text{Perceived saturation} = \frac{\text{chromaticness}}{\text{whiteness}} \quad (2)$$

The correlations of perceived saturation for OB-mode, UN-mode, and LS-mode were 0.441, 0.664, and 0.676 respectively as shown in figure 4 (d) and Table 2. The result showed that the preference score increased when the perceived saturation increased within each color appearance mode. This result corresponded with the perceived chromaticness. Even though the color chip loses saturation in light source color mode, the degree of color preference is still high. A possible reason is that the loss of saturation in light source color mode was compensated by the bright or luminous color chip.

4 CONCLUSIONS

In this study, thirty-three color chips varying in hues and chromas were assessed on six conditions covered three color appearance modes. Findings showed that the color chips having maximum saturation were found to give high score. Both of environmental illumination and luminance of the color chip have an influence over the color preference.

In the present study, we assigned the different environment illumination and different luminance of color chips for simulating the situations of color appearance mode. The degree of i_{mode} increased when the luminance of color chip increased. Furthermore, we found that the color preference related to color appearance mode. The color chips which were high degree of i_{mode} dropped in positive side of preference score. This revealed that subject preferred color appeared in light source color mode to the other modes.

Although dominant wavelength plays a leading role in the determination of color preferences, perceived color attributes and mode of color appearance are also significant. We conclude that the degree of color preference was dominated not only by color attributes (hue, chroma, and lightness), but also by mode of color appearance. We found two components play a role as underlying mechanism on the determination of color preference. One is the perceived whiteness and another one is perceived blackness. Thus, it may be possible to use these components as a scale for predicting color preference on the different color appearance modes.

Colors in our daily life are never viewed in object color mode only. To attract one's attention, some item should be appeared in light source color mode or unnatural object color mode such as advertising board, mobile phone display, show window display, etc. This study attempts to contribute to the preference response for colors in different color appearance mode. The results of the study may be used in design applications like window lighting set-up, product designs, etc.

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The principles of Dynamic Colour Model development

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ABSTRACT

Background. The sunlight is the only source of light on the macroscopic level, which defines natural cycles. The framework of continuously changing light conditions was defined in daily- and yearly-cycles.
Aim. To explain the main features of daily-, yearly-cycles and, the geometric series of Major- and Minor-angled colour circles, which presents an input for Dynamic Colour Model (DCM) to expose changing positions of colour dominance.
Methods. The daily- and yearly-cycle systems base on different palettes typology, resulting in two different geometric series, which have certain influences on the colour-dominance selection process.
Results. We present the example of two basic palette extensions of Major- and Minor-angled colour circles, showing us the specific features of each system and their ability to function as input in DCM.
Conclusion. The potentials of DCM, as a complex analytical and prognostic tool, are lying in its systematic and further development abilities.

Key words: Macro-Cycle System, Daily-, Yearly-Cycle, Major-, Minor-Angled Circles, Mini-Colour System, Four-, Twelve-Period Seasonal Colour Model, Dynamic-Colour-Model (DCM);

1 INTRODUCTION

The Sunlight is the only source of light, which defines the natural cycles. Constantly changing light conditions in the natural environment has been defined as “the basis of colour perception experience”, which significantly influences the evolution of the eye and, simultaneously, the evolution of its visual perception.

2 AIMS

AIM is to explain the main features of daily-, yearly-cycles and, the geometric series of Major- and Minor-angled colour circles, which presents an input for Dynamic Colour Model (DCM) to expose changing positions of colour dominance.

3 EXPERIMENTAL

3.1 Macro level

Constantly changing light conditions in nature are the basis for a general colour perception experience. The colour systematization is based on two main principles: a Twelve-level grey-scale in Daily-cycle and a Seven-level colour circle in Yearly-cycle.

3.1.1 Daily-cycle

Daily-cycle encompasses 24-hour-time (3), when the Earth rotates 360° along its axis in its helix continuum. The brightest and lightest point is around noon and the darkest around midnight. The simplest division results in two extremes: White-Black (W-K), but more advanced on 12 levels grey scale (Figure 1).

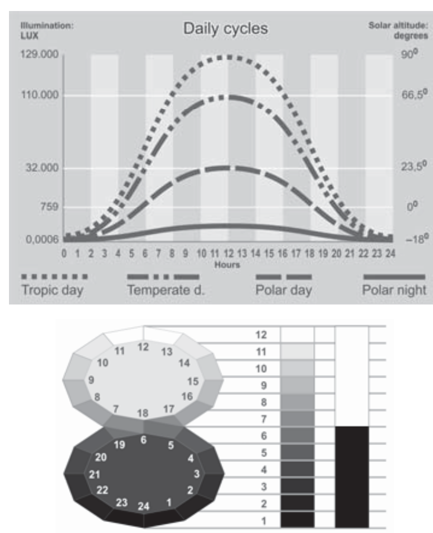


Figure 1: Daily-cycle encompasses 24-hour-time and result in a twelve-level grey-scale.

3.1.2 Yearly-cycle

Yearly-cycle presents one of the dominant cycles in human life. The Earth revolves around the Sun within a year and creates five symmetrically equal, horizontal levels and one antagonistic pair on ecliptic rail. The simplified division results in minimally two general oppositions, which are the basis for Four-seasonal-model (3, 4).

In more advanced interpretation, the distributed illumination symbolically correlates with relative values of the 7 achromatic scale steps, what is typical for each half-year period from one observing point of the globe (Figure 2) and, at the same time it is just opposite on the other side.

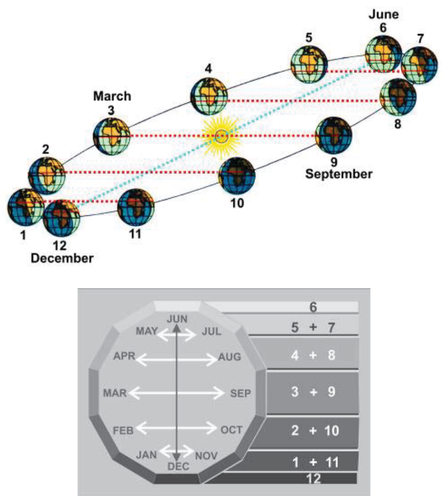


Figure 2: yearly-cycle is divided on the 5 equal horizontal levels and one vertical opposition.

The simplified version is divided on Yellow-Blue (Y-B), Red-Green (R-G) and White-Black (W-K) relation and that is also the smallest possible version of a complete colour universe, presented in a Mini-Colour System. More advanced model has been developed through transition from 7-level achromatic-scale to 12-part chromatic-colour circle. A certain level of achromatic scale corresponds with a certain lightness-level on the chromatic scale, allowing the colours to appear in two different qualities: warm and cold (1, 3, 4). That unique characteristic of colours in connection to wavelength is the background for colour-circles (Figure 3).

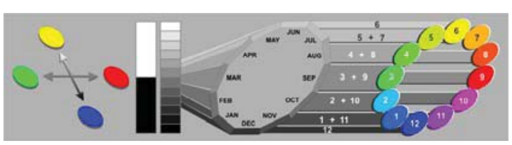


Figure 3: Integration of Yearly- and Daily-cycles: from the Mini-colour-system to the maximal extended one, in sense of the natural cycles.

3.2 Typology of colour circles

The circles rely on two different geometrical series of Major- and Minor-angled circle line. Major-angled circle consists of two pairs of opponent colours and one achromatic pair, with an angle of $\alpha=90^0$ in all directions. Minor-angled circle consists of three pairs of opponent colours and one achromatic pair, with an angle of $\alpha=60^0$ in horizontal plane only. All further palette extensions rely on differentiation of this two basic angle lines.

3.2.1 Major-angled circles

Major-angled circles (Figure 4) rely on following geometrical series:

$4x2^0 \rightarrow 4x2^1 \rightarrow 4x2^2 \rightarrow 4x2^3 \rightarrow 4x2^{n-1}$, resulting in corresponding number of angle-parts in circles: 4-, 8-, 16-, 32-, 64-parts, etc.

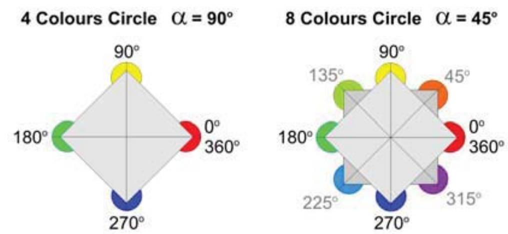


Figure 4: The sample of 4- and 8-part geometrical series of Major-angled circles line.

3.2.2 Minor-angled circles

Minor-angled circles (Figure 5) rely on following geometrical series:

$6x2^0 \rightarrow 6x2^1 \rightarrow 6x2^2 \rightarrow 6x2^3 \rightarrow 6x2^{n-1}$, resulting in corresponding number of angle-parts in circles: 6-, 12-, 24-, 48-parts, etc.

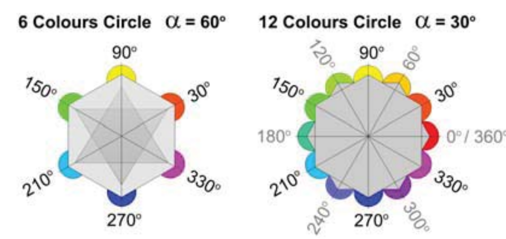


Figure 5: The sample of 6- and 12-part geometrical series of Minor-angled circles line.

Comparing Major- and Minor-angled circle-series, we observe, that each selection of opposed colours has different angle in circles, what results in different harmonious selection of opposed pairs, triples, quadrilles, quintuplets, etc.

3.3.1 Major-angled Mini-Colour-System

The Major-angled Mini-Colour-System (Figure 6a) is based on three discriminating oppositions: R–G on x– plane, Y–B on y–plane and W–K on z–plane, colour-related angle is $\alpha = 90^0$.

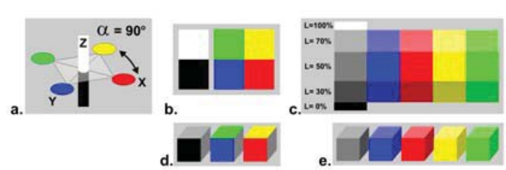


Figure 6: **a.** R–G on x–plane and Y–B on y–plane and W–K on z–plane, **b.** Cold-warm and light-dark oppositions, **c.** Nuances related to grey scale, **d.** Three cubes formed of 3 opposed pairs, **e.** Five cubes formed of minimally (3 steps) extended nuances.

The Mini-palette (Figure 6b) of the cold-warm and light-dark colours forms the smallest possible colour system.

A Mini-palette (Figure 6c), based on 4 colours, is vertically mono-angularly widened for one tone towards highlights (L=70%) and for one tone towards shadows (L=30%). Each colour-nuance is on relatively equal level with achromatic tones. Generally, the W–K opposition shows us already basic principle: White represents highlighted colours and Black shadowed ones. Therefore, Yellow is perceived as highlighted towards Red as shadowed or, as Green towards Blue, etc.

The palette sample (Figure 6d) consists of 3 Cubes, where opposed colour pairs describe 3D solid and presents the ability of a spatial construction of 4 colours and of White-Black.

The palette sample (Figure 6e) consists of 5 Cubes. Each is composed of the three nuances of palette 8c. Colours perform their proper logic of differentiation by each side of the Cube or 3D solid. Such principles of colour modulation were already developed in medieval heraldry, fine arts, illumination, known as local colouring principle.

3.3.2 Minor-angled Mini-colour-system

Minor-angled Mini-colour-system (Figure 7) is based on three discriminating oppositions: empty x–plane, Y–B on y–plane and, W–K on z–plane, horizontally colour-related angle is $\alpha = 60^0$ and, evidently differs from a previous one (3.3.1).

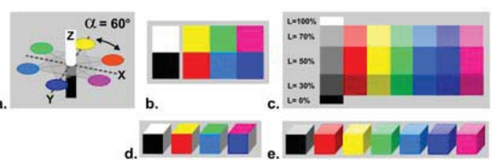
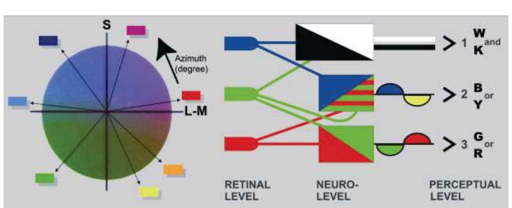


Figure 7: **a.** empty x–plane, Y–B on y–plane and, W–K on z–plane **b.** Cold-warm and light-dark oppositions, **c.** Nuances related to grey scale, **d.** Four cubes formed of 4 opposed pairs, **e.** Seven cubes formed of minimally (3 steps) extended nuances of palette 7c.

3.4 Micro level - Phenomenon "Urfarben"

Ewald Hering defined natural colour system by six "Urfarben" (2) in three antagonistic, non-simultaneous pairs that are visually always different (W-K, Y-B, R-G) (Figure 8).



a. b.

Figure 8: "Urfarben" with opposed colours (a) and the transmission of the receipted signal (b).

The "Urfarben" are defined by human visual perception ability to transform the electromagnetic signal from cone receptors over neurological to perceptual level.

Many colour systems base on this oppositions: from CIELAB, NCS to all ancient: Chinese Yin-Yang, Heraldry, Seal of Solomon, 6 colours in cardinal oppositions, Yantras of India, Tibetan Chortens, Japanese Stupas, all signifying Roles of the four elements, as well as Colour Cycle System-CCS and, Dynamic Colour Model-DCM.

3.5 Test of the colour differentiation

To analyse the plausibility of unambiguous colour differentiation, we made a simple test with 4 and 12 colours on different backgrounds. In 4- colour test, the colour differentiation was kept all the way in all samples. Uncertainty evidently grows by complexity and by the number of colours, as shown in test with 12 displaced colours. Some colours are from one to another background not anymore receipted as the same (Figure 9). Test convinced us that it would be necessary to examine limitations of all basic palettes.

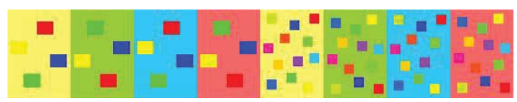


Figure 9: in test are 4 colours always unambiguous different on all backgrounds, but in 12 colours test uncertainty of unambiguous differentiation is growing.

3.6 The limitations of colours' systems

A *Major-* and *Minor-angled Mini Colour System* performs the smallest possible complete systems, which are already able to create harmonious combinations. Next enlargement of both systems results in 8- and 12-colour system, which present the reasonable peak of natural logic for human perceptive ability to differentiate colours unambiguously. A palette of 8 or 12 colours is giving much wider spectrum of colour combinations, but unambiguous differentiation is slowly vanishing by each added colour. Moreover, the psychological phenomenon of brain contrast enhancement and constantly changing visual conditions additionally cut down the number of possible colour differentiations! In that frame the functional abilities and values of each palette should be observed.

4 RESULTS

4. The Seasonal-Colour-Model

This model presents a kind of completed colour circle, correlated with already described natural time cycles and all psychological data related to colours. As an example, only the smallest Four-Seasonal Colour Model (4S-CM) will be presented (Figure 10), which is the base for more complex Twelve-Period Seasonal Colour Model (12PS-CM). Actually, both are 3D-models, interpreted in two dimensional schemes, applied as input in Dynamic-Colour-Model (DCM).

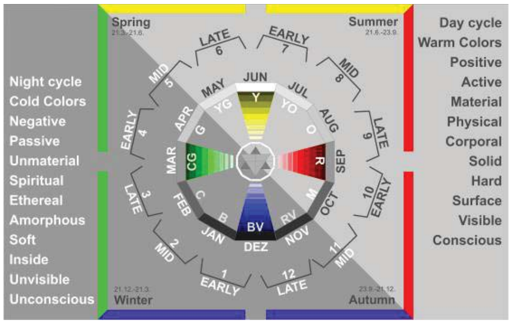


Figure 10: Version of Four-Seasonal-Colour-Model with all basic relations among different time cycles, periods, lightness levels, colours and terms.

5. Dynamic Colour Model - DCM

DCM presents 4-dimensional (4D) geometric colour model related to time and any type of cycles, with ability to process different data. For example we present as input Four-Seasonal-Colour-Model (4S-CM), which is rotating along the longitudinal axis from 0^0 to 360^0 (Figure 11).

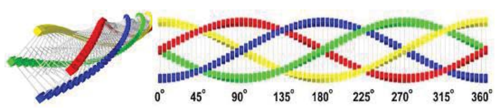


Figure 11: The simplified scheme of DCM with changing sequences of colour dominance.

Presented scheme of DCM is simplified and may produce too simple conclusions, but at the same time it would be more advanced and more accurate version, too complex to give the whole picture, what is all about.

5.1 DCM Formula

The example of the DCM formula, based on input of Four-Seasonal-Colour-Model (4S-CM):
t: 0,…,360
Y: (cos t, sin t)
R: $(\cos(t - 90^0), \sin(t - 90^0)) = (\sin t, -\cos t)$
B: $(\cos(t - 180^0), \sin(t - 180^0)) = (-\cos t, -\sin t)$
G: $(\cos(t - 270^0), \sin(t - 270^0)) = (-\sin t, \cos t)$

6. Sequences of colour dominance

In DCM we may observe changing sequences of colour dominance such as all values of terms related to colours, lightness levels, cycles, periods, colour angles and so forth - incorporated in 4S-CM, are constantly changing their positions, their ranking and their correlative meaning as well.

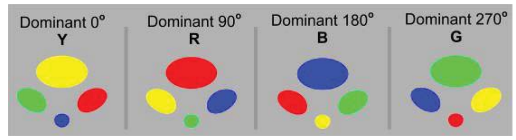


Figure 12: The sequences of colour dominance.

5 DISCUSSION & CONCLUSIONS

Results of this study lead us to conclusion that colours are in relation to the natural cycle system. We assume that cycles have notable impact on philosophy of colour perception, as well as on the colour appearance model development. In future we should define the functions of DCM in four dimensional space-time geometry, what involves some new legislations of existing colour models. The relation between colours and time-cycles postulate some new logic in achromatic scale and chromatic circle, for instance the question of the colour cycles spin, etc.

DCM allows us some new conclusions in translation of basic meanings in common cultural and visual communications. It could have irrepressible impact on colour systematic as its grammatical background. All the relations between lightness, colours and time-cycles, observed in DCM, could mean prospective background for systematic analyses and prognoses in the field of colours or in its psychological correlations. It could mean a new way of colour instrumentation and new tool for processing colours as composing elements of visual communication systems.

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Affective judgment of color in relation to visual stimuli

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ABSTRACT

Two empirical studies were carried out in order to investigate the affective judgment of color in two stimulus contexts. In the first experiment (N=46) 36 color stimuli were assessed in terms of valence, arousal, and dominance using the Self-Assessment-Manikin (SAM) scale. In the second experiment (N=45) subjects were shown to not only 17 colors, but also other types of visual stimulus modality, such as 8 pictures, 9 film-clips, and 9 adjectives. Consequently, the emotional profiles of visual stimuli were characterized by dimensions of emotion, and the SAM ratings of the 17 identical colors from the both experiments were compared. Empirical results showed that the reference field of emotional responses to colors was significantly shifted to be less arousing ($p<.05$, two-tailed).

Keywords: Color, Emotion, Affective Judgment, SAM, Context Effect

1 INTRODUCTION

Much concern has derived on research on color affectivity in various disciplines. Recent studies on color affectivity characterize emotional profiles of color in terms of emotional dimensions, thus approaching the issue of emotional influence of color attributes[1].

On the other side, the stimulus context has always been dedicated to color, which seems rather far from reality. Such limitations may weaken the relevance of the results of empirical studies on the impact of color on emotional reaction. Thus, it is necessary to investigate color affectivity not only within colors, but also in relation to other modalities of visual stimulus.

2 GOALS AND STUDY PLAN

2.1 Goals and Hypotheses

The purposes of this study are to describe emotional responses to colors in terms of three dimensions of emotion and to investigate a judgmental shift of color affectivity in a multi-stimulus-modality-context, in which other visual stimuli with higher semantic intensity are presented. Therefore, the following two hypotheses were formulated:

[H.1] Emotional response to color can be profiled in terms of three dimensions of emotion, valence, arousal, and dominance.

[H.2] The magnitude of affectivity is relative, and thus, the emotional response to color in a multi-stimulus-modality context may appear in a weaker pattern.

2.2 Plans of the Experiments

The affective judgment of color in the first experiment would provide the relative affectivity in valence, arousal, and dominance dimensions among color stimuli. Thus, the empirical results of the Experiment I provide a baseline that would be compared with those of the Experiment II. Between the two experiments a preliminary study had been carried out to select film stimuli for Experiment II.

3 MEASURING EMOTION

In comparison with discrete approach the dimensional approach to conceptualize emotion has the advantage of generality and potential versatility as a descriptive system for emotion. It characterizes an emotional profile of the stimulus and it provides a base for geometric construction, in order to explain the relationship among stimuli. However, it has been taken into consideration by only few researchers and the selection of color stimuli has not yet been systemically approached. Rather, the majority of the studies on color and emotion have focused on the synesthesia between basic categories of color and primary emotional terms. Valdez et al.[1] characterized this categorical approach as insufficient to produce reliable, valid, or comprehensive measures of emotional responses to color stimuli.

In this study, the emotional responses to colors were conceptualized with three dimensions of emotion and the Self-Assessment-Manikins

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(SAM) was employed to assess the affectivity in each dimension.

3.1 Self-Assessment-Manikins(SAM)

Developed by Lang[2], SAM is a nonverbal, culture-fair rating system based on a three-dimensional system of emotion consisting of valence, arousal, and dominance. The SAM rating scale is comprised of three sets of graphic figures, respectively representing the three dimensions (see Figure 1).

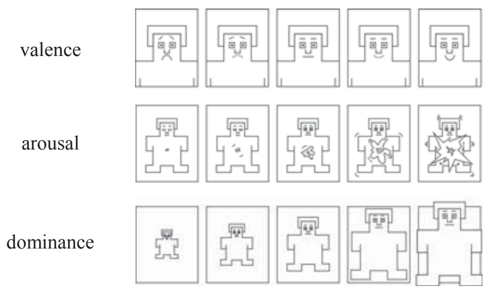

Figure 1 SAM figures.

Those graphic figures, which depict values along each of the three dimensions on a continuously varying scale, are used to indicate emotional reactions. As shown in Figure 1, SAM ranges from a frowning, unhappy figure to a smiling happy figure, when representing the valence dimension. For the arousal dimension, SAM ranges from a relaxed, sleepy figure to an excited, wide-eyed figure. For the dominance dimension, SAM ranges from a small figure (dominated) to a large figure (in control). The subject can elect any of the five figures comprising each scale.

In the following experiments, SAM will be used to assess emotional response to a stimulus implemented through PXLab© (www.pxlab.de) software in computer based experiments.

4 EXPERIMENT I

4.1 Method

4.1.1 Subjects

Forty-six people including 19 men and 27 women served as subject and were recruited through advertisements in the University of Mannheim (age: M=24.43, SD= 8.99). As reward, € 4.00 were offered for the approximately 20-minute experiment.

4.1.2 Stimuli

Five hue categories were fixed and the hue degrees of categories in CIELab Lch system are h=30° (red), h=80° (yellow), h=160° (green), h=260° (blue), and h=320° (violet). From each of them, representative colors of the following five tone segments were chosen: 'dark', 'deep', 'vivid', 'brilliant', and 'light'.

It was intended to let subjects recognize the same quality of tone (combination of Chroma and lightness) across hue categories. In fact, the segmentation of tone categories varies with hue, especially in case of yellow, a slight change of lightness results into a color of olive. Thus, it was necessary to consider different segments of Chroma and lightness that would be representative for the specific tone category of each hue.

In addition, cool gray (h=260°), warm gray(h=80°), and gray colors with lightness levels of 30, 50, and 70 were included, and black and white were added to the color stimuli.

4.1.3 Procedure

At the beginning of the experiment, a gray stimulus (L=30) was shown, in order to get acquainted with the SAM interface. Color stimuli were displayed centered on CRT monitors, in a size of 25.1 cm width × 15.2cm height.

Below every stimulus, a row of SAM pictograms was presented and subjects could select any of five by mouse click. Pressing a space bar, the next row of SAM appeared in an order of valence, arousal, and dominance. Once a stimulus was assessed by all three dimensions, the next stimulus was provided. All subjects were exposed to all stimuli.

4.2 Result

Based on SAM ratings of 46 subjects, reliability of internal consistency was tested. Cronbach's alpha yielded significant values to support [H.1] and thus, valence(α=0.793), arousal(α=0.880), and dominance(α=0.904) are adequate to describe emotional responses to digital colors.

The empirical results of the Experiment I provided a baseline that those of the Experiment II would be compared with.

4.3 Discussion

Although hypotheses, [H.1] was statistically supported, it does not seem safe to say whether color would induce emotion in a similar way in the context of other categories of visual stimuli, in particular, when other modalities of stimuli exhibit a higher intensity of semantic content. In reality, people may perceive colored surface as a sequence, while they are experiencing pictures or moving images (e.g. reading a magazine or watching TV).

This issue converges into stimulus context effects and their influences on target stimuli. The judgment of the target stimulus is affected by the given context. Thus, by viewing color in a multi-stimulus-modality-context, the affectivity of color as target stimulus, may be influenced by other stimulus modalities (e.g. film-clips, pictures, words).

In Experiment II, the context effect will be investigated focusing on judgmental shifts of color affectivity.

5 PRELIMINARY TEST

The Preliminary Test intended to select film-clips to be employed later in Experiment II. The film-clips could be seen as 'background stimuli' or 'anchor stimuli'[3] and may modify the affective impact of focal or target stimuli, i.e. the colors.

Moreover, in this test, the main concern was to express moving images by film-clips, which distinguishes film-clips from static pictures (still images) during the experiment. Hence, the role of film-clips differs from story-telling.

5.1 Method

5.1.1 Subjects

Twenty-four students including 11 men and 13 women volunteered and served as subjects for Preliminary test (age: M=26.38, SD=3.05).

5.1.2 Stimuli

19 Film-clips were collected from commercial films and the length of the film-clips for this Preliminary Test was edited to be 13 to 14 seconds in length in order to increase the homogeneity of semantic contents of film-clips.

5.1.3 Procedure

The 19 film-clips were played repeatedly without break, and the sound was switched off to focus on the effect of visual contents. The film-clips were presented in random order and subjects assessed emotional responses with SAM ratings by pencil-and-paper method.

5.2 Result

From the Preliminary Test, nine were selected (see Table 1), representing certain patterns of emotions. For instance, the film clip 'gangsters' and 'fighter' induced similar emotional responses. Thus, the 'gangster' clip was chosen, on behalf of semantic contents related to 'violence'.

However, the reliability coefficients were not satisfactory. It is thus still unclear whether the movie clips were robust enough to induce certain type of emotion (α=0.537: valence; α=0.683: arousal; α=0.380: dominance). Through a larger number of subjects, future research is expected to yield better internal consistency.

Table 1 The selected 9 film-clips for the Experiment II

film	t(sec)	scene description
A Clockwork Orange, S. Kubrick (1971)	14	viewing some buildings from flying vehicle
	13	Jesus Christ walking with the cross, tortured
	14	a man surrounded by three semi naked women
	14	four men assaulting on a homeless old man
Le Papillon, P. Muyl (2003)	14	big tree on the hill. Leaves fanning in the breeze
	14	a young girl calmly opens a door to butterfly garden
Amélie, J.P. Jeunet (2001)	13	a little girl photographing bunny-shaped clouds
Unfaithful, A. Lyne (2002)	14	husband and wife caressing each other
Legally blond, R. Luketic (2001)	14	many girls celebrating

6 EXPERIMENT II

6.1 Method

6.1.1 Subjects

The experiment was announced with flyers at the University of Mannheim and 45 subjects, including 24 men and 21 women, participated. They were either paid € 6.00 or given course credit for their participation (age; M=26.76, SD=10.58).

6.1.2 Stimuli

Target Stimuli: 17 colors

17 color stimuli were taken from those used in Experiment I: Each of the hue-categories 'red', 'yellow', 'green', and 'blue' possessed the three tone categories—dark, vivid, and light—and vivid violet was also included. In addition, dark gray, light gray, light warm gray, and light cool gray were used for Experiment II.

Background Stimuli: film-clips, pictures, words

The nine film-clips, 8 pictures—4 chromatic and 4 achromatic—from IAPS[4](see Figure 2), a standardized affective picture database, and 9 adjectives—'laut'(*loud*), 'langwilig'(*boring*), 'hektisch'(*hectic*), 'leicht'(*light*), 'aktiv'(*active*), 'dynamisch'(*dynamic*), 'gesund'(*healthy*), urban, and modern—were shown. The background stimuli were supposed to cover various emotional profiles in terms of valence, arousal, and dominance.

Figure 2 The 8 pictures selected from IAPS (IAPS nr.)

6.1.3 Procedure

Since film-clips were in different formats, PXLab© software adjusted them either to size of 19.0 cm width ·14.9 cm height or to that of 22.1 cm width · 14.9 cm height. Therefore, all film-clips were presented in the same height as colors and pictures (22.1 cm width × 14.9 cm height).

Taken together, a set of 43 stimuli and SAM figures were implemented by PXLab© software in Experiment II. All the stimuli were displayed identically like in the Experiment I and presented in a random order. Each subject was exposed to all stimuli and no missing data occurred.

6.2 Result

Cronbach's alpha was calculated and provided satisfactory level of reliable internal consistency of the measurements on valence(α=0.729), arousal(α=0.919), and dominance(α=0.842).

6.2.1 Judgmental Shift of Target Stimuli

Mean values of valence, arousal, and dominance of the 17 colors from Experiment I and II were observed as figure 3 illustrates; the arrows explain the direction and magnitude of judgmental shifts. Emotional responses to the 17 colors in Experiment II tended to shift towards negative ('–' valence) and calm ('–' arousal).

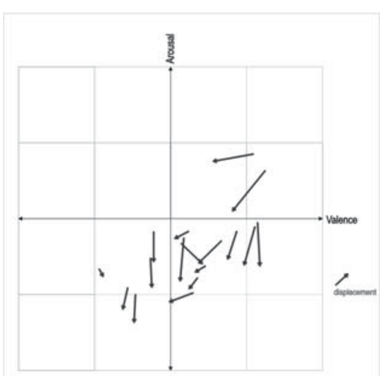

Figure 3 The displacements of 17 colors from Experiment I to Experiment II, illustrated with vectors in emotion space defined by valence × arousal.

The judgmental shift was statistically compared by running two-way ANOVA with repeated measurement on one factor, colors. The difference between Experiments I and II is significant in the arousal dimension [$F_{(1, 89)}$=5.002, p=0.028], whereas judgmental shifts in the other dimensions were not significant at α level of 0.05. Thus, the result partially supports the [H. 2].

7 GENERAL DISCUSSION

In Experiment I, the measurement with the 5-scale SAM system provided evidence for explaining the relationship between color and emotion, confirming the [H.1]. However, the measured values represent the affective relativity within colored surfaces only. Therefore, in Experiment II, it was examined whether visual stimuli with higher semantic intensity (than color) would anchor emotional reference in a multi-stimulus-modality-context. Hence, it was hypothesized that emotional responses to color would appear in a weaker pattern due to film-clips, which contain a higher degree of semantic intensity [H.2]. From statistical test, the judgmental shift of 17 colors from Experiment I to Experiment II was significant (p=0.028) in arousal dimension, partially confirming the [H.2]. Based on the empirical results, it is assumed that by increasing/decreasing the semantic contrast among stimulus modalities, more/less significant shifts of affective judgment of color would be found.

ACKNOWLEDGMENTS

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Absolut Industrial Art

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ABSTRACT

This paper looks into the conceptual transference of Duchamp's bottle rack from article of everyday use to art object and back again. Analysis is made of the contribution by Swedish artist Dan Wolgers to the *Absolut Art* advertising campaign of the *Absolut* spirits brand with the aid of philosopher Nelson Goodman's semiotically influenced discussion on original and copy, and autographic and allographic art. Differences in the mode of exposure and use of colour between Duchamp and Dan Wolgers are addressed. The paper notes that Wolgers' working method is metaphorical in Goodman's sense through utilization of the copying technique initiated by the twentieth century writer Pierre Menard, who according to Borges enriches reading through the use of deliberate anachronisms and erroneous attributions.

Keywords: Colour philosophy, conceptual art, industrial art, semiotics, visual semiotics, Jorge Luis Borges, Marcel Duchamp, Nelson Goodman

INTRODUCTION

Using a semiotic approach mainly derived from Nelson Goodman this paper discusses an everyday industrial product. Originally this product was created as a work of art, and eighty years later it has been taken back again from the realm of art to the world of industrial production.

Absolut Vodka, the Swedish registered trademark, is the third largest international premium spirit in the world, and the number two brand of premium vodka worldwide. Since its launch in 1979 it has achieved significant sales growth, from 90 000 litres to 83 millions of litres in 2005. Some 500 000 bottles are produced every day in the small city of Åhus in southern Sweden. The explanation of this worldwide success is, of course, an excellent product quality, but not least important is a determined and organized marketing strategy. Choosing the brand name of *Absolut Vodka* was deliberate and well thought out in every respect.

Sweden has more than 400 years of vodka-making tradition, namely of spirit made of potatoes or grain. But never before has the liquid been poured into such a unique and conspicuous bottle. This famous bottle is inspired by an eigtheenth century Swedish medicine bottle, and is made with special low-iron sand to ensure crystal clear glass. Before they are filled, every bottle is rinsed with *Absolut Vodka*.

And never before has a bottle been depicted in such glamorous ways, so to say detached from its everyday context. Closely related to the bottle is the award-winning advertising and marketing campaign. Skilfully made advertisements are published principally in exclusive life-style magazines all over the world. These ads are created successively by well-known artists using the bottle in an imaginative and unexpected way. The artistic pictures are finally signed with the name of the artist together with the word ABSOLUT in capital letters and the typeface of the trademark, e.g. ABSOLUT WARHOL (the very first involvment, in 1985, of Absolut Vodka with the arts) [fig. 1] or ABSOLUT CLEMENTE (a more recent example from the Italian artist Francesco Clemente, made in 1999) [fig. 2].

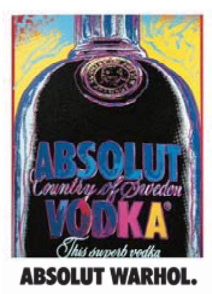

Fig. 1

Fig. 2

WOLGERS' CONTRIBUTION

In spite of *Absolut Vodka* being a genuine Swedish brand, only a few Swedish artists have been invited to create an advertisement. Among them is Dan Wolgers [fig. 3].

As depicted in the figure, the advertisement by Wolgers consists of a sharply focused photo of a bottle rack in galvanised iron, clearly illuminated in frontal portrait so observers are able to reach a conclusion regarding both character of material and function. We also soon see that an empty bottle of *Absolut Vodka* hangs from one of the upper spikes. Something of the bottle rack's light spills over onto the vodka bottle and illuminates its distinctive form and label. At the bottom of the ad are the words ABSOLUT WOLGERS in capitals and grotesque type, thus concurring with the typography of the *Absolut Art* series.

In chapter I of his *Languages of Art* the American philosopher Nelson Goodman states, "application and classification of a label are relative to a system" [p. 40]. It is likely that many readers of the lifestyle magazines in which the spirits advertisement is printed on full gloss paper know that bottle dryers of this type have long since been used in French cafés and restaurants. Drunk from and rinsed out, the bottles hang to dry from their spikes on the rack before once again being filled with the house *vin de table* for serving at the next lunch.

In the terminology of Goodman we can establish that the vodka bottle is an observable *sample* of how the bottle rack might be used, but it is also – quite literally – a *label* denoting a specific drink, a particular brand. The distinguishing of the label transforms the anonymous, interchangeable standard bottle.

At the same time, the Absolut bottle connotes to a longing to once again taste the refilled contents, or rather the choice liquid that is permitted to fill the labelled bottle. (I use the verb connote in accordance with Chandler's definition of *connotation:* "The socio-culture and 'personal' associations produced as a reader decodes a text." [p. 225]. The connotative reference is lacking in Goodman's symbol system, something I will soon take up.)

DUCHAMP'S READY-MADE

The bottle dryer in the vodka ad is likely to be recognised by many potential consumers leafing through the lifestyle magazine. In fact, Wolgers took great pains to portray his *objet trouvé* in perfect accord with the original work of art by Duchamp – if such an expression is valid in this respect. For comprehensible reasons the rounded bottle rack of Duchamp is usually depicted *en face*, and so to speak workaday or artlessly. And this is how observers encounter the bottle dryer at the museum of modern art in Stockholm (Moderna museet), where one of many replicas produced on the basis of Duchamp's *ready-made* is to be found on a simple plinth.

As is well known, in 1914 the French artist Marcel Duchamp bought an ordinary bottle rack in a Parisian department store. A few years later Duchamp exhibited his ready-made or *objet trouvé*, and thereby transferred it into an *objet d'art*, which has been regarded as a milestone in 20th century Western art [fig. 4]. Placed on a plinth, the bottle rack was seen by the public as a sculpture. It was the observers rather than Duchamp who made art of it. "It is the *viewers* who make the paintings", said Duchamp himself. His exploit (or that of the viewing public) meant that the hegemony of realism in western art came to be replaced by other modes of expression during the rest of the twentieth century, not least conceptual modes. And here we can recall Goodman's rather famous assertion in *Languages of Art* that "Realism is relative, determined by the system of representation standard for a given culture or person at a given time" [p. 37].

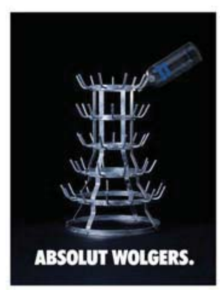

Fig. 3

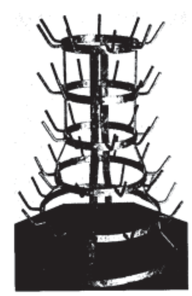

Fig. 4

AUTOGRAPHIC OR ALLOGRAPHIC?

In his approach to a theory of symbols Goodman makes use of the terms *autographic* and *allographic* art. The first term is applicable to art where the relationship between original and forgery has significance. In its turn, allographic art is determined with the help of a notation system such as a music score or text edition. "Thus painting is autographic, music nonautographic or *allographic*" [p. 113]. In systematic manner the philosopher works his way towards further designations: "Among other arts, sculpture is autographic; cast sculpture is comparable to printmaking while carved sculpture is comparable to painting" [p. 120]. The specifications of Goodman end in the following conclusion: "A forgery of a work of art is an object falsely purporting to have the history of production requisite for the (or an) original of the work." [p. 122].

With regard to the vodka advertisement we are able to instantly establish that this "history of production" is what Wolgers works with. The Swedish artist borrows and re-uses the production history of the Duchamp work openly and unabashed.

PIERRE MENARD'S DON QUIXOTE

Such a procedure is discussed in detail in another of Goodman's books: *Reconceptions in Philosophy and Other Arts and Sciences* (with Catherine Z. Elgin as co-author). The reasoning is based on an allographic example, the famous short story by Borges: *Pierre Menard, Author of the Quixote.* In the tale Borges has Pierre Menard, a French twentieth century *novelista*, write down *Don Quixote* with scrupulous care and precision in full concordance with the novel text of Cervantes 300 years previous.

Menard's work remains unfinished, with only chapters IX and XXXVIII and a fragment of chapter XXII in the first section of *Don Quixote* being realised. But according to Borges, the aim of Menard was clear: "His admirable intention was to produce a few pages which would coincide – word for word and line for line – with those of Miguel de Cervantes" [p. 6].

For Goodman Menard's work is "simply another inscription" of Cervantes' original. Goodman claims that by random effort a monkey could achieve the same results [p. 62]. Various interpretations of the allographic work may appear, but as long as the text or notation is identical then the work is once and for all "settled syntactically and semantically" [p. 65].

Thus as mentioned, according to the symbol theory of Goodman the connotative reference is lacking, the reference that points away from the denotational root meaning or the literal example. It appears to me that through his disregard of the further implications of connotation – the singling out of the historical, societal and reflexive functions of art – Goodman closes his eyes to the true contents and importance of *Pierre Menard, Author of the Quixote.* Goodman writes:

> Who wrote *Don Quixote* or when simply does not matter to the identity of the work. In both autographic and allographic arts the identity of particular works is independent of work-attribution. Although the identity of an autographic work depends on its history, that identity is not affected by our knowledge or ignorance of its history. [p. 65]

The latter sentence appears still more remarkable when read in the light of Duchamp's work. Without any attention paid to the production history of the bottle dryer, the copy by Wolgers would be far less luminous, both as artistic picture and advertising picture.

Despite being hidden in the shadows of fiction, the understanding of Borges appears contrary to that of Goodman: "Cervantes' text and Menard's are verbally identical, but the second is almost infinitely richer" [Borges, p. 11]. And Pierre Menard writes in a reflection on his work: "It is not in vain that three hundred years have gone by, filled with exceedingly complex events. Amongst them, to mention only one, is the *Quixote* itself." [p. 10]

THE WOLGERS VARIATION

But we are faced with a further issue. By hanging an empty bottle on one of the spikes, Wolgers made an addition to the naked bottle dryer of Duchamp.

In *Languages of Art* (chap. II) Goodman gave considerable space to the role of metaphor in a theory of symbols that he is in the process of developing. "Yet", he asks, "what distinguishes metaphorical truth from literal truth on the one hand and falsity on the other?" [p. 51]. The attention of Goodman is drawn equally towards the use of metaphors in language and pictorially. "A picture literally possesses a gray color, really belongs to the class of gray things; but only metaphorically does it possess sadness or belong to the class of things that feel sad" [p. 50f]. According to Goodman [p. 79f] metaphors work best when they combine the idiosyncratic with the obvious, newness with the habitual. That is to say when the result is changed organisation of our knowledge rather than the fastening of the new label of control on top of the old. In a chapter on *reference* in *Of Minds and Other Matters* Goodman summarises what he terms in the book "Fictive and Figurative Denotation" as opposed to literal reference. He writes that a symbol may denote metaphorically what it does not denote literally:

> Metaphor arises by transferring a schema of labels for sorting a given realm to the sorting of another realm (or the same realm in a different way) under the guidance or influence or suggestion of the earlier sorting. The new sorting echoes the old

> and is genuine, as 'factual', but is different. [p. 61]

Now we are able to see how Wolgers' empty bottle renders – or better recycles – the original function of the bottle dryer as a day-to-day, workaday object. That is to say the function it had, and still has in many cases, independent of Duchamp's conceptual metamorphosis of the rack into sculpture. But at the same time the metaphorical transfer transports the bottle from recycling bin to museum exhibition case. It is endowed with the aura of a cultural object and the mythology of art history. And as a guarantee of its authentic content, the label of its production history is ultimately attached to the bottle: ABSOLUT DUCHAMP.

Wolgers has at last done what the Swedish Duchamp expert Ulf Linde reflected on (and perhaps called for) from the exhibition public attending the opening back in 1914: "If the public had dispassionately hung up their bottles of wine to dry on Duchamp's 'sculpture' they would have offered him resistance" [Linde 1960, p. 44, my transl.].

Let us now consider how Wolgers packaged the bottle dryer, after eight decades of relative tranquillity in the art museums of the West, in its transference to the unshielded production conditions of industry and the world market.

He endeavoured to achieve a clear and illuminated exposure of the bottle rack, which emerges against a deep black background. We first become aware of the vodka bottle after attentive study of the picture. The blue upper case lettering of the label (PMS 286C+BLACK) is what initially extracts itself from the black. The seal of the bottle appears to melt into the rack. The sophisticated presentation is reminiscent of the use of light in a different picture with meta-motif – that is to say a work of art depicting a work of art – that of Velázquez' *Las Meninas*. The top lighting is the same, as is the dark background, the illuminated bottle corresponding to the inlet of light provided by the door ajar, and the form of the bottle rack correlating with the stiff crinoline of princess Margarita Maria.

On the other hand, Wolgers' picture hardly corresponds to Duchamp's own presentation of the bottle dryer. In his dialogues with Cabanne, Duchamp spoke of his practically random choice of ready-mades based on seeming indifference, with no aesthetic feeling. Which indeed was how the bottle dryer was exhibited at the *Exposition Surréaliste d'Objets* in Paris 1936; squeezed in among a score or so other objects in a poorly lit display case.

Duchamp's use of colour differs altogether from that of the industrial and utmost conscious use of colour of today. Companies now protect their choice of colours with patents, and assure correct reproduction via codes and numbers from various colour systems and models such as Munsell, Pantone, CMYK or NCS.

Occasionally even Duchamp however had to touch up his works [fig. 5]. In this rectified ready-made he changed a small enamel sign advertising the *Sapolin* brand of paint into the painted enamel sign *Apolinère Enameled*, the act enabled by the little girl's careful painting. Note the lettering in the lower right of the image. *Any act red*, it says, pointing out the colour of passion.

CONSEQUENCES

Wolgers, the well-read disciple of Duchamp, makes belated use of the knowledge at hand in *Pierre Menard, Author of the Quixote*, which according to Borges accommodates infinite applications:

> Menard (perhaps without wanting to) has enriched, by means of a new technique, the halting and rudimentary art of reading: this new technique is that of the deliberate anachronism and the erroneous attribution. [Borges, p. 14]

Transferring such insights from a conceptual world to what on a day-to-day basis is frequently termed tangible reality is of course not without risk. The demurral of Goodman has been noted. Wolgers himself appears to have suffered an adverse fate, like one taken from a dark tale by Borges.

How are we otherwise to interpret the image of Dan Wolgers, accomplished by his protégée the young artist Linn Fernström in a new contribution to the *Absolut Art* series of advertisements [fig. 6]? Should anyone by chance wonder, the blonde lady siren of the woods is Miss Fernström herself embracing her worldly goods, the vodka bottle to the left, and to the right Mr Wolgers.

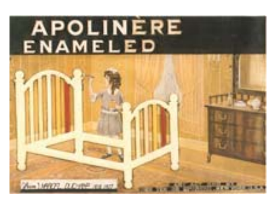

Fig. 5

Fig. 6

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ILLUSTRATIONS

Fig. 1, Andy WARHOL – *Absolut Warhol*. © 1985 The Andy Warhol Foundation for the Visual Arts

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Fig. 5, Marcel DUCHAMP – *Apolinère Enameled*. 1916–17. Arensberg Collection, Philadelphia Museum of Art

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Festivals of Colours: Ottoman Miniatures

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ABSTRACT

"Colours" of the miniatures were used effectively to reflect the historical reality during Ottoman period. While Ottoman contemplation used janissary band music to scare away the enemy on their way to the battle field, miniaturists (nakkaş) described the warriors with flowers in their hands. Along reflecting the hictorical facts, miniatures that are the products of the realm of colors and imagination, also reflect the fantastic world of the East. Festivals and daily life are also demonstrated by miniatures. The miniatures are called 'little paintings' throughout Europe. In our study, we will undertake the semiotical analysis of the miniatuares whose subjects are festivals.

Keywords: Miniature, Ottoman, festivals, semiotics, culture, colour, meaning, aesthetic, signs, semiotical analysis.

1 FESTIVALS

Festivals are somewhat abolishment of the cultural order and domination, where collective life is experienced and a released energy and and extravavancy prevail for a temporarary period[1]. As Bachtin argues, " in festivals it is possible to view the world from a different angle and we get a sensation that everything is relative in this world"[2]. In the laws of Platon, "Gods presented the annual thanksgivings to forget their problems (matters, issues) and they gave them to the God of Muses, Apollo and Dionysos who would accompany them in festivals. And with this holy unity the order among humans were always to be protected[3]. The realization of the festivals are based on the two basic units: Game and leisure.

1.1 Game

Game is apart from the rationality of actual life; there is no relation to the concepts of necessity, effectivesness or task and reality. According to Platon says, indeed game is an important factor of the festivities where young people can not control their bodies and voices and are in constant action in the field of festival.

1.2 Leisure

For Aristotales, apprehension, leisure and "spare time" is the core principal of the cosmos. It can be prefered to work, and in actually, this is the main goal at the end of the whole work.

According to Herbert Marcuse, concept of happiness in recent hedonist perception is reduced to consumption and free time which is distinct from working[4]. According to Thorstein Veblen, in Aristocrat Class Theory, the most important significant characteristics of aristocratic class, which consisted of clergy, soldiers, management group, is to be far from the manufacturer workers and use their leisure time to consume their wealth for luxury[5].

Our objective in this article is to analyze different aspects of the festivities in relation to the different perspectives of colour. In the light of this article, some samples will be taken[6] of the Surname-i Humayun, miniatures that is made for the occasion of the circumcision of Sultan Mehmed III in 1582.

2 OTTOMAN FESTIVALS

In Ottoman festivals, alongside with the leisure (free time) and games, different kinds of festival aspects are observed.

2.1 Social Aspect

In all festivals it is observed that people are either close to each other or stands in solidarity. Social relations are strengtened expecially in festival periods. In public festivals, all the

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institutionalized work units such as eraftsman, soldiers, paths come together.

This is a scene that Ottoman Sultan stands up and bestrews gold, silver and money. The main colour is red; the other colours are green, white, purple, pink and brick-red.

In the miniature 46, Sultan is sitting at Şahnişin (bay window). On the right bottom of corner, people are standing up. It is differentiated from the Christians, people who are carying nature maquette and walking in their apparels and turbans. In apparels, the main colour are red the rest of them are, colour of green, pink, purple, dark blue and white.

2.2 Religious Aspect

Though not seen as a religious activity, at fist sight, Ottoman festivals were not depicted as a religious activity. The feast of sacrifice, Sugar Feast, Mevlüd Kandili (Islamic Holy night). The master of the festival was the Sultan who was both the leader of Islam (Caliph) and the Empire. Thus the festivals were in a way a means of propaganda on the foreigners and symbolized the superiority of Islam.

The circumcision of many children during this festival may be associated to this aim, the promotion of Islam. In the miniature 30 green is the dominant color in Seyyid clothes. White, red, dark blue, brown and brick-red are the other colours.

Various factors and symbols of the festival had religious characteristics. Dominant non-religious attributions were dance, music, songs, bonfires, masked games and eating.

In the miniature no 33 musicians were illustrated in non-religious activities. Green, red and brown were dominant colours in the caftans worn by the musicians (sazende). Red is the dominant colour while green, purple, white and black are the other colors.

In these illustrations of the javelin game named Cündiyan (horse show – miniature 43), red colour is also dominant colour and green, white, pink, black and purple are the other colours.

A scene is from a snake charmer's show (miniature 54). Red is also dominant colour and white, purple, green, color mustard and dark blue are the other colors. The main show is performed on the attendance of Sultan.

A wrestling show takes place in the miniature no 64. Red, gray, brown are the dominant colours, while green, white and colour mustard are the others.

Shows of the jugglers are seen in no 67th miniature. Red, gray and brown are the dominant colours, while blue, green, color mustard and white are the other colours. Juggler is dressed in red.

2.3 Political Scene

The political aspect of the festival both within and outside of the Empire and was a demand to prove the dominance of sultan; the one and the only symbol of the government.

Those who witnessed the Ottoman festivals inform us that when a military expedition was declared, all the cities were in cheer and amusement. Flambeaus, candles and oil lamps were shining all over the city.

In the 75th miniature; with its extraordinary colours and appearance, mythical bird "simurgh", that is not proven to exist in the nature, symbolyzes the flamboyance of the festival and the Empire. In this scene, many statesmen are illustrated in the audience/ public gallery (seyirlik) both as a member of audience and the performers.

2.4 Aesthetic Appearance

In festivals, magnificent appearance, stage order, dress and finery, lighting, colour, motion, sound, contrast, that provided all the aesthetic necessities and requirements were presented together. Festivals can not be regarded as an art, but it is the natural source of arts. In Ottoman festivals, everyone worked for the achievement of the festival. There was no difference in this respect between an organizer and a viewer.

The happenings in Surname-i Humayun are shown in two places in order. One of them is the İbrahim Pasha Palace where Sultan Murad III. was watching the players and the displayers, and the public gallery with its three stages where the non-Muslims, foreigner guests and the ladies were seated.

The events are shown in complete, simple and detailed form in this work of art that was depicted by the muralist group under the direction of muralist (Nakkash) Osman. The muralist overwiev and decor are stable, subject -festival- is dynamic in Surname-i Humayun.

The scenes that are related to aesthetic appearance are shown in miniature numbered 38.

The main colours are red, purple, pink and the rest of them are white, blue and green.

In the miniature numbered 76 is shown the drapers (Kemhacı). They pass by holding the stick with fabric. The main colour is red and the rest of them are purple, green, blue and pink.

In the miniature numbered 79 loinclothers pass by holding the fabric stick with animal figure. The main colour is red; the rest of them are, green, purple and white.

In the miniature numbered 80 Egyptian spice sellers catch up the Garden of Heaven. They pass with the ceramic jar and plate on their hands. The main colour is red; the rest of them are green, blue, orange, white and beige.

3 CONCLUSION

In this analysis of miniatures, we made a research into th Surname-i Humayun festival, we analyzed the visual variables that constructed the miniatures. In another word especially colours out of the plastic elements (shapes, textures and colours) and the perception of these elements were inspected.. By emphasizing their functions (the meaning they transfered); we analyzed the imagery and content levels of these miniatures.

This kind of analysis is micro-semiotical analysis[7]. Our empirical analysis is based on the perception and interpretation of the symbols[8].

Multicoloured variability of human clothing and the decor that is used in the Festival, from the beginning to the end, is noticeable in the miniatures' rhetorical order of the Surname-i Humayun.. Multicolours and multiculturalism are observed among the Muslims and Non-Muslims as well as ine the public and the residents of the court and various craftsman.

The main colors in Surname-i Humayun are red, green, white, purple and blue, but the dominance of red in the miniatures is conspicious. And the colours as red, yellow, brown, green are used to communicate the power and the dynamism of the Sultan (miniature 84).

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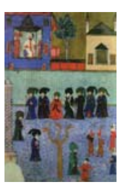
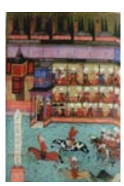
Miniature 46


Miniature 30


Miniature 33

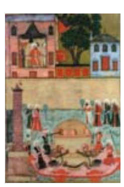

Miniature 43

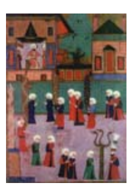

Miniature 54


Miniature 64


Miniature 67


Miniature 75


Miniature 38


Miniature 76


Miniature 79


Miniature 80


Miniature 84

Colour	People(s)	Costumes	Space/Decor	Effects	Indicators
Red	Spice-seller Loincloth-seller A kind of silk glassman magician snake charmer javelin Musician Wrestler	hat clothes	Fence window blind a kind of a fairy bird	dynamism attraction action power	-Power of the Government and Sultan
Green **Green (Light)**	A kind of a silk magician musician wrestler glassman Loincloth-seller Spice-seller	clothes	hippodrome roof palace walls balcony (the sultans's seat) house	-balance -reality -belief -natural	-Religion -the naturality of Sultan -
White	Loincloth-seller Spice-seller javelin wrestler magician glassman	turban clothes	a kind of a fairy bird	-cleanliness -communication -purity -virtue	-Good Luck - The virtue and the lightness od Sultan
Purple	A kind of a silk glassman Snake charmer javelin Loincloth-seller	clothes		-freshness -hope	-Hope given by festival
Brown	Musicians Snake charmer wrestler magician	hat clothes		-fertility -comfort -Steadiness	-the fertility of Sultan -The steadiness of dynasty
Blue (Dark)	Snake charmer	clothes		-wisdom -the clolor of the Kingdom -nobility	-the wisdom of Sultan -Enthrone (Sultan)
Black	Javelin	hat clothes		-authority -seriosness -wisdom -nobility	- the wisdom of Sultan -the authority of Sultan
Grey	Wrestler magician	clothes		-realibility	-the realibility of the dynasty
Blue (Light)	Magician glassman a kind of a silk spice-seller	clothes	a kind of a fairy bird balcony (the sultans's seat) house	-realist -peaceful	-the realibility of the dynasty -the peacefulness of the dynasty
Orange	spice-seller	clothes	house palace walls balcony (the sultans's seat	-active -sociable	-the power of social relationship of the dynasty
Yellow (Light)	Spice-seller	clothes	Palace walls window	-gold -sun -the color of the Kingdom -success	-Power of the Government
Mustard	Wrestler magician	clothes		-intuition -revival	-thepower of intuition and wit of Sultan

Tales of Tiles in Ottoman Empire

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ABSTRACT

Ottoman tile art has many different techniques so called as "minai" technique, "mosaic tile" technique, "over glazed" technique (perdah technique), "colour glazed" technique. In the second half of the 16th century, innovation in the coloured glaze technique and under glaze technique can be seen. 17th century is the decline of the tile technique and art. Ottoman craftsman were seeking for colours; inspite of using only three colours they founded "naturalist style" which was independently improved from the Chinese, Iranian and Islamic traditions.

Keywords: Tile, Çin-i, tile colours, tile production techniques, Damascus Work, Ottoman Naturalist Style, Topkapı Palace, Sokollu Mosque, Rüstem Pasha Mosque.

INTRODUCTION

The origin of the word "tile" comes from Persian noun phrase "Çin-i" (tiles) which means the Chinese style. The same word has been used in Turkish for glazed pattern or coloured panel. Tile art, that has a great importance in Traditional Turkish art, has been used since ages. Tiles are widely used in the architecture of many Turkish, monuments, as well as other states in Asia (Figure 1). In conjuction with the Anatolian Seljuks, usage of Tile Art in both the interior and the exterior architecture is commonly seen where Turquise was dominant. During the expansion of the Ottoman Empire, optimize the endurance of tile art, various efforts were made. It's been the other way round during deterioration and decadence periods of the Ottoman Empire. The transparency of the glazed surface caused an aesthetical feeling that attenuates the mass of the architectural constitiution. Many techniques have been used during the developmental period.

1. "MINAI" TECHNIQUE

The colour of dough in "minai" technique is yellowish. Lime (alkalili) has been used as the binding material to form dough. It was turned into a moulded dough panel, and was glazed without undercoating. Seven colours were used in these tiles. Green, dark blue, purple and turquise colours that were temperature-resistant were painted, underglazed and were then patterned. Afterwards, black, brick red, white, gold leaf were painted again over, the glaze and the kiln was dried in low temperature. High-quality products were achieved with this method that was hard to practice. By this technique, star and cross shaped square tile panels and diamond shaped tile panels were produced on these art pieces, throne scenes that represented the court life, various animals that were hunted and special flowers can be seen[1]. Konya Alaaddin Köşkü (Kiosk) is the only building in Anatolia where tiles that were produced by this tecqnique were used [2] (Figure 2).

2. "MOSAIC TILE" TECHNIQUE

Pieces of tiles were glazed with various colours such as turquoise, purple, green, dark blue in "mosaic tile" technique and they were cut in accordance with its' patterns and were put together on a plaster base. Dome of the Konya

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[1] Ş. Yetkin, "*Çini Sanatı*" p.2, İstanbul University Fine Arts Department Lectures.
[2] O. Aslanapa, *Turkish Tile and Ceramic Art*, p.16, İstanbul, 1999.

Karatay Madrasaha (Figure 3) is an example that was produced with this technique were foliate and geometrical motifs, can be seen Sivas Gök Madrasaha (1272) is a monumental structure with its iwan of entrance[3].

3. "OVER GLAZED" TECHNIQUE

It's generally an adornment technique over glazed tiles (opaque). Glaze paints are kiln-dried on 750-800 degrees centigrate. This technique shows metallic glitter over glaze. In this process, a mixture of silver or copper oxide over matt white, purple are turquise glazed tiles are kiln-dried, again at low temperature. In this method, a metal oxide mixture covers tiles' surface as a thin layer. The tiles of Kubadabat Court is an important example where the walls are covered with stars and cross shaped human and animal figures[4] (Figure 4)

4. "COLOUR GLAZED" TECHNIQUE

In this technique, the contour outlines of the patterns are carved or pressed on a red dough, the inside is tilled in paint and then it's kiln-dried. Another way is after applying a red dough panel on a white undercoat, outlines of the patterns are drawn with a sugary mixture of chrome and manganese, then filled with coloured glaze paint and kiln-dried. Black outlines prevents mixing of colours[5]. At the end of the kiln-drying process, the melted glaze were prevented from pouring into each other with the help of outlines that was bloated. "Tiled Kiosk" is a building that belongs to the Early periods of the Ottoman Empire where the developments of the mosaic tile art techniques can be seen (Figure 5). It is appraised as an iwan (monumental entrance-door) covered with tiles.Geometric shapes and tile panels with Kufi and Sulus writing makes this affect more dominant. It's an important example in Ottoman Art where tiles are used as exterior ornaments. Karamans were also aware of this technique which was invented by Seljuq's. But, during Ottoman times, Konya lost its importance[6]. Bursa, The Green Mosque (1419-1422) tiles shows the conceptual level of the early Ottoman Art. The colour palette is richened with the addition of yellow, peanut green and lavender. Hatayi compositions[7] and peoni motifs of fareast origin were added to tile art.

4.1 Innovation in the Coloured Glaze Technique

Coloured glaze technique was still used in İstanbul during the 16th century. At the end of 15th century and the beginning of the 16th century, along with the fareast that has origins back to the Ming Period, chinese cloud, stylized dragon, peony and bunch of grapes, next to the symbol of "çintemani" (three ball design) Also, other patterns were existed such as curling branches of Rumi, bird, deer, fish, hunting, sytlized flowers, rosette, kufic ve nesih (rounish) writing were seen (Figure 6).

5. UNDER GLAZE TECHNIQUE

Craftsman started to use a new method called "underglaze" in the second half of the 16th century. In this method, they cover the tile panels with a lining and paint the inside. Tile panel is filled with glaze and then it's kiln-dried. The transparent glaze becomes a thin glass layer inside the oven and colours come out very shiny. Blue, turquise, olive green richens the color palette, they are put together and the patterns were drawn onto a white dough where chrysanthemum or cloud, bunches of hyacinth, tulip and rose were used. They were called "Damascus work" by mistake, because they were the parts of the walls of the architecture that belongs to the 16th century in Damascus[8] (Figure 7). By adding grass green and coral red to these colours, the best examples of İznik tiles were produced.

In the second half of the 16th century, in the samples of tiles competence and technical quality was seen.Tile patterns were handed by palace miniaturists in İstanbul and then they were sent to İznik. The tile patterns were colorized, with the colors of Cobalt-blue, turquoise, green, white, occcasionally brown, pink and gray.The coral red that symbolized the century - was in used as relief under the glazes. The black hardy lines that

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[3] O.Aslanapa, *ibid*, p. 27.
[4] O.Aslanapa, *ibid*, p. 27.
[5] M.Sözen, U.Tanyeli, *Sanat Kavram veTerimleri Sözlüğü*, p. 200, Remzi Press, İstanbul., 1994.
[6] *O. Aslanapa, Yüzyıllar Boyunca Türk Sanatı (14.yüzyıl)*, p.45, MEB, İstanbul, 1977
[7] Baba Nakkaş was the first craftsman of the Palace and the inventor of Rumi and Hatayi. Ref. S. Ünver, *Fatih Devri Saray Nakkaşhanesi ve Baba Nakkaş Çalışmaları*, Kemal Press, İstanbul, 1958
[8] N. Ö. Fındık, *İznik Tiyatro Kazı Buluntuları (1980-1995) Arasındaki Osmanlı Keramikleri*, pp. 216-221, Ministry of Cultures, Ankara, 2001

formed the pattern is more effective on these multiple colours. This period was called as Naturalist style as we can see various kinds of flower styles, descriptions on the miniatures were tulip like and they were called as “Turkish Flower”, rose, carnation, pomegrate, flower nyacinth, violet, sprays, grape louse, and cupressus sempervirens. Rüstem Pasha Mosque (1561) is an example for a new technical development and patterns of tile art in the second half of the 16th century, the walls, attars and pillars of the whole mosque was covered by tiles[9] (Figure 8).

The Sokullu Mehmet Pasha Mosque, located in Kadırga, (1571) is a succesful pattern of tile art too, the contruction of the composition is not dominant on architecture. Tile patterns pass through the structure with pendant pelmets, circle of the marble altar, and the tiles covered the altar’s coif, may be eveluated as the competence patterns of the period. “Takkeci İbrahim Ağa Mosque” (1591) in İstanbul is a important example of the 16 th century Ottoman tile art.

The Hırka-i Saadet (relic) room at the Topkapı Palace is one of the places where high quality tiles exist. The tiles in Sultan III. Murad is Room (1578) cover the whole wall up to the dome.

It’s clear that, the miniaturists of the palace patterned the tiles on the panels which include rumi and birds on curly branchs that is smaller then the previous examples. Similar panels were seen in Baghdad Pavillion that was built in 1639.

6. DECLINE

As the result of the technical decline, coral red turned to brown and pale colours appeared the Glazes run out of white ground turned into dirty bluish and dots appeared on the glaze. The glazes lost their brilliant look and multiple breaks appeared on them. In spite of the technical backtrack in the second half of the 17th century, various patterns are still used, and also green turquise and dark blue are the dominant colours in tiles of *İstanbul New Mosque* (1663) (Figure 9). At the beginning of the 18th century, İznik tiles weren't produced anymore. Sultan Ahmed III built a small factory with tile ovens and its' materials for reproducing tile art in Tekfur Palace and tiles similar to İznik tiles were produced in the beginning[10]. But after these attempts that lasted for 25 years, production Tekfur tiles come to an end, too. On the other hand, tile production permanently shows itself in Kütahya as a traditional public style.

7. TURKISH RENAISSANCE

At the beginng of the 20th century, İznik tiles with classical patterns were reproduced again by the effects of Neo-classical understanding. But an art that belongs to an empire that was about to descend could not survive anylonger. Nevertheless the architect Kemalettin built a school in 1900 called “Çapa Trainers School” which represented a National Movement in architecture with Turquoise tiles on the facade.

7.1 New Interpretation

Turkish Cultural Ministry announced 1989 as “İznik Tiles Year” and arranged meetings and exibitions. While tile art takes an important place in museums all around the world as masterpieces, contemporary examples; a monument in Montreal is covered with tulips that symbolize the peace**.** İstanbul subway stations are covered with panels of tiles which was decorated like a classical style of İznik. These are new commentments of İznik tiles as postmodern thought.

CONCLUSION

According to the Pierce semiology, the present study is based on the concepts of “firstness”, “secondness” and “thirdness”. “Firstness” the grand and ambiguity in the concept of “tiles”, the concept of “secondness” is the point in question during the Ottoman Empire Period at the tiles and the tales of tiles. Tales of tiles in the Ottoman Empire is extrapolated as a special case on tiles. Colours, the order of the aesthetical and technical items are approached as diachronic, and thirdness, in other words, secondness (the figuration of the feasible) set up the outcome of the study based on the rules, the methods, technical and cultural extent and historical process.

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[9] Ş.Yetkin, “*İstanbul Rüstem Paşa Camii Çinileri Üzerinde Bazı Gözlemler ve Saray Nakkaşlarının Bu Çizimler Üzerindeki Etkileri*”, p.19, Kültür ve Sanat Periodical, 4, 1989.

[10] A. Refik, “İznik Çinileri”, *Darülfünun Edebiyat Fakültesi Periodical*, pp. 48-49, VIII. Cilt, 4, 1932

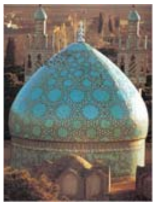

Figure 1. Shah Nimetullah's Tomb

Figure 2. Allaaddin Kiosk

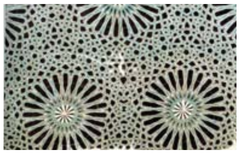

Figure 3. Karatay Madrasaha

Figure 4. Kubadabat Court

Figure 5. Iwan of the Tiled Kiosk

Figure 6. Ottoman Ware

Figure 7. Three coloured ware

Figure 8. New Mosque

Figure 9. Rüstem Pasha Mosque

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Symphony of Two City Colors

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ABSTRACT

This article will deal with the interplay of special colors and the smells identified with the colors of Mardin and Bursa. Strong rays of sun reflecting different tones of brown are an overture followed by different shades of yellows, coffee and orange colors. This symphony of colors is followed by a comparison between the natural browns of this Southeastern Turkish city of Mardin and the greens of the Western city of Bursa. The latter was called Green Bursa for centuries due to its gardens, orchards and the predominant greenery inside the city and the surrounding areas. We will apply the tools of Semiotics to the analysis of these two urban areas in Turkey located in the East and West respectively.

Keywords: Semiotics, history, seasons and colors, green, yellow, brown

1 INTRODUCTION

The art of past and recent cultures is an area that historians have delved deeply into[1]. There are a number of factors which influence the fabric, smell and color of cities. One of the most important factors is the historical evolution of cities. As history leaves the imprint of events during different periods, Nature contributes to this imprint. Nevertheless, over a period of historical evolution, human influence may change and even decrease the influence of colors on the city landscape. This article will undertake a color related semiotic analysis of to Turkish cities; Mardin in the East and Bursa in the West. The reason we have chosen these two cities are their history sating back for centuries and their importance in regional and world mythology. Cities that are far apart in geographic terms exhibit environmental (climate, natural resources) and cultural (language, art) differences. Nevertheless, despite these differences, there are also similarities such as the language spoken and religious beliefs. In our analysis we will study the differences and similarities between these two cities influenced by the natural environment, history and the cultures that existed and especially the colors of each area that have evolved under cultural influences. In our analysis we will refer to "Green" Bursa and "Yellow" Mardin and in our conclusions we will determine whether these colors are an appropriate description and proper fit from a Semiotic point of view.

2 THE HISTORICAL EVOLUTION OF THE CITY OF BURSA

Bursa has existed as a human settlement for five thousand years. Historical records indicate that it was established by Prusias in 232-192 B.C. Hannibal the king of Carthage, after losing the battle against the Roman Empire seeks the protection of Prusias 1. Hannibal is well received and builds a city to express his appreciation to give to Prusias 1 and names it Prusias. Later on the Roman Empire invades the city and names it Prusa ad Olympium. Mount Olimpus where the Mythical Greek gods dwelled is called Uludag in Turkish. This the Turkish name was Uludag Bursasi. During the 14th century the city of Bursa became the capital of the Ottoman Empire[2]. The city contains two historical mounds dating from antiquity. The "Demirtash Mound" from the Bronze Age, circa 2500 B. C. and the "Çayirkoy Mound" dating from 2700 B. C., contain ceramic artifacts and shards in gray, red, grayish brown and black. In addition to its archeological past the city is also a center of mythology. The Argonauts who searched for the Golden Fleece crossed the Black Sea and the Marmara Sea docking their ships in the ancient port of Mysia, which is called Mudanya today. One of the crew members the handsome Hylas ventured into woods in search of water and does not return. When he reaches the source of fresh water Zeus's daughters fall in love

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[1] Goldberg., "Careers for Color Connoisseurs and Other Visual Types", Blacklick, OH, USA: Mc Graw-Hill, p.2, 2005.

[2] E. Özendes., "Osmanlının ilk Başkenti Bursa" İstanbul, Yem Yayın, p.20-21, 2000.

with him and make him immortal. In an area near Mysia where the blues of the sea embrace the green of the land a new city is built named Prusa[3].The city leans against Mount Uludag and exhibits different colors during the four seasons of the year. The white and cream colored flowers of the apple orchards in the spring are accompanied by the pinks of peach orchards. In the springtime the pure tints of the orchards together with the bright green leaves and smells offer us a veritable symphony of colors. The romanticism and elegance of white and pink and the contrast of the bright green leaves gives a new meaning to a "live" description of freshness. (TDK) As the fields and trees spout their greenery reminding us of the deep color of emeralds it also brings to mind the conversion of fertility to wealth. The pink and cream colors of the fruits and flowers endow the city with romantic feelings. Pink suggests romance and "…added to red in varying and is the lightened value of red."[4]. It is important to note that different sources of light structurally contain different colors[5]. At different times of the day of a particular season or in different seasons the same light source can contain different colors.

3 SEASONS AND COLORS

The valley gives the city of Bursa green toned colors around and in the city. This green is deepened by the darker greens of the pine, oak and beech forests on Mount Uludag facing the city. As the mountain is covered with different tones of green the smell of fresh oregano accompanies this harmony of colors. "In works of art the relationship of the whole with its parts is called Harmony"[6]In Uludag there is an aesthetic harmony between the colors, and smells of Nature. Green is a calm and soft color and the bright green of the trees and grass reminds one of abundance and Spring. Nevertheless, there is strength and virility in green. Green in a negative and disagreement laden context can indicate poison and jealousy[7]. However, in our analyis we will deal exclusively with its positive aspects. In the Summer green matures all the light green leaves take on a deeper and nobler shade. Dark green also reflects the pine forests richness and nobility. Dark greens such as forest green and pine green provides a calm and peaceful alertness to the observer. As it gets darker it becomes a more dense and heavy color and reflects the city's immortality[8]. In the Fall the oak trees in Uludag are a warm potpourri of yellow and red. In the sunlight these colors seem much brighter and warm. Yellow represents life and happiness. It is the sun's color. The lighter versions of yellow remind one of a spring breeze[9]. In the winter Uludag is dressed in white. The mixture of snow white mixes with the sky's very light blue reflected by the sun's rays. Despite the cold nature of blue and white the sun's rays and their brightness adds a warm dimension to this interplay of colors. In Uludag the colors according to the seasons start off with light green, then dark green, yellow and red as components of a burning fire. As white is added on top of everything it is as if the fire and of autumn is about to be put off. The rhapsody of colors in Uludag extends from cold to hot colors and from there to colorless spaces.

4 HISTORICAL STRUCTURES AND COLORS

The urban core of Bursa is symbolized by the Green Mosque and the Green Mausoleum. From a horizontal and spatial point of view the green of the grass and the fields in addition to the blue-green of the sea extends over a broad area and provides a contrast and a show of strength to the vertical Green Mausoleum. The Green Mausoleum is an octagon shaped structure whose surface is covered with green turquoise tiles. This gives the city a unique color and smell. It is as if this vertical structure challenges the horizontal grass fields.

The people of Bursa have named their city Green Bursa[10]. Green has a sacred status in Islam while turquoise represents protection from the evil eye and curses. The color blue adds meaning and identity to the green in this city. The turquoise colors of the Mausoleum seem like a marriage of the valley's green with blue color of the sky. The frames of the windows are made of stone. They are light gray mixed with skin tones. All the Ottoman historical structures were built with cream colored stones and add elegance to the

[3] E. Özendes, "Osmanlı'nın ilk Başkenti Bursa" İstanbul, Yem Yayın, p. 5, 2000.
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[6] C. Deliman, İ. Gerce, B. Orhon "Temel Sanat Eğitimi" Ankara Gerhun Yayıncılık, p. 58, 2000.
[7] C. Hideaki , "Color Harmony" USA. MA., Rockport Punlishers, p.14, 1987.

[8] C. Hideaki, p. 14.
[9] C. Hideaki, p. 13.
[10] www.bursa.gov.tr

panorama of the city. One of the special features of an elegant color is the mixture of white with yellow which provides us with a pastel cream. The architectural details adorned with natural light and few shadows provide an impression of modernity. "Elegant color combinations use only the pallets'' tints. For example, whisper of yellow combined with white makes a pastel cream"[11]

5 HISTORICAL EVOLUTION OF MARDIN

The province of Mardin was established by the Subaris almost seven thousand years ago. It is one of the oldest cities of Mesopotamia. The Subaris lived in this area from 4500 to 3500 BC.[12]. After its invasion by Shah Ishmael the Mardin castle fell into Ottoman hands during the reign of Sultan Selim[13]. Mardin is full of structures from antiquity which extend as far as the eye can see[14]. Mardin has been an Ottoman city since 1517. Within a heterogeneous population there have been Jews, Christians (Armenians, Sourianis and Chaldeans) Moslems and Zoroastrians who have lived here for centuries[15]. Mardin's original name was Merdin which meant castle. It is an eastern city surrounded by mountains. Its population consisted of transhumant that moved their herds and those that lived in settlements. The height of the mountains reaches 1500 meters and is 600 meters above a wide valley where the city originated. There are two climactic systems prevalent in the province. In the valley summers are hot and winters are mild and rainy. In the mountains the summers are cooler; winters are colder with more rain and snow. The valleys exhibit the colors and climactic characteristics of four seasons. In spring time nature awakens with the light green tones of vegetation. The green which is a combination of yellow and blue has a range of colors from yellow to dark green in the valley. In other words, the valley exhibits a whole range of tonal and shiny variations just like a green ocean. These valleys symbolize the rebirth and awakening of nature. With spring the fertile land mass between the Tigris and Euphrates rivers turn the blue waters of the rivers into blue. The blue green of the water brings us to a state of mind where "… we feel more freshly the value of the mere tints and shadings, and became aware of any lack of purely sensible harmony or balance which they show"[16]. Thus we observe a balance in the harmony of colors.

The mountains generally are bare and exhibit the effects of erosion after the disappearance of forests. Soils have clay and lime structure. We van not find the fertility and the green of the valleys in the mountainous regions of the province. These mountains with significant clay deposits and under the influence of a desert like climate give the impression of bare stones and earth. From a color point of view, this picture emphasizes the depth of its history, the nobility of the colors which have predominated the area providing a rich, warm and homey feeling. The rocks in the mountains as a result of the hot rays of the sun give the observer the feeling of polished terracotta copper. This coloring is similar to those observed in the Mayan pyramids in Mexico, which range from brown to yellow. This combination of colors is indicative of a natural union of the sun with nature and reflects the love, happiness and youth in our planet. The yellow tones of the earth are indicative not just of a natural union but an exciting union [17]. The yellows extend to a melon's greenish yellow and then to citrus and orange and then to red. Saffron flowers, which are common to the area, are yellow but turn to a reddish pink in acidic soils[18]. The mountains of Mardin exhibit a rhapsody of colors which resemble a melon colored velvet artificial saffron flower.

The most important characteristic of Mardin as far as its colors are concerned and which differentiates it from other cities, is the overlapping colors of its houses, historical structures, the earth and the stones. The stones used in residential construction have a predominating color combination of yellows and beige. Yellow is symbolic of life and happiness; it is the color of the sun and its rays. A faded yellow

[11] B. M. Whelan, "Color Harmony 2" USA. MA. Rockport Publishers, p. 62., 1994
[12] H. Dolaponu Metropolit, "Tarihte Mardin" İstanbul, Hilal Yayınları, p.14., 1972
[13] N. Göyünç, "XVI. Yüzyılda Mardin Sancağı", Ankara, Türk Tarih Kurumu Basımevi, p.37., 1991
[14] F. Katip, "Mardin Artuklu Melikleri Tarihi" İstanbul, İmak Ofset, p.2.,
[15] İ. Özcoşar, H. Dinç, F. Dinç "242 Nolu Mardin Şer'iye Sicili Belge Özetleri ve Mardin" İstanbul, İhtisas Kütüphanesi. Yayın No 1, p.96., 2006
[16] M. Barash,, "Modern of Art: From Impressionism to Kandinsky". Volume 2. New York. NY, USA. New York. University press. P. 42., 1998
[17] B, M Whelan, p.42.,
[18] V. Finlay, "Renkler: Boya Kutusunda Yolculuklar", Çev. Kudret Emiroğlu, Ankara Dost Yayınları. p.168., 2007.

reminds one of a spring breeze[19]. This yellow, together with the cool mountain breezes of the summer creates an aesthetic whole. When mixed with white the yellows soften the pale hue disappears and emanates romantic sensations[20]. Thus, "Landscape architects and designers bring their love of color outdoors, choosing the right combinations of plants, and flowers that thrive in a variety of climates and condition." [21]. The buildings in Mardin are a symphony of smells, colors and sounds, removed from history and yet as "data of pre-history "[22]. As colors are a special characteristic of cities and play an important role in the design of its structures[23]. Colors in Mardin change throughout the day. In early morning and late evening after sunset, the mountains and the houses on the hills exhibit tones of beige and blue. As darkness descends it adds a mysterious and cold curtain which accentuates the city's proud image. This image of pride is even more emphatic in the mid-day sun which represents Mardin's real colors. The city is dressed in a golden and warm yellow. In the afternoon as the sun is about to set the city seems to be aflame. All the tones between red and yellow of the city are reflected on the mountains. These are warm colors. The different tones of red-orange and yellow-orange are an important part of the emotional spectrum as they are warm and comforting.

6 CONCLUSION

Colour is powerful shorthand for conveying ideas and information. There is infinite number of colours and shades, hues and tints (some suggest as many as 16 million). Nature is a rich source of color perceptions. The flora, fauna, animals, minerals, mountains and stones and their composition attracts our attention. In describing and analyzing the symphony of colors of Bursa and Mardin, we started off with a brief review of their history and geological structure. We studied the colors of the historical structures and their relations with the colors influenced by seasons in the mountains and the valleys. We have presented a comparative analysis of the two symphonies of colors identifying similarities and differences. From a historical point of view both cities have existed for more that 5000 years. When we study them from a color and geological point of view, mountains and valleys play an important rile in both. Both cities have four seasons, and these seasons have an important role in determining the colors.

In Bursa and Mardin the colors change as the seasons do. In spring time the colors in both cities extend from yellow to light green and dark green. However, the white cream colors of apple and plum flowers and the pink flowers of peach orchards in Bursa are not observed in Mardin. Mount Uludag in Bursa expresses all the tones, tints and shades of green. Uludag lives different colors throughout the four seasons. During spring and summer the tones of green present a green symphony. In autumn the green symphony is aflame and dances with the colors of fire. In the winter months the flame is put out by a pure white. The mountains of Mardin, with its clay soils and earth tones start off with yellow and turns into beige, orange, copper and brown exhibiting an elegant presence. The two mountains, one green and the other beige are different than each other.

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Memorizing visuospatial and verbal colors in working memory: An fMRI study

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ABSTRACT

Using fMRI, the hypothesis that colors could be memorized either in verbal or visual working memory depending on the color category borders was tested. We introduced a 2-back task to investigate the involvement of verbal and visual working memory in color memory. Colors across the categories, defined by basic color names, strongly activated the left inferior frontal gyrus and left inferior parietal lobule corresponding to the phonological loop as verbal working memory, whereas colors within the same category strongly activated the right inferior frontal gyrus corresponding to the visuospatial sketchpad as visual working memory. The choice of colors to memorize might modulate the cognitive load balance between the phonological loop and the visuospatial sketchpad.

Keywords: Working memory, Memorized color, Color name, Visual color, fMRI

1 INTRODUCTION

How are colors memorized in working memory? Is it based on verbal- or visual-code under WM task? Furthermore, do both codes share dissociated brain areas? Although color is used broadly as a visual stimulus, considering the influence of verbal code, the representation of color in the brain could be equally manipulated both verbally and visually. The dual-code property of color evokes a conflict between the two codes. Colors that cross the borders of color hue categories could be verbally coded because of the involvement of the corresponding color names, whereas colors within a single color category are likely difficult to be verbally coded because of the involvement of slight hue differences.

A brain imaging study focused on colors in WM in a domain-dependent dissociable brain has not been reported previously. This study investigated the specific dissociated brain areas responsible for color memory under both verbal and visual coding, using functional magnetic resonance imaging (fMRI). In Baddeley's [1] model, WM is a limited capacity system that temporarily retains and manipulates information. The model involves an executive function as a supervisory system and two domain-specific subsystems: the phonological loop (PL) that is responsible for language processing involving color names, and the visuospatial sketchpad (VSSP) that manages visuospatial processing involving shade of colors. On the basis of current neuroimaging studies [2,3], PL is thought to be localized in the inferior parietal region in the left hemisphere (BA 40; working as short-term phonological store) in connection with Broca's area (BA 44 and ventral part of BA 6 known as the mirror system), whereas VSSP, especially the spatial component, is known to be distributed in the right hemisphere. We hypothesize that colors that cross different categories (Cross condition) would activate PL more easily because colors having large hue differences could be more easily coded verbally, as in the case of color words (Word condition), than colors within the same category with slight hue differences (Within condition). Under such Within condition, memory for adjacent colors should not rely on PL [4]. Thus, left frontoparietal network activation would be expected to increase under both Cross and Word conditions, whereas the right frontoparietal network activation would be expected to increase under Within condition.

2 METHODS

2.1 Procedures

Nine right-handed healthy participants aged 20–28 years were recruited. The n-back task has been employed in many human studies to investigate the neural basis of WM [3]. The task requires the participant to monitor, update, and manipulate the information he could remember. The participant is required to monitor whether the current stimulus is the same as the one presented in n trials previously, in which n is a preliminarily specified integer, usually 1, 2, or 3. This study introduced the 2-back task to achieve an adequate difficulty level under three conditions: Word, Cross, and Within. The experiment was based on block design. A series of nine stimuli was presented on the screen in a single block (36.5 s). Each stimulus was presented for 500 ms followed by a

4000ms interstimulus interval. Participants had to press a key with the left or right thumb as instructed.

2.2 Procedures

A single block had a color group consisting of three stimuli, from which one was selected as the specified color (red, yellow, green or blue). Under the Cross condition, the stimuli were presented as a colored square of a specified color along with two typical colors of adjacent hue categories (e.g. red group: purple, red and orange), whereas under the Within condition, the stimuli were a specified color along with two adjacent colors in the same category to minimize possible verbal labeling. Under the Word condition, stimuli were color names printed in Japanese. To cancel activation by the thumb press response, we also introduced a finger response condition. The four conditions were pseudorandomized (4 conditions x 4 color groups). Stimuli were presented with Presentation □20 and displayed in the center of a gray background on a backprojection screen that was viewed by the subjects via a mirror attached to the head coil. Before scanning, all participants received training for all conditions using stimuli differing from those used during image acquisition.

2.3 fMRI data

Whole brain imaging data were acquired on a 1.5-T wholebody magnetic resonance imaging scanner (Shimadzu-Marconi Magnex Eclipse) using a head coil. Head motion was minimized with a forehead strap. For functional imaging, we used a gradient-echo echo-planer imaging sequence with the following parameters: TR.2500 ms, TE.4□ ms, flip angle.801, 6mm slice thickness, FOV.256mm□256mm, and pixel matrix.64□64. After collection of functional images, T1-weighted images (154 slices with no gap), using a conventional spin-echo pulse sequence (TR.12 ms, TE.5 ms, flip angle.81, FOV.220mm□220 mm, and pixel matrix.256□256), were collected for anatomical coregistration at the same location as the functional images.

After image construction, functional images were analyzed using SPM2 (Wellcome □epartment of Imaging Neuroscience). Six initial images were discarded from analysis to eliminate nonequilibrium effects of magnetization. All functional images were realigned to correct for head movement, which were less than 1mm within runs. The functional images were normalized and spatially smoothed with an isotropic □aussian filter (8mm full-width at half-maximum). Low-frequency noise was removed with high-pass filtering (450 s). □ata were modeled using a box-car regressor corresponding to a single block convolved with HRF. □roup data were analyzed using a random effects model. We specified activation areas of all conditions at the threshold P□0.05, corrected for multiple comparisons (false discovery rate, F□R).

3 RESUTS & DISCUSSION

As for behavioral data, the mean proportions of correct responses were □3□ (Word), □3□ (Cross), and 87□ (Within). The data were analyzed in one-way repeated measures analysis of variance (ANOVA). The main effect was not significant. Therefore, we confirmed sufficient task performance and slight differences in task difficulty among the three conditions. We selected cortical regions of interest (ROI) according to previous studies [2,3] and inspection of activated clusters: bilateral inferior frontal gyrus (IF□: BA 44□45; Talairach coordinates; -48, 6, 36; 42, 21, -1), bilateral premotor area (PM: BA 6; -36, 12, 44; 28, 6, 48), supplementary motor area (SMA: BA 6□8; -2, 24, 4□), left inferior parietal lobule (IPL: BA 40; -32, -48, 41), and right intraparietal sulcus (IPS: BA 40; 44, -42, 50).The percentages of signal change in each ROI across the three conditions were calculated relative to control baseline (rest) by averaging the signal plateau. The radius of each ROI was 6mm. These data were submitted to two-way repeated measures ANOVA (condition x ROI). The main effects of ROI □F(6,48)□6.440, P□0.001□ and interaction □F(12,□6)□ 11.23, P□0.001□were significant. The main effect of condition was not significant. On the basis of analysis of the interaction by Tukey's HS□, significant difference among the three conditions were found in the bilateral IF□, left PM, left IPL, and right IPS (P□0.05). In addition, the data in IF□, PM, and IPL□IPS were divided into two groups by the hemispheres and were submitted to two-way repeated measures ANOVA (condition x hemisphere). No significant effects of condition and hemisphere were found. Significant effect of interaction, however, found □F(2,16)□7□57, P□0.001□. From the result of multiple comparison test (Tukey's HS□: P□0.05), we found that the left hemisphere was strongly activated under the Word condition whereas the right hemisphere under the Within condition. Under the Cross condition, the signal intensity was intermediate between the Word and the Within condition.

Under the Word condition, we found dominant activation in the left IF□–IPL, although activated regions were generally the same for both the visual colors (Cross□Within) and verbal (Word) tasks. Although there have been previous studies addressing the possible influence of language on color memory at the behavioral level, our brain imaging study suggests that PL is surely employed when we memorize colors especially under the Cross condition. Furthermore, we investigated the involvement of PL and VSSP by analyzing signal changes in each ROI across the three conditions. Significant differences were found in the bilateral IF□, the left PM, the left IPL, and the right IPS. Considerable evidence of PL from neuroimaging studies and neurological patients has suggested that IPL, specifically the left supramarginal gyrus, subserving as a passive storage buffer, and frontal areas such as IF□ and PM comprise the active rehearsal circuit, which is known to be involved in the preparation of active subvocal rehearsal [5]. It is assumed that the right IPS is a visual storage buffer, analogous to PL in the left, which is increasingly activated as the number of color patches increases [6]. Although a rehearsal process for color has not yet been clearly elucidated [7,8], considering that the ventral prefrontal region could subserve the buffer [□,10], the right IF□ (BA 44 and related areas) would be expected to involve the right IPS as a buffer for visual color image. The right IF□ activation uniquely observed under the Within condition might plausibly be considered recruitment of that area, instead of a verbal strategy in the left IF□, to retrieve visual colors under the Within condition. Another possibility is that the right IF□ was related to visual attention. Previous study [11] of visual WM for color maintenance showed strong left hemispheric activation. Under the Within condition, demand on visual attention might be increased to hold two or more complicated color representations. It is difficult to investigate time-based functional segregation using the 2-back task, thus further study of the right IF□ will be expected. On comparison of the Cross condition to the Within condition, memorizing colors across several categories strongly employed the left IF□ and the left IPL, respectively. This suggests that an implicit verbal strategy was very effective when executing the 2-back task under the Cross condition. Colors within the same category, however, activated the right IF□ instead of the left IF□ and the left IPL, indicating that a visual strategy is more useful than a verbal strategy to achieve a good performance under the Within condition.

4 CONCLUSION

The present findings suggest that both PL and VSSP are employed depending on the property of the colors being memorized. Furthermore, colors across the categories increased the signal intensity toward the left IF□, whereas, to the contrary, colors within the same category increased the signal intensity toward the right IF□.

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Colour appearance reproduction from small to large Sizes

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ABSTRACT

An experiment was carried out to study the change of colour appearance between a small uniform patch and a large colour on a wall projected using a characterised data projector. Ten observers adjusted the projected light to match small colour patches presented in a viewing cabinet. The results showed that the projected large colours appear to be more colourful and lighter than the small uniform patches.

Keywords: psychophysical experiment, size effect, device characterisation.

1 INTRODUCTION

There is a need in industry to be able to accurately reproduce colours between different sizes. For example, in the paint industry, customers normally select colours from small colour patches in a shop and apply them in a variety of sizes of walls. It is often found that there is a large mismatch between the colour appearance of the desired colour based on the small patch in the shop and that painted on the wall. In the display and TV industries, the same problem occurs when an image needs to be accurately reproduced on displays with varying sizes.

Earlier work was conducted by Xiao *et al.* [1]. They conduct the experiment in a real room painted by real colours. Observers were asked to match room colours by adjusting colours on a CRT display and by selecting small size colours from a colour book. The results showed an increase of lightness and chroma for room colours.

The above problem triggered the motivation of the present study. The method used here was to project lights from a data projector onto a wall and to adjust its colour appearance to match a small uniform colour patch presented in a viewing cabinet. A group of 10 observers with normal colour vision participated in the experiment. The data projector was used because it is an easy and low-cost way to generate experimental colours. Software was implemented to control projected colours in terms of lightness, colourfulness and hue.

The experiment was designed to answer the following 3 questions:

- Can a projected light give a satisfactory match to a small size colour?
- Can the projected light on the wall surrounded by a dark border and a dim border give the same colour appearance?
- Is there a change of colour appearance due to the sizes of projection?

2 EXPERIMENTAL

2.1 Device Characterisation

A devise characterisation model[2] was first implemented to convert the device independent data (projector's RGB signals) into the device independent data (CIE tristimulus values), and vice versa.

A Minolta tele-spectroradiometer (TSR) was used to measure various colours on the projected colours. The projected colours on the wall are viewing condition dependent. They are affected by parameters such as the luminance of the peak white of projector, background and surround. Hence, the colour measurement was carried out at the same situation as the experiment.

Characterisation of the projector was based on the work of Berns[3]. The well known GOG (Gain-Offset-Gamma) model was implemented. It can be based upon either by measuring colours in terms of spectral radiance or tristimulus values. The relationship for the red channel can be expressed in equation (1).

$$L_{\lambda,r} = \begin{cases} L_{\lambda,r,max}\left[k_{g,r}\left[\frac{LUT_r(d_r)}{2^N-1}\right]+k_{0,r}\right]^{\gamma_r}; \\ \left[k_{g,r}\left[\frac{LUT_r(d_r)}{2^N-1}\right]+k_{0,r}\right] \geq 0 \\ 0; \left[k_{g,r}\left[\frac{LUT_r(d_r)}{2^N-1}\right]+k_{0,r}\right] < 0 \end{cases} \tag{1}$$

where *LUT* represents the look-up-table, *N* is the number of bits in the digital-to-analogue converter (DAC), γ_r is an exponent accounting for the non-linearity between amplified video voltages and beam currents, constants $k_{g,r}$ and $k_{o,r}$ are referred to as the system *gain* and system *offset*, respectively. $L_{\lambda,r,max}$ defines the maximum spectral radiance of the red channel. The radiometric scalar *R* is defined as $L_{\lambda,r} = RL_{\lambda,r,max}$.

2.2 Experimental Setup

The experiment was conducted in a room with a size of 4 × 4 × 3 cubic meters. One side of the wall was used for colour projection. A software was developed for observers to adjust projected colours on the wall via CIELAB, L*, C* and hue attributes. The projector, observer and TSR were located about the same position with a distance of 3 meter from the wall. The TSR was used to measure[4] the projected colours by individual observers and the target colours presented in a viewing cabinet, which was placed between observer and the wall and had a viewing distance of 2 meters from the observer. The luminance level of the viewing cabinet was about 25 cd/m^2.

Ten observers matched fifteen target colours three times in each of the three viewing conditions, named 'box', 'large' and 'small', which are illustrated in Figures 1(a) to 1(c), respectively.

Each observer wore a helmet with a viewing field shown in Figure 1(a). The position of their head was fixed and could only view the large wall colour projected by the projector and the small physical colour presented in the cabinet. The 'large' viewing condition (Figure 2(b)) is the same as the 'box' condition except without the helmet. The difference between 'large' and 'small' conditions is the projected size on the wall. The latter size is about 25% of the former. There is a large difference of surround conditions between the 'box', and the 'large' and 'small' conditions. The former is much darker than the latter two due to the use of helmet.

The ages of observers were ranged between 20 and 30 years old. They were postgraduate students in the Department of Colour Science, University of Leeds, including four females and six males.

Each observer's results in terms of RGB signals were first stored in a computer. They were then displayed and measured using the TSR. In addition, all target colours in the viewing cabinet were also measured using the TSR. The results were transformed to CIELAB values from the tristimulus values. (The reference white was set to the visual results of a white test colour projected on the wall.) The average results from all observers were used to represent overall panel results. The three sets of results corresponding to three viewing conditions together with the targeted colour in the viewing cabinet (named 'cabinet') were used for the subsequent data analysis.

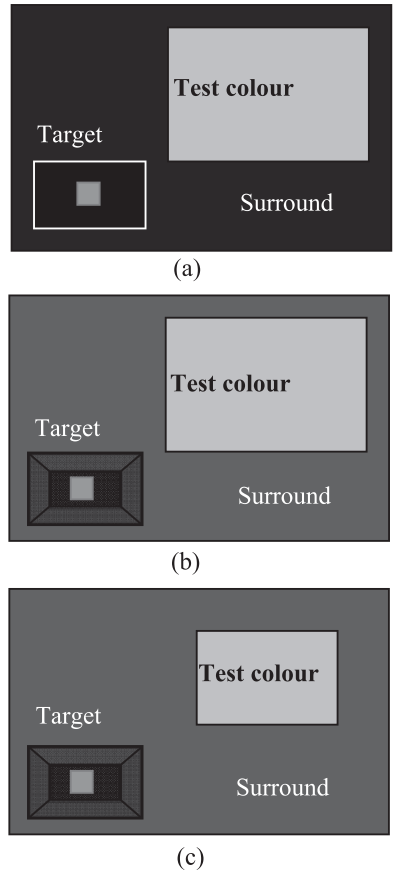

Figure 1 The 3 viewing conditions studied: a) 'box', (b) 'large' and (c) 'small'.

3 RESULTS AND DISCUSSION

The results are summarised in Figure 2 by plotting the visual results between 'Box' and 'Cabinet', 'Large' and 'Cabinet', 'Small' and 'Cabinet', 'Box' and 'Large', and 'Large' and 'Small' conditions. A 45° line is also drawn in Figure 2.

It can be seen in Figure 2 that the data points can be divided into two groups, those close to 45^{o} line and those well above 45° line. The former group includes the comparisons made between the 'box', and 'large' and 'small' conditions. The visual results in general agreed well between them. For all three attributes, L*, C* and hue angle.

Comparing the results between 'cabinet' and three viewing conditions ('box', 'large' and 'small'), the results clearly showed that the projected large colours appear to be much brighter and more colourful than the small colours in the cabinet. However, there is hardly any change in hue.

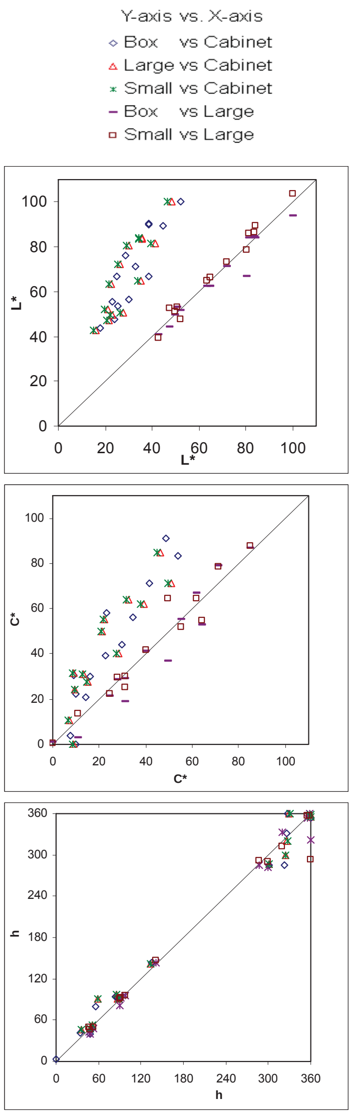

Figure 2 Comparing the visual results in terms of CIELAB L* (top), C* (middle) and hue angle (bottom). There are 5 comparisons in each diagram: between 'Box' and 'Cabinet', 'Large' and 'Cabinet', 'Small' and 'Cabinet', 'Box' and 'Large', and 'Large' and 'Small' conditions.

The results verified that the small target colour can be matched by the projected colour in a real room. The projected size ('large') and a ¼ size ('small') giving very similar results implies that typically a minimum of 70 by 62 cm on a wall should be sufficient to provide to paint customers to produce the same visual experience as the large wall, i.e. 162 by 120 cm^2.

Comparing the 'box' and 'large' conditions, the main difference is degree of adaptation due to surround. The former had a much darker surround than the latter. However, colour appearance is not affected by the surround conditions used.

Another way to look the results is to plot the data between a pair of results in CIELAB a*b* and L*C planes as shown in Figure 3(a) and 3(b), respectively. They showed the plots of the visual results between 'cabinet' and 'box', between 'cabinet' and 'large', and between 'box' and 'small', from top to boom respectively. Each of the 15 colours was plotted in vectors between the two conditions compared.

It can be seen that the patterns of colour shifts between three figures are all very similar. This again indicates a small difference between the visual results of the three viewing conditions studied. In L*C* planes, all vectors converge to the black point. This implies that all wall colours are lighter and more colourful than the target colours presented in the cabinet. In a*b* planes, it can be seen that all vectors converge towards the neutral origin. This strongly indicates almost no change in hue angle and large wall colours are more colourful than small target colours. Furthermore, there is a tendency that all vectors converge to a slightly yellowish neutral point. This could be caused by the size effect. Further study is required to clarify this shift.

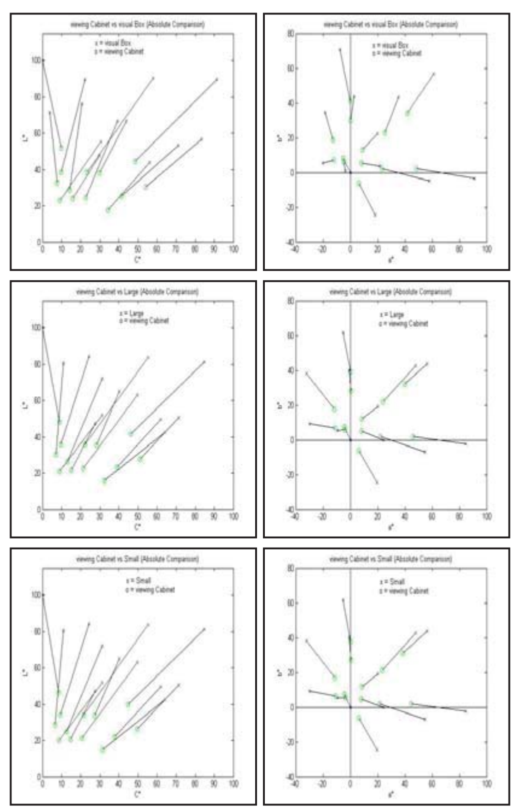

Figure 3 The colour shifts between the results from (top) 'box' and 'cabinet', (middle) 'large' and 'cabinet', and (bottom) 'small' and 'cabinet'. Each vector indicates the distance between the colour sample in the viewing cabinet (circle) and the colour in the three viewing conditions studied (cross).

The results from the present study were also compared with the earlier study by Xiao *et al.*[1]. Figure 4 shows comparisons of the results between the current work (left) and theirs (right).

Only the visual results from the 'large' condition were used to represent the present study because the viewing condition is similar to that used by Xiao *et al.* It can be seen that the trends are very similar, i.e. no difference in hue but an increase of lightness and chroma for small size colours is required to match large size colours. The magnitude of increase in C* values are similar in both experiments. However, the present results show a much larger increase of lightness than Xiao *et al's* study. This could be mainly caused by the surround conditions used. The latter experiment was conducted in a room with light in the ceiling. i.e. the wall was illuminated by the light. Hence, it had a much brighter surround than the present one.

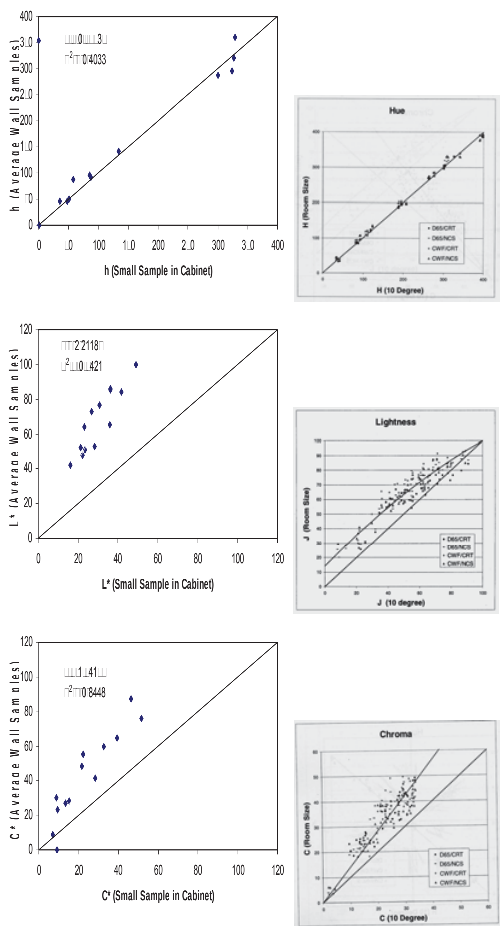

Figure 4 Current work results (left) vs. previous work results (right) to show size effect.

4 CONCLUSION

A psychophysical experiment was conducted to match small size physical samples in a viewing cabinet by the projected lights on a large wall. The results are summarized below:-

- A successful colour match can be achieved between small physical samples and large projected lights on a wall.
- Very similar results were found between the dark and dim surrounds used and between the two different projected sizes used.
- There is a need to increase lightness and chroma for small size colours to match large size colours. No change of hue is needed.
- The present results in general agreed well with those by Xiao *et al,* except a much larger lightness is required than theirs to match large colours. This is caused by the different surround conditions used.
- There is also a consistent shift of neutral point, i.e. the projected colour appears to be more bluish than the small physical samples.

ACKNOWLEDGMENTS

The authors would like to thank the State Scholarship Foundation (IKY) of Greece for the financial support.

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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.

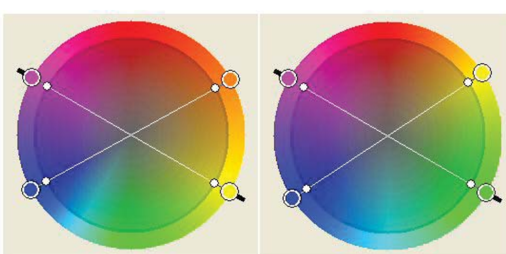

Figure 1: Colorant mixing (left) and visual (right) colour wheel show inconsistent complementary relationships**.**

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

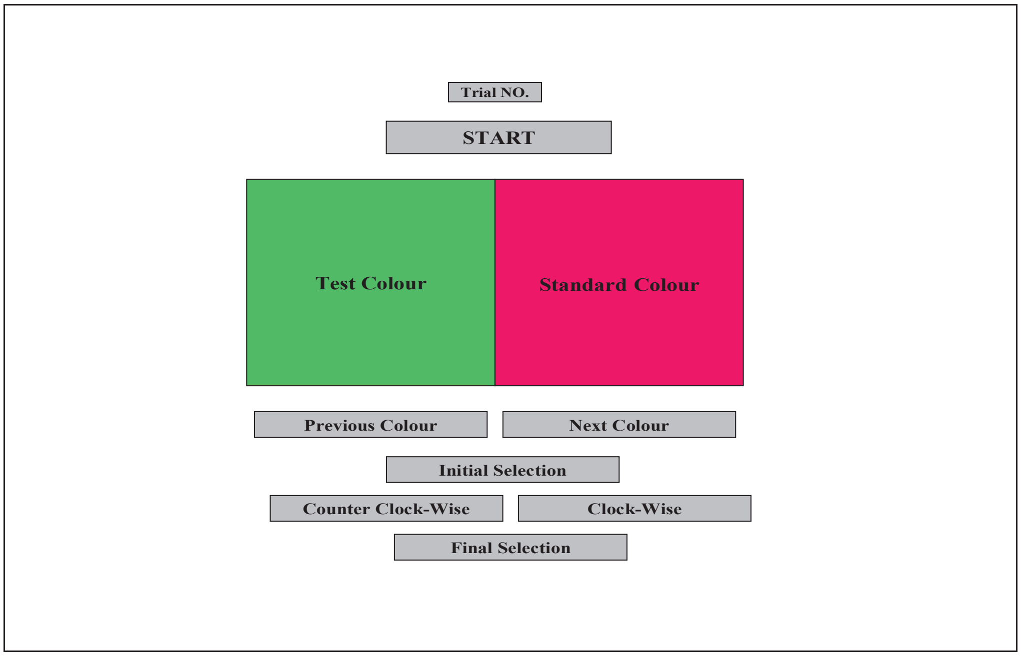

Figure 2 : The user interface used in the experiment

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.)

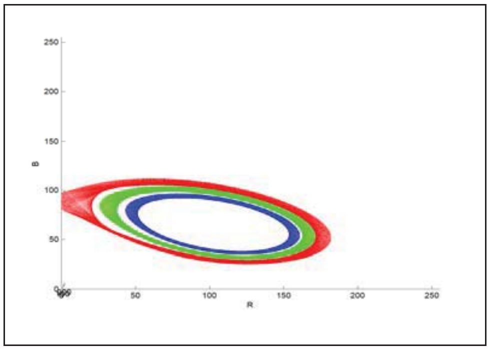

Figure 3a: Optimal Chroma Circle in comparison to the Monitor Gamut in R value vs. B value diagram

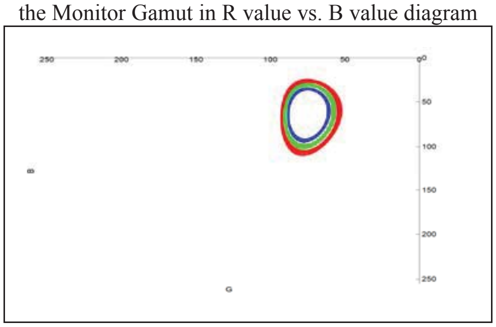

Figure 3b: Optimal Chroma Circle in comparison to the Monitor Gamut in G value vs. B value diagram

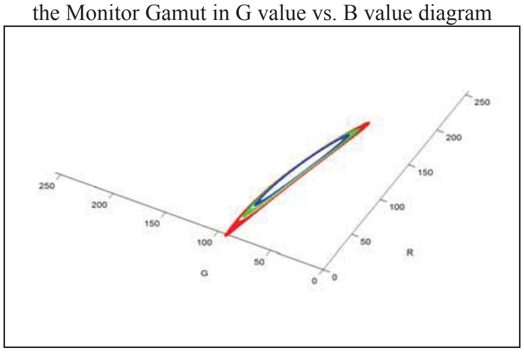

Figure 3c: Optimal Chroma Circle in comparison to the Monitor Gamut in R value vs. G value diagram

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).

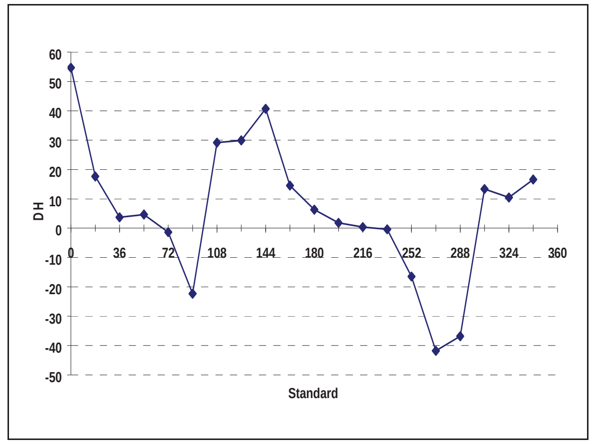

Figure 4: The Angle Difference between the selected test hue and the predicted test hue for each standard colour

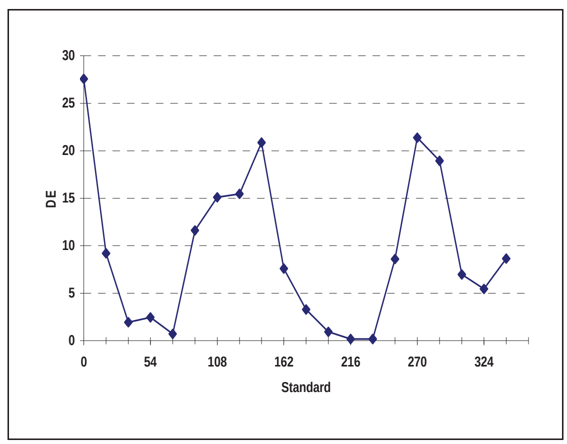

Figure 5: CIELAB Colour Difference between the selected and the opposite colours for each standard hue

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)

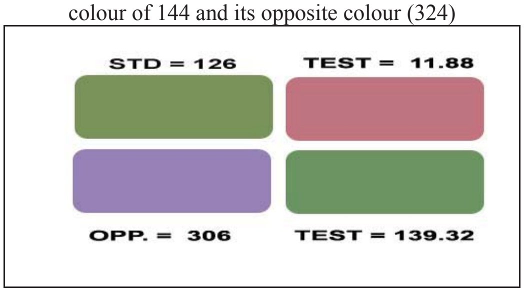

Figure 7 : The selected test colours for standard colour of 126 and its opposite colour (306)

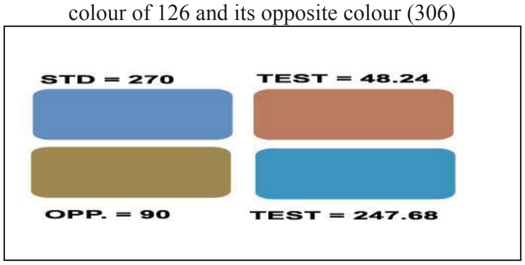

Figure 8 : The selected test colours for standard colour of 270 and its opposite colour (90)

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).

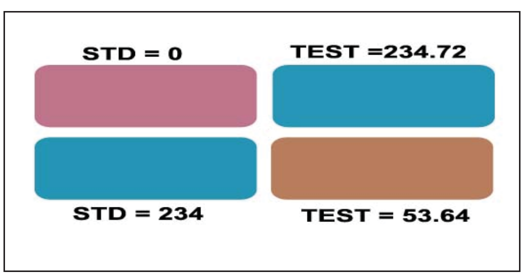

Figure 9 : Test colour selection for the same colour and different orientation

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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Effect of Haze of Cataract Eyes to Color Perception of Elderlies

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ABSTRACT

When people become older it is inevitable to get cataract in their eyes and meet various new inconvenient situations about their visual perception. Change of color perception is one of them. It is caused by the yellowing of the crystalline lens, but more seriously by the haze of crystalline lens which desaturates all the color that they see. In the present paper we investigated the effect of the haze on desaturation by two experiments. Haze goggles with six different haze values were made to simulate different degree of cataract and used to judge color outdoors. In Experiment 1 the color of various objects such as tree leaves and signs at far distance was judged whether the color is perceived. With increase of haze value the colors gradually desaturated and finally faded out. The observers could not tell what colors they were. In Experiment 2 fourteen colored charts were used in stead of normal objects and the distance limit over which their colors became unperceivable was measured. The distance became shorter for heavier haze goggles because of desaturation of color of the test colored charts.

Keywords: cataract, haze, desaturation, color perception, elderlies

1 INTRODUCTION

The population ratio of aged to young people is increasing in many countries and the adjustment of the visual environment to suit the aged people is becoming an urgent subject. To achieve the adjustment the investigation of color perception of aged people is a first step and some researches have been reported in past meetings of the AIC[1-8]. Obama et al. developed the cataract experiencing goggles to simulate the visual system of cataract aged people who began to feel visual inconveniences in their daily life[9]. They investigated visual perception of 48 cataract patients who got cataract operation for one eye. They came to a conclusion that the visual perception of senile cataract eyes can be expressed by three elements, haze, brightness, and color, caused by the frosted crystalline lens, the overall decline of light transmittance, and the specific decline of transmittance at short wavelengths, respectively. The goggles were installed with these three elements. It was found in experiments using the goggles that the color perception of cataract eyes was influenced greatly by the opacity of the crystalline lens in such a way that all the colors were desaturated[10]. The authors reasoned the desaturation to the environment light which enters the eyes from every direction of the outside and is scattered by the frosted crystalline lenses to fall on the entire retina. The environment light is white and thus it desaturates the color of any objects that the eyes are looking at.

In this paper the goggles with different degrees of haze were made and two experiments were conducted to investigate the effect of haze on the color desaturation. In Experiment 1 the color appearance of normal objects at far distance was judged with the goggles, and in Experiment 2 the distance limit for color perception was obtained for 14 colored charts with the goggles. This experiment was conducted in the outdoor also.

2 HAZE GOGGLES

Obama et al. employed a frosted plate for the cataract experiencing goggles. It was made by blasting glass powder onto the plate. By controlling the pressure of the blasting, number of blasting nozzles, and others, the haze value of the plate can be adjusted from low to high. Haze value is defined as the transmitting scattered light divided by the entire transmitting light. It is expressed by percentage. We made six goggles, G0, G1, G2, G3, G4, and G5, of different haze values, 0.1, 5.5, 13.4, 17.5, 23.8, and 25.5 %. The haze value almost linearly increases for the goggles. The goggle G3 is same as that of the cataract experiencing goggles and it represents the haze perception of cataract patients who just started feeling inconvenience in their daily life. No color filter was employed in these goggles. The goggles were made to have a clear plate at the left eye side. The color of the goggles frame was made clear as the frosted plate.

3 EXPERIMENT

3.1 Experiment 1: Color Perception of Outdoor Scene

The test targets that subjects observed with his/her right eye through the goggle were objects at various distances in the outdoor as seen in the first and second columns of Table 1. The measurement was conducted in a cloudy afternoon in Yokohama with the horizontal plane illuminance 2,000 lx at a clear space. Two subjects, KT (Japanese female, 41 years old) and MI (Japanese male, 73), participated in the experiment. The subject MI had IOL in both eyes after cataract operation. The subjects reported whether the color of the objects is seen when they looked outside from a window position of a residence.

3.2 Results of Color Perception

Results are shown in Table 1 by circles, triangles and exes. The circles indicate that both subjects responded with "Yes, I can see color", exes "No, I can't see color", and triangles indicate that responses of two subjects disagreed. It is clear that the subjects could not see colors for already desaturated colors of leaves at very far distance when the degree of haze increased. The most significant result is exes for all goggles but G0 and G1 for yellow leaves seen against sky. Environment light heavily entered the goggle and the color of leaves became so much desaturated that the color was not seen at all.

It may not be serious for aged people when they can not enjoy beautiful color of scene, but is very serious when they can not discriminate traffic signs which utilize colors.

Table 1 Results of color appearance of objects with different haze goggles.

Distance	Test targets	G 0	G 1	G 2	G 3	G 4	G 5
Very far	Leaves colored in a mountain	○	○	○	×	×	×
Far	Yellow signboard	○	○	○	○	△	△
Far	Red signboard	○	○	○	△	×	×
Far	Green roof	○	○	○	○	△	×
Far	Brown roof	○	○	○	○	○	△
About 100m	Red signal for pedestrian	○	○	○	○	○	○
About 100m	Green t signal for pedestrian	○	○	○	○	△	△
Near	Red of no-parking sign	○	○	○	○	○	○
Near	Blue of no-parking sign	○	○	○	○	○	○
Near	Red small fruits	○	○	○	○	○	△
Near	Orange tangerine	○	○	○	○	○	○
Near	Blue water-pipe	○	○	○	○	○	○
Near	Yellow leaves against sky	○	○	×	×	×	×

3.3 Experiment 2: Distance limit for color perception of colored charts observed outdoors.

In this experiment we measured how far distance the color of colored charts can be recognized with goggles. We employed 14 colored charts for observation as summarized in Table 2. It appeared that some of charts were painted with fluorescent substance. Their chromaticity points are shown on the CIE xy chromaticity diagram in Fig. 1. Test charts of 1 through 10, shown by open squares and connected by a line, were chosen to cover hue and to represent typical color of Thailand. Their color names are written. The colors turned out to be vivid. So less saturated colors of 11 through 14 were added. They are shown by open circles and connected by another line. The size of the test chart was 20×20 cm^2.

Table 2 Color specifications of test charts.

No.	Color of charts	x	y	Y	L*
1	Yellow	0.431	0.480	72.4	87.9
2	Golden Yellow	0.464	0.450	57.5	80.1
3	Orange	0.554	0.401	28.2	60.0
4	Red	0.608	0.311	11.1	39.3
5	Pink	0.457	0.272	18.5	50.1
6	Purple	0.315	0.227	10.7	38.9
7	Blue	0.202	0.202	10.8	39.1
8	Sky Blue	0.185	0.252	23.3	55.4
9	Green	0.251	0.413	19.1	50.6
10	Yellow Green	0.345	0.527	36.6	67.2
11	Pale Yellow	0.375	0.430	76.9	90.2
12	Pale Pink	0.359	0.312	36.7	67.1
13	Blue Green	0.284	0.359	50.8	76.4
14	Deep Green	0.344	0.434	10.0	36.8

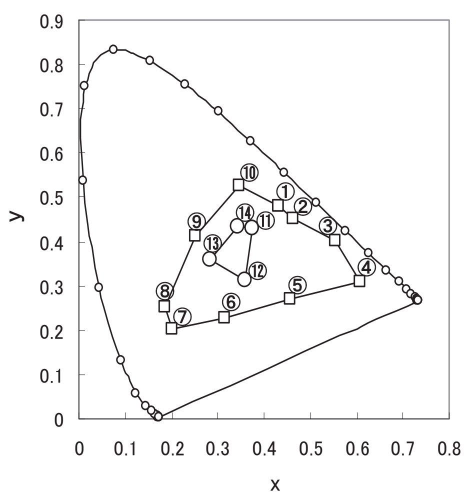

Fig. 1 Chromatic points of test charts.

A colored test chart was placed at the eye level in a shade of big trees planted at the edge of a large clear ground in Chulalongkorn University campus, Bangkok. An observer looked at the chart at various distance on the ground under the direct sunshine. The observer faced the sun so that the light from the sun directly hit the goggle. This was to maximize the effect of haze in the eye. He/she was not allowed to use a hat that might intercept the direct sun light. Only right eye was used. The task of the observer was to decide the distance from the test chart when its color became just indistinguishable. He walked back and forth on the ground along a fixed direction from the test chart until he found the distance. There was placed in the direction a rope of 100 m long with tags at every 5 m and the observer could measure the distance and wrote it down on a note.

The experiment was carried out in January and started at around 10 am on fine days without any clouds. The illuminance under the direct sun light varied depending on time, and was about from 50,000 to 90,000 lx. The illuminance in the shade under trees where the test chart was placed varied also from about 10,000 to 15,000 lx. One experimental session to complete measurement for 14 test charts took one to two hours and only one session was conducted with one person in one day. Three sessions were conducted with each observer on different days. Three observers, KT, MI and PP, participated in the experiment. The subjects KT and MI were the same persons as Experiment 1. The subject PP was a Thai female of 55 years old.

3.4 Results of distance limit

Results are shown for three subjects in Fig. 2. Along the abscissa the goggle is taken and along the ordinate the distance limit for recognition of color in m. Fourteen curves correspond to test charts. We repeated the measurement for three times and three, two or one experimental points were obtained for each goggle. In some case the distance limits were all within 100 m, but in some other case one or two distance limits went out beyond 100 m and not measurable. In this case the curve obtained within 100 m was used to estimate the shape of other one or two curves beyond 100 m, and the average was taken for three distance limits. The average curve obtained in this way has data points beyond 100 m, but the accuracy of the data points is not necessarily good. Dotted horizontal lines indicate 100 m.

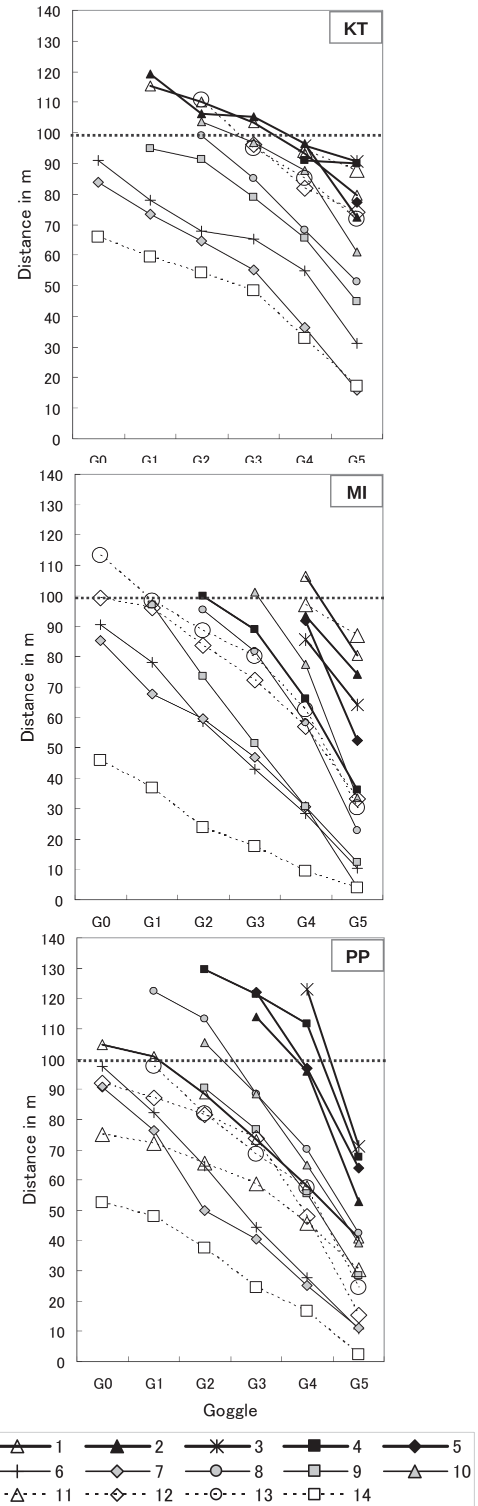

Fig. 2 Distance limit plotted for goggles. Symbols represent test charts. Sections correspond to subjects, KT, MI, and PP.

All curves have a similar shape. They decrease gradually for larger haze value of goggle. With the haze goggle the scene appears foggy and the color of test charts appears desaturated. When the observation distance is increased the color fades more and more, and finally at some distance the color completely fades out. When the observer changed to another goggle with a larger haze value, he/she had to come closer to the test patch in order to perceive its color again. The haze caused the color of test patches to desaturate and harder to recognize the color.

The vertical location of curves in Fig. 2 differs depending on the test patches. The higher curves indicate that the colors of the test patches were able to be perceived at far distances. They were test charts 3, orange, 2, golden yellow, and 5, pink. Those colors are vivid ones and/or bright ones. The lower curves indicate that the colors were hard to perceive at distance. They were test charts 14, deep green, 7, blue, and 6, purple. Those colors are all of low lightness.

4 DISCUSSION

The effect of haze installed in a goggle for color perception was investigated and we found that the larger the haze value the greater the desaturation of color. Objects at far distance in the outdoor became achromatic with goggle. The distance limit at which the color of test patches can be recognized became shorter for larger haze value. To derive a formula to get the distance limit as a function of haze value, we averaged six curves of purple, blue and deep green of KT and MI in Fig. 2. Those curves were complete up to 100 m. Figure 3 plots the averaged distance limit for haze value by circles. Except for G5 they approximately lie on a straight line and we can get a formula, $DL(m) = -1.83 \times HV(\%) + D0(m)$.

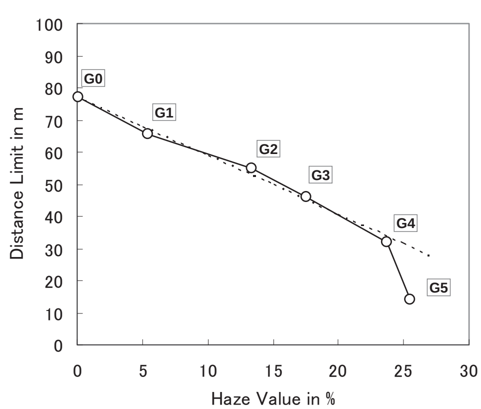

Fig. 3 Distance limit estimated from haze value.

HV represents haze value and D0 the distance limit without haze. It is shown by a straight dotted line. With the haze value 17.5% which is same as the cataract experiencing goggles, the DL becomes 45.1 m. D0 in the averaged curve is 77.1 m and the distance limit is shortened down to 58 %. It is firstly important to choose proper color that can be perceived at a far distance. , but we should not forget the distance limit for perceiving the color by elderlies becomes much shorter.

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Effect of Environment Light on Color Appearance with the Cataract Experiencing Goggles

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ABSTRACT

The effect of environment light on the color appearance with the cataract experiencing goggles was investigated. The experimental booth was composed of two rooms, the subject room and the test room separated by a wall with a window. The subjects observed a colored test patch placed in the test room through the window. In one case the effect of illuminance of the subject room was investigated by changing to 0, 30, 100, 200 and 300 lx. The chromaticness judged by the elementary color naming method decreased while the surrounding light increased. In another case the effect of the window size was investigated by changing to W1, W2, and W3. Even when the environment light from the subject room was zero, the desaturation took place when the window was enlarged to W3. This implies that the light in the test room started to work as the environment light with that window size.

Keywords: cataract, color perception, elder lies, desaturation

1 INTRODUCTION

Most of elderly people have problem of cataract which affect their visual ability. Obama et al. developed the cataract experiencing goggles to simulate the color perception of the senile cataract1). The goggles were composed of a haze filter and a colored filter, the former to represent the frosted crystalline lens and the latter the lowered light transmittance of the lens. The color perception with the goggles has been intensely investigated to understand the color perception of elderly people and one important result was obtained2-4). It is obviously supposed that the colored filter changes the color appearance of blue and green objects, but it was found unexpectedly that the haze filter also changed the color appearance of objects of any color in a way to desaturate it. The investigators concluded that the desaturation was caused by the environment light coming to the goggles from every direction. The light is scattered into the eyes to cover the retinal image of objects that the eyes are looking at. The environment light is normally white and the color of the objects is desaturated.

The objective of this study is to investigate the effect of environment light on the color appearance by changing the strength of the environment light. The same cataract experiencing goggles developed by Obama et al. were used.

2 APARATUS

The experimental booth was composed of two rooms, the subject room and the test room, separated by a wall with a window of variable sizes. Both rooms were furnished with the same achromatic wall paper of about N9.3 with some texture. The subject room had the size of 1.3 m long, 1 m wide and 2.4 m high and various objects were decorated on the shelf attached to the front wall such as a doll, real green leaves, and artificial flowers as seen at the bottom and at the top of Fig. 1. At the center in the figure there is a rectangular frame. This is the window through which a subject saw the test room. The window size was changed by replacing pieces of plywood on which apertures of 19 x 19, 60 x 60 and 270 mm x 320 mm were opened respectively. They were denoted as W1, W2, and W3, respectively.

Figure 1 Subject's view of the subject room and the test room.

The test room was also decorated by various objects such as a dog doll, real plant, towel, and others. The window in Fig. 1 is the case of W3, the largest window employed. Other window sizes W2 and W1 are indicated by squares with black lines. There is a placed test patch of the size 8 x 8 cm^2 locating at the center of the window seen by the subject. It was attached at the top of a supporting arm which was temporally fixed on a shelf. The arm was easily changed to another one when the test patch was to be changed. With the smallest window, W1 the test patch was larger than the window and the test patch filled the window completely. With W2 the window was slightly larger than the test patch. With W3 the subject could see wide range of the test room as seen in Fig. 1. Test patches were judged by one eye.

Both subject and test rooms were illuminated by fluorescent lamps of daylight type and their illuminance was controlled by light controllers, separately. The illuminance of the test room was kept constant at 200 lx measured vertically in front of the test patch. The illuminance of the subject room was adjusted to one of 5 levels; 0, 30, 100, 200 and 300 lx. It was measured by an illuminometer placed on the shelf.

Four different colors were employed for the test patch, 5R4/10, 5Y7/10, 5G5/10 and 5B4/9.

3 EXPERIMENTAL AIM

With the window W1 only the test patch is seen and no other area of the test room is seen by the subject. If the illuminance of the subject room is zero, no environment light comes in the subject eye and the desaturation of color of the test patch should not take place. The subject should see the original color of the test patch. If, however, the illuminance of the subject room is gradually increased, the environment light increases, and the color of the test patch should gradually appear desaturated. This is one point to investigate in the present experiment.

Next, the window becomes larger. Even when the subject room is dark and the environment light coming from the subject room is zero, if the window is made larger, the environment light may come to the eye from the test room. The desaturation of color of test patch may take place. The second point to investigate in the present experiment is to see whether the desaturation takes place for widening the window.

4 EXPERIMNET

The illuminance of the subject room was set at one of five levels, 0, 30, 100, 200 and 300 lx. The subject was asked to sit in the subject room and look around to adapt himself to the room illumination for few minutes. He was instructed to wear the cataract experiencing goggles, to look at the test patch, with one eye, through the window and to judge the color appearance of the color patch by the elementary color naming. Four test patches, R, G, Y, B, were randomly presented and three windows W1, W2, and W3 were also randomly employed. The experiment was repeated without goggles to complete one experimental session. Five such sessions were carried out for each illumination of the subject room.

Four subjects participated in the experiment, PH (Thai female, 26 years old, KT (Japanese female, 41, PP (Thai female, 55) and MI (Japanese male, 73). The subject MI had IOL in both eyes after cataract operation.

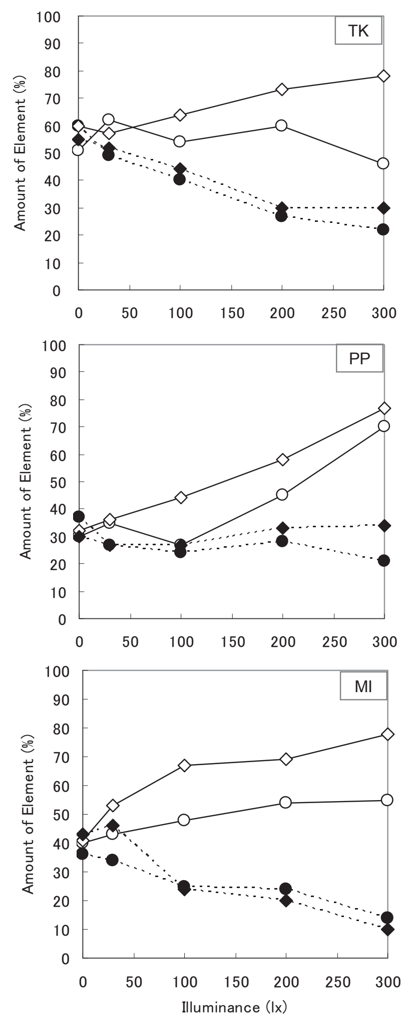

Figure 2 Effect of illuminance on chromaticness.

5 RESULTS

5.1 Effect of the illuminance

The results of the red and green test patches are shown in Fig. 2 for three subjects, KT, PP, and MI. The window size was the smallest one, W1. Those from PH are not shown here as her criterion for assessing the color appearance was different from these three subjects and gave quite different results. The abscissa gives the illuminance of the subject room and the ordinate the percentage of chromatic element. Circles are for the red test patch and diamonds for green. The open symbols show the results without the goggles and filled ones with goggles.

When the subject room was dark, without illumination, the amount of chromatic element was about the same with or without the goggles. Even with the cataract experiencing goggles the subjects could see the color of test patches clearly and equally as the case of no goggles. But when the room illuminance was increased the amounts of chromatic element went separatly. The difference between without-goggles condition and with-goggles condition became larger. The color appearance of the test patches relatively desaturated with the goggles compared to the without-goggles condition for higher illuminance. The change of absolute amount of element differed among subjects. In the case of KT the chromatic element stayed relatively constant for the increase of room illuminance without the goggles, but in the case of PP it increased rather rapidly. The subject MI showed the in-between result. But the relative decrease of the chromatic element with the goggles compared to without goggles was found for all the subjects. The goggles affected the color of test patches in the way to desaturate more with higher room illuminance. This is to confirm our first prediction given in experimental aim.

5.2 Effect of the window size

The effect of the window size on the color appearance is shown in Fig. 3. Here again, the results of only red and green test patches are given, circles for red and diamonds for green. The illuminance of the subject room is 0 lx. The abscissa represents the window size, 1, 2 and 3 corresponding to W1, W2, and W3. The ordinate gives the amount of chromaticness. Open symbols are from the result of with-goggles condition and filled symbols are from the result of without-goggles condition. We see that open symbols and filled symbols are about same in % at W1 and they slightly separate at W2, but not much. They greatly separate at W3 and filled symbols dropped down. There should be no effect of the environment light of the subject room and if there is any, it must be the effect from the test room. The environment light became effective when the window was enlarging to W3.

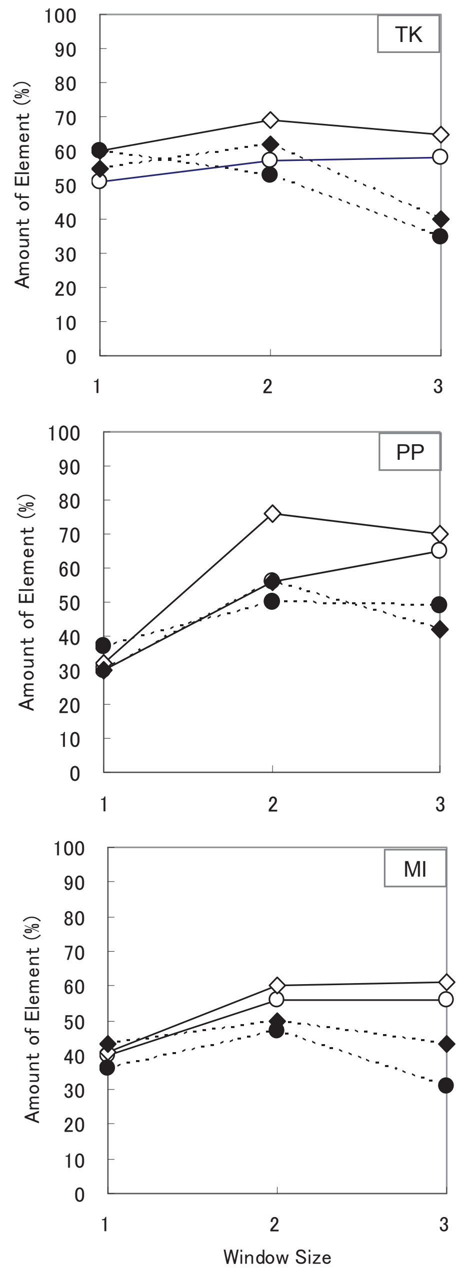

Figure 3 Effect of window size on chromaticness.

6 DISCUSSION

It was shown that the chromaticness deceased when the illuminance of the subject room was increased to imply the desaturation of color appearance. This phenomenon was clear with the window W1, when subjects could see only the test patch in the test room. According to the results, we suggest that if elderly people wish to see real color of objects the objects may be presented to them without the environment light. Such tool has been already developed by Shinoda et al.5) and the tool is placed in some department stores.

When the objects are only illuminated without the environment light as in the case of Shinoda et al.'s tool, it becomes a problem how widely the objects should be illuminated. Our second investigation where the window size was change, it was shown that up to W2 there was not much effect of the environment light. Through this window some objects of the test room were seen around the test patch. This indicates that the illumination area for the objects to be observed may be a little bit wider than the area of the object.

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Effects of natural and unnatural spatial structure on color constancy

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ABSTRACT

The recognition of spatial structure is important for color constancy because we cannot identify the color of an object under different illuminations without knowing which space it is in and how the space is illuminated. To show the importance of natural structure of environment to color constancy, it was investigated how color appearance was affected by an unnatural viewing condition where a spatial structure was distorted. Observers were judged color of a test patch placed in the center of a small room illuminated by white or reddish lights. In a natural viewing condition an observer saw the room(s) through a viewing window, whereas in an unnatural viewing condition the scene structure was jumbled by a kaleidoscope-type viewing box. Results showed that the degree of color constancy was decreased in the unnatural viewing condition, suggesting that naturalness and spatial factors play an important role in color constancy under a complex environment.

Keywords: Color appearance, Color constancy, illumination, Naturalness

1 INTRODUCTION

Color constancy has been studied by many researches in many years. It is often explained by mechanisms in lower levels of visual process such as an adaptation of photoreceptor on the retina and adaptation to the averaged color of a visual field. We, however, still do not have the consensus of the mechanisms. The degree of constancy differed depending on researches. This is most likely due to the difference of experimental environments. A study using nearly natural environment showed high degree[1] and that using a simple stimulus like Mondrian pattern on a monitor showed poor color constancy[2]. It also has found that the degree of color constancy decreased when a photograph was jumbled[3]. These results lead us an assumption that color constancy is not a low-level mechanism but much higher one and influenced by the naturalness of an environment. In other words, natural environment is necessary for color constancy.

The recognition of spatial structure is important for having a stable color appearance because we cannot identify the color of an object under different illuminations without knowing which space the object is placed and how the space is illuminated. In natural environments with three-dimensional structure, we have no difficulty on recognizing objects' color since we can recognize a space and illumination.

What happens if we are thrown into an unnatural environment? We might not be able to construct those recognitions correctly and fail to have good color constancy.

In this study we examine how color constancy is affected by an unnatural viewing condition where its spatial structure was distorted. It is predicted that the degree of color constancy decreased in the unnatural viewing condition due to the lack of naturalness.

2 EXPERIMENT

2.1 Apparatus

An experimental booth was built as shown in Figure 1. Size of the booth was 150 cm wide, 300 cm deep and 210 cm high. The booth consisted of two rooms arranged in depth and connected with a window; a back and a front room, and a dark space where an observer stayed and saw the rooms trough a viewing box installed on a wall facing the front room. Many objects with various colors were placed on both rooms to simulate a natural indoor environment. The back and front room were illuminated by fluorescent lamps with correlated color temperature of 5000 K (Toshiba FLR40S·N-SDL/M·A·NU, Ra 90) and 3000 K (FLR40S·L-EDL/M·A·NU, Ra 95), respectively. Illuminance was set at 500 lx on a desk at 70 cm high just below the test patches for color judgments (T_b, T_f) in both rooms.

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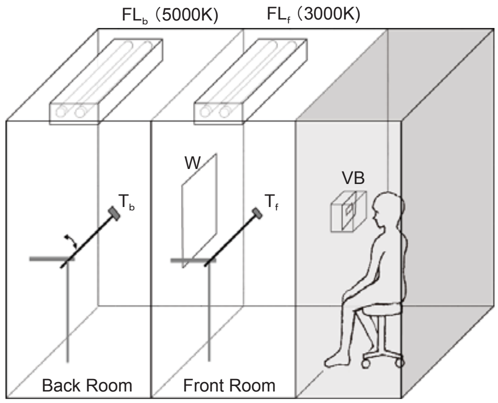

Figure 1 Scheme of an experimental booth. FLb, FLf, lamps at back and front room; Tb, Tf, test patches; VB, Viewing box; W, window between back and front room.

An observer saw the inside of the rooms through a viewing box and judged the color of a test patch which was supported by a black pole and placed in the center of either the back or the front room at the height of 115 cm. A viewing box with a rectangular aperture was used in the natural viewing condition. In the unnatural viewing condition it was replaced by a box with a kaleidoscope made of three rectangular mirrors of 25 x 60 mm that are the same size arranged in an e□uilateral triangle. The spatial structure of an observer's view was jumbled due to reflections from the mirrors. The test patch and its adjacent surround was the same as the natural viewing condition since the aperture of the kaleidoscope was aligned with the patch. The field of view and the averaged color of the visual field were roughly the same in both conditions. The observer viewed the rooms binocularly in the natural viewing condition and monocularly in the unnatural viewing condition.

Figure 2 shows the examples of a view from the observer. In 1-room condition (a), the window between the back and the front room (W in Fig. 1) was covered by a board with the same wall paper as that on the other walls so that the observer only saw the front room. In 2-rooms condition (b), the window was open and he/she saw both rooms at the same time. The natural and the unnatural viewing condition (c) were tested for both 1-room and 2-rooms conditions.

Test patches prepared for judgments covered a range of Munsell notation from 7.5YR5/3.0 to 5□□5/8 via N5 with 0.25 Chroma steps. Their chromaticity coordinates measured by spectroradiometer (Minolta CS-1000) from the position of an observer are shown in Figure 3. They vary approximately along the black body locus. Luminance of the test patches were approximately the same and about 60 cd/m^2. To make the visual angle of test patches 2 degree, 7 cm and 3 cm s□uare patches were used in the back and the front room, respectively.

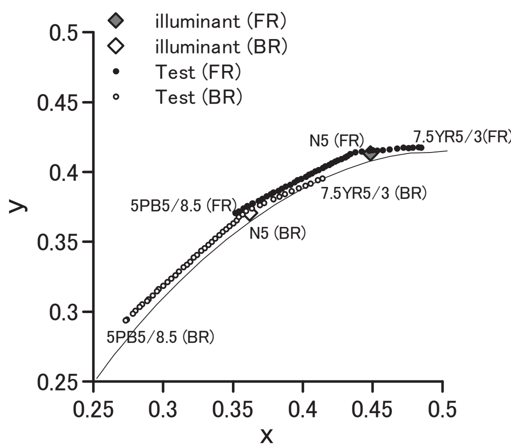

Figure 3 CIE1931 chromaticity coordinates of test patches with a range of 7.5YR5/0.25~3.0, N5, 5PB5/0.25~8 (circles) in front room (FR) and back room (BR). Diamond shows illuminant of each room. Thin curve indicates black body locus.

(a) (b) (c)

Figure 2 Examples of view from an observer. (a) 1-room condition (under natural viewing condition) (b) 2-rooms condition (under natural viewing condition) (c) Unnatural viewing condition at 2-rooms condition.

2.2 Procedure

An experimenter changed test patches one by one. The observer judged the color of each test patch by answering one or two hues out of Red, Green, Blue and Yellow. A series of test patches were tested and a color where the judgment changed from Y, R, or YR to B, G or BG was considered as a neutral perception point. This simplified color naming method was reasonable since the series of test patches changed along the black body locus shifting the color from YR to B.

One session consisted of judgments for test patches at the front room under 1-room condition, and at the back and the front room under 2-rooms condition. The natural and the unnatural viewing conditions were tested for the three room conditions, respectively. The order of conditions tested was randomized in each session and each observer. Experiments were conducted by a method of adjustment for 12 observers. An observer made a judgment just once for each condition. Detailed data was also obtained from two observers by a method of constant stimuli. In this case, five test patches were judged five times each in each condition during one session and five sessions were conducted for each observer.

3 RESULTS AND DISCUSSION

Figure 4 shows results from 12 observers on CIE xy diagram. In the results of 1-room condition (a) neutral points of the natural and the unnatural condition are overlapped each other. They are close to the illuminant color of the front room which means color constancy was high in both viewing conditions. This suggests that the color of illumination can be recognized even if the spatial structure is jumbled in the case of an environment with a single illumination.

The results of the front room at 2-rooms condition (b) differed in the viewing conditions. Mean neutral point of the unnatural viewing condition (open triangle) is further from the illuminant color of the front room than that of the natural viewing condition (filled triangle). This means that the degree of color constancy for the front room degreased in the unnatural viewing condition. However, those differences are smaller than expected, mainly because the neutral perception point at the front room is shifted even in the natural viewing condition. This issue will be discussed later.

In the case of the back room (c), mean neutral points of both viewing conditions are overlapped and stay close to the illuminant color of the back room which means the degree of color constancy is high in both viewing conditions.

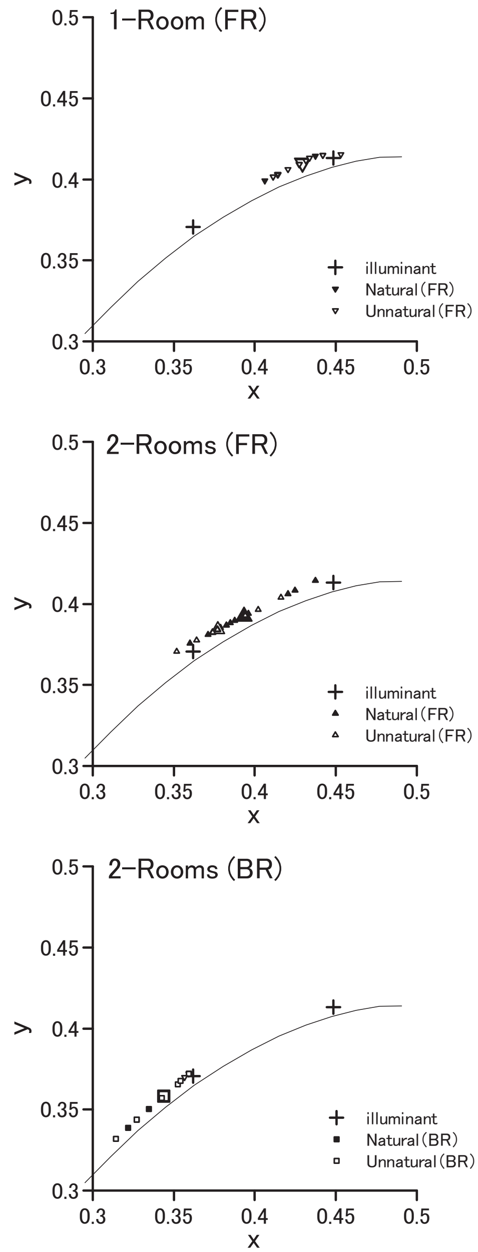

Figure 4 Results from 12 observers. (a) Front room in 1-room condition. (b) Front room in 2-room condition. (c) Back room in 2-rooms condition. Filled and open symbols indicate natural and unnatural viewing condition. Small symbols are individual neutral points and their means are shown by large symbols.

Although the individual difference of neutral points is large as shown by small symbols in each graph, the overall trend was the same in most observers. The variation was large in the front room at 2-rooms condition, suggesting the difficulty and unstableness of color judgments particularly in this condition.

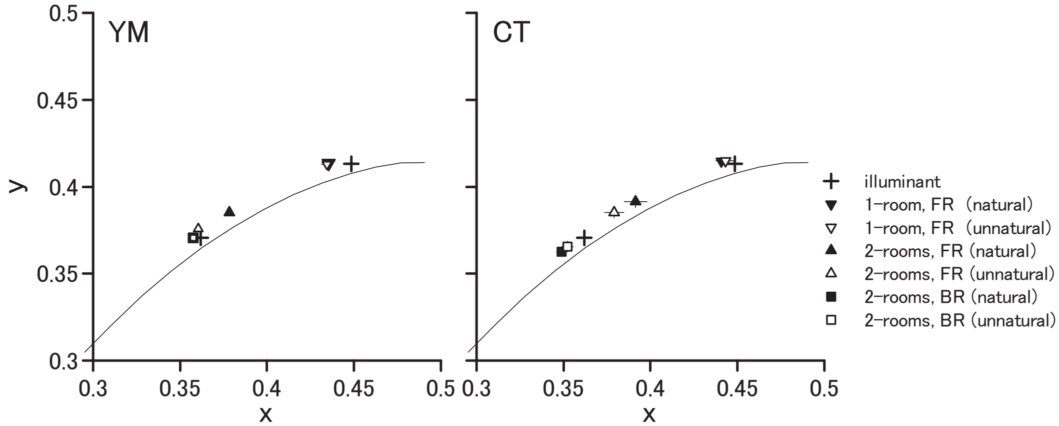

Figure 5 Results from observer YM and CT on xy chromaticity diagram. Filled and open symbols indicate natural and unnatural viewing condition, respectively. Standard deviations are shown by error bars. Inverted triangles, front room in 1-room condition; triangles, front room in 2-room condition; squares, back room in 2-rooms condition.

Figure □shows the results from two observers. The mean of five sessions is shown in each condition. Each symbol has error bars indicating standard deviation, but most of them are smaller than symbols, showing the reliability of judgments. Both observes showed similar trend to the results shown in Figure 4.

It is interesting that the difference between observers especially large in the neutral points of the front room at 2-room condition. The neutral point of YM under the unnatural condition is close to the illuminant color of the back room, or no color constancy and it also very close to the neutral point of the back room. This suggests that it was hard to locate the position of the test patches either in the back or in the front room and those colors were judged mainly based on the immediate background (i.e., the wall of the back room). In the case of CT, the neutral point of the front room is closer to that of the back room, but the shift is smaller than YM. The large individual difference in this particular condition implies that the color appearance under a complex environment tend to become unstable.

It should be mentioned that the neutral perception point at the front room is shifted even in the natural viewing condition. This shows that the back room largely influenced the neutral perception in the front room. Although the reason of the large influence is not clear at the present moment, there are some possibilities. One of them is the simultaneous color contrast effect. It has been reported that a local effect still existed even if a target and its surround was separated in depth[4]. However, there also have been shown that the color appearance was not determined only by local contrast[1]. In the present research the local contrast may have influenced to the color judgment. It may possible that the separation of two rooms was not enough because of the large window and bright background, or the white illumination gave a strong cue.

We did not find the difference between the natural and the unnatural viewing condition under 1-room condition in the present study. This suggests that there were rich cues of illumination color available even if the spatial structure is distorted. However, there is a possibility that the distortion by the kaleidoscope was not enough since it was able to recognize objects in each particle on the kaleidoscope image.

Although there are a number of factors should be examined further, the difference between the natural and the unnatural viewing condition in 2-rooms condition show that color appearance is influenced by an unnatural spatial structure.

To conclude, our results suggest that naturalness and spatial factors play important roles on color constancy in at least a complex environment, and should be considered when the color appearance of an object is predicted.

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ABSTRACT

Psychophysical experiments of color discrimination give us important data for evaluating color difference formula as well as investigating the mechanism of human color vision. It is known that the post-receptoral channels, the luminance channel and two opponent-color channels contribute to the color discrimination threshold. In the present study, we measured color discrimination threshold using test stimuli of various temporal frequency profiles. Contrast thresholds were measured on the (L+M, S) plane, the (L, M) plane and on the (L-M, S) plane in the cone excitation space. Experimental results show that the threshold elevation due to the temporal frequency changes independently to the direction of L+M, L-M, and S. We apply the probability summation model to explain the effect of temporal frequency on the color discrimination threshold.

Keywords: Color discrimination, Contrast threshold, Probability summation model, Color vision, Contrast sensitivity function

1 INTRODUCTION

Color discrimination is one of the most important factors in human color vision. Color discrimination thresholds provide information of response properties of cones and post-receptoral channels, the luminance and the two opponent-color channels. Color discrimination depends on the experimental conditions such as spatiotemporal characteristics, background colors for adaptation as well as the stimulus color itself[1)-7)]. It is necessary to take into account these factors to evaluate color differences for general purposes. The analysis of quantitative influence of these factors to the color discrimination is also important to investigate the mechanisms of color vision.

In the present study, we focus on temporal characteristics of color discrimination. Temporal contrast sensitivity functions were studied by many researchers[8)-12)]. It is well known that the luminance temporal CSFs show band-path characteristics and the isoluminance chromatic temporal CSFs reveal low-path characteristics. We measure the discrimination on the (L+M, S) plane, the (L, M) plane and on the (L-M, S) plane in the cone excitation space and examine the temporal characteristics of the luminance (L+M) channel, red-green opponent color channel (L-M), and the channel deviated by the S-cone. We apply the probability summation model[13)] to explain the independency of these three channels and the effect of temporal frequency on the color discrimination threshold.

2 EXPERIMENT

We measured color discrimination thresholds using several temporal profiles of test the stimulus presentation.

2.1 Apparatus

The stimuli were generated on a color monitor (EIZO FlexScan T566) controlled by a Cambridge Research Systems VSG 2/4 graphics board, with 15-bit luminance-calibrated lookup tables. Each phosphor output was calibrated with a spectroradiometer (Minolta CS-100) and photometer (Cambridge Research System OptiCAL).

2.2 Stimuli

The spatial arrangement of the stimulus was shown in Figure 1. The observer saw a temporally modulated test stimulus with a color slightly different from a background color for adaptation. The test field was at the center of a 6º square background and consisted of a two by two array of four 1º squares with a 0.1º black separation. We employed the equal energy white in luminance of 34.5 cd/m^2 as a background stimulus. The test stimulus was modulated with sine Gabor profile with each temporal frequency of 1, 4, 8, and 16 Hz.

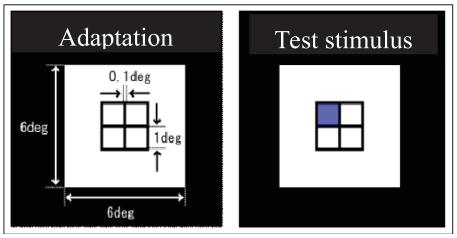


Figure 1. Schematic view of the test stimulus.

Increment or decrement stimuli were presented on three planes□the (L+M, S) plane, the (L, M) plane and the (L-M, S) plane, in the cone excitation space. The excitations of L-, M- S-cones are calculated with the cone spectral sensitivity functions derived by Smith and Pokorny[14)]. We defined the cone excitation values, L, M, S so that L+M is equal to the luminance and L□M□S □2□1□3 for the equal energy white. Consequently, the amount of L-2M is assumed to correspond to the red/green color opponent component. Contrast of the test stimulus was defined by the following equation,

$$C = \left[\left(\frac{\Delta L}{L}\right)^2 + \left(\frac{\Delta M}{M}\right)^2 + \left(\frac{\Delta S}{S}\right)^2\right]^{1/2} \qquad (1)$$

where L, M, and S is cone excitation value of the L-, M-, and S-cone of the background color, respectively, and ΔL, ΔM, and ΔS is the increment or decrement cone excitation value of each cone.

2.□ Procedure

Before the trial start, observer adapted to the background field for one minute. Test was presented at one of four panes with the other three unchanged. The observer□s task was to report which of the four panes contained the test stimulus. The test stimulus contrast changed following the observer□s response by a typical, one-up-one-down staircase procedure.

2.□ Observers and Viewing Condition

The experiment was done in a dark room and the monitor screen was viewed binocularly at 50 cm distance with natural pupils. Four observers participated to the experiment. All observers had normal trichromats checked with the Ishihara pseudochromatic plates and Farnworth-Munsell 100-Hue test.

□ RESULTS

Thresholds obtained by the experiment were plotted on three planes□the luminance vs. S-cone excitation, the red/green vs. S-cone excitation, and the luminance vs. red/green plane in the cone contrast space.

□.1 The (S, L+M) plane

Figure 2 shows the thresholds for 1, 4, 8 and 16 Hz plotted on the (S, L+M) plane obtained from the observer T□. The threshold elevation due to the change of temporal frequency seems to be independent to the direction of change of the luminance and that of the S cone excitation except for 1 Hz. As expected by the temporal characteristics of the contrast sensitivity function of the luminance channel and the yellow-blue opponent color channel, the threshold in the direction of luminance is smaller than those of the direction of the S cone excitation at the high temporal frequency. On the other hand, at the low temporal frequency, the threshold of the S-cone direction is getting small rather than the luminance channel.

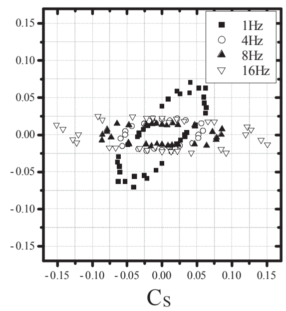


Figure 2. Contrast thresholds on the S-cone vs. luminance plane for the observer T□.

□.2 The (L-M, S) plane

Figure 3 shows the thresholds for 1, 4, 8 and 16 Hz plotted on the (L-M, S) plane obtained from the observer HU. Here again, the threshold elevation due to the change of temporal frequency seems to be independent to the direction of the red/green opponent color channel and that of the S-cone excitation. Thresholds elevate with increasing temporal frequency in both S-cone and red/green direction.

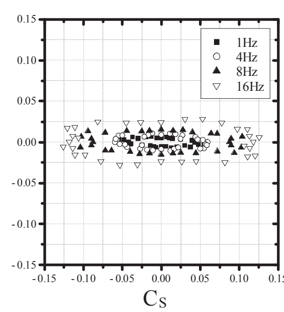
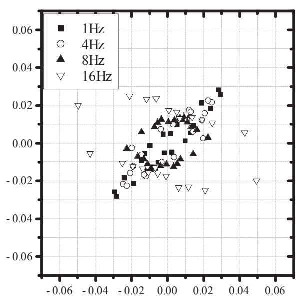


Figure □. Contrast thresholds on the (S, L-2M) plane for the observer HU.

□.□T□e □□□M□pla□e

Figure 4 shows the thresholds for 1, 4, 8 and 16 Hz plotted on the (L, M) plane obtained from the observer MO. In this plane, the direction of 45º roughly corresponds to the luminance change, and □45º to the change of red/green opponent color direction. The independency between the luminance channel and thee red/green channel is observed in Figure 4. At a low temporal frequency, 1 Hz, threshold contour elongated to the direction of luminance channel. In contrast, at a high temporal frequency, 16 Hz, threshold elevated to the direction of red/green opponent channel.



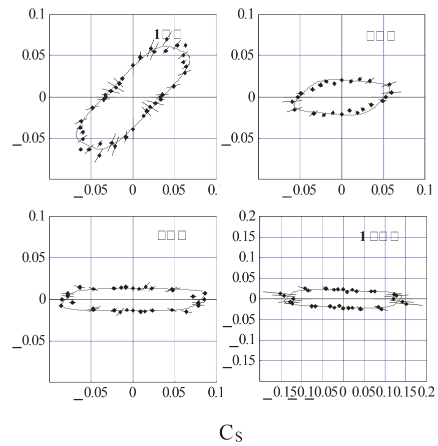
□i□ure □ Contrast thresholds on the (L, M) plane for the observer MO.

□ DISCUSSION

We apply the probability summation model expressed in the following equation to explain the effect of temporal frequency on the color discrimination threshold.

$$\left[\frac{1}{\square_{LUM}}\left(\square_{LUM,S}C_S+\square_{LUM,LUM}C_{LUM}\right)\right]^{\beta}+\left[\frac{1}{\square_{Y\square}}\left(\square_{Y\square,S}C_S+\square_{Y\square,LUM}C_{LUM}\right)\right]^{\beta}=1 \quad (2)$$

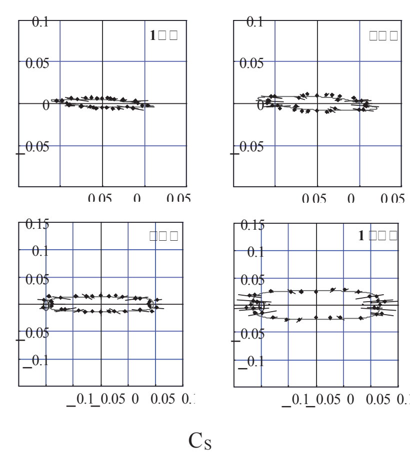
In this equation, $\square_{LUM}$ and $\square_{Y\square}$ is the threshold coefficient for the luminance channel and the yellow-blue opponent color channels, respectively. $\square_{\square,Y}$s are weighting coefficients of Y axis in the graph to determine the direction of □ channel. β is the degree of the probability summation. Weighting coefficient of the luminance channel $\square_{LUM}$ depended on the temporal frequency of test stimulus presentation. Weighting coefficient of the yellow/blue opponent color channel was determined from the experimental data for the lowest temporal frequency, 1 Hz. The curves shown in Figure 5 are predicted by the probability summation model, where β□4 is adopted. The prediction seems to be quite well.



□i□ure □ Contrast threshold curves on the (L+M, S) plane predicted by the probability summation model.

The equations of probability summation among the red/green opponent channel and the yellow/blue channel is described as the equations (3). In this equation, we assume that no contribution of S-cone to the red/green opponent color channel. Weighting coefficient of the yellow/blue opponent color channel, $\square_{Y\square}$ was determined from the experimental threshold contour for each temporal frequency. Predicted contrast threshold curves are shown in Figure 6.

$$\left[\frac{C_{L\text{-}2M}}{\square_{RG}}\right]^{\beta}+\left[\frac{1}{\square_{Y\square}}\left(\square_{Y\square,S}C_S+\square_{Y\square,L\text{-}2M}C_{L\text{-}2M}\right)\right]^{\beta}=1 \quad (3)$$



□i□ure □ Contrast threshold curves on the (S, L-2M) plane predicted by the probability summation model.

The probability summation among the luminance channel and the red/green opponent color channel is described in the equation (4).

$\square_{LUM}$ and $\square_{RG}$ are determined from the experimental data of 16 Hz and 1 Hz, respectively. Predicted contrast threshold curves are shown in Figure 7.

$$\left[\frac{1}{\square_{LUM}}\left(\square_{LUM,L}\frac{\Lambda L}{L}+\square_{LUM,M}\frac{\Lambda M}{M}\right)\right]^{\beta} + \left[\frac{1}{\square_{RG}}\left(\square_{RG,L}\frac{\Lambda L}{L}+\square_{RG,M}\frac{\Lambda M}{M}\right)\right]^{\beta}=1 \qquad (4)$$

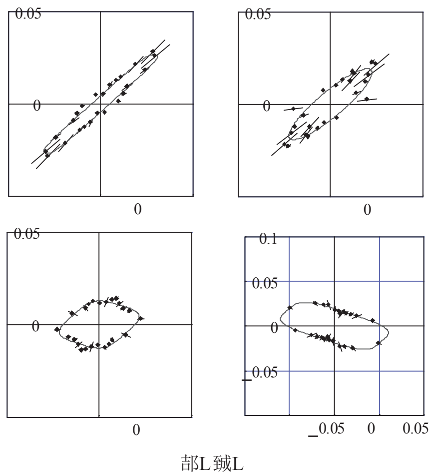


Figure 7. Contrast threshold curves on the (L, M) plane predicted by the probability summation model.

5 CONCLUSION

Contrast thresholds of test stimulus presentation for various temporal frequencies were measured on the (L+M, S) plane, the (L, M) plane and on the (L-M, S) plane in the cone excitation space. The threshold change due to the temporal frequency was obtained independently to the direction of luminance, red/green opponent color channel, and S-cone excitation. The temporal characteristics of the color discrimination was well predicted by a model assuming probability summation among independent channels in the post-receptoral stage.

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Illumination Estimation via Non-Negative Matrix Factorization

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ABSTRACT

The problem of illumination estimation for colour constancy and automatic white balancing of digital color imagery can be viewed as the separation of the image into illumination and reflectance components. We propose using nonnegative matrix factorization with sparseness constraints (NMFsc) to separate the components. Since illumination and reflectance are combined multiplicatively, the first step is to move to the logarithm domain so that the components are additive. The image data is then organized as a matrix to be factored into nonnegative components. Sparseness constraints imposed on the resulting factors help distinguish illumination from reflectance. Experiments on a large set of real images demonstrate accuracy that is competitive with other illumination-estimation algorithms. One advantage of the NMFsc approach is that, unlike statistics- or learning-based approaches, it requires no calibration or training.

Keywords: Color Constancy, Non-Negative Matrix Factorization, Automatic White Balancing

1. INTRODUCTION

A new approach to illumination estimation for color constancy and automatic white balancing is presented based on the technique of nonnegative matrix factorization with sparseness constraints (NMFsc). In essence, the logarithm of the input color image is viewed as a matrix to be factored into independent components. The resulting components represent the scene's illumination and the reflectance. The nonnegative constraint on the factorization is important because illumination and reflectance are both nonnegative physical quantities. The sparseness constraints---illumination is non-sparse, reflectance is sparse---guide the factorization to obtain an illumination component that is relatively constant across the scene, while allowing the reflectance component to vary. Experiments on a large data set of real images show that both methods are competitive with existing illumination estimation methods.

One advantage of the NMFsc illumination method is that like a few other methods[1-4], it avoids the training step required by the many methods that rely on image statistics[5-9] or finite-dimensional models of spectra[10].

For a particular pixel in a color image, the RGB sensor response is defined by the model in Equation (1). Let $E(\lambda)$ and $S(\lambda)$ be the illumination spectral power distribution and matte surface reflectance function respectively, let $R_k(\lambda)$ be the sensor sensitivity function for a colour channel k, then the model can be defined as

$$p_k = \int E(\lambda) S(\lambda) R_k(\lambda) \qquad k = R, G, B. \tag{1}$$

Assuming the camera has narrowband spectral sensitivity functions that can be modelled by a Dirac delta function, Equation (1) simplifies to:

$$p_k = E(\lambda_k) S(\lambda_k) \qquad k = R, G, B. \tag{2}$$

By taking logarithm on both sides of the Equation (2), we have

$$\log(p_k) = \log[E(\lambda_k)] + \log[S(\lambda_k)],\ k = R, G, B. \tag{3}$$

This has the advantage that the non-linear multiplicative combination of the illumination and reflectance becomes linear.

For an image or image subwindow arranged as a vector, Equation (2) yields

$$\mathbf{I} = \mathbf{E} \circ \mathbf{S}, \tag{4}$$

where $\mathbf{I}$ is a 2D image, and $\mathbf{E}$ and $\mathbf{S}$ are the illumination and surface reflectance images, respectively. The operator $\circ$ denotes element-wise multiplication. Applying logarithms again, we have

$$\log \mathbf{I} = \log \mathbf{E} + \log \mathbf{S}. \tag{5}$$

Here, log $\mathbf{E}$ is the illumination term, and log $\mathbf{S}$ is the reflectance term. They correspond to the

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"illumination image" and "reflectance image" in log space.

Generally, illumination is relatively constant across an image, while the reflectance varies. The reflectance image in log space can be further decomposed and represented as a weighted linear combination of "feature" reflectances.

$$\log \mathbf{S} = \sum_{i=1}^{M} \mathbf{F}_i h_i, \tag{6}$$

where $\mathbf{F}_i$ are independent reflectance features and h_i are the weighting coefficients. In order to be independent, these features need to be "non-overlapping," which means that most entries of the vectors are zeros, and the non-zero entries appear at distinct locations. These non-overlapping, sparse features can be thought of as building blocks from which the image is constructed. Therefore, in log space, by Equation (5) and (6), the image can be represented in terms of the illumination and M surface features as

$$\log \mathbf{I} = \log \mathbf{E} + \sum_{i=1}^{M} \mathbf{F}_i h_i \tag{7}$$

Since we expect the illumination to vary slowly across an image, log $\mathbf{E}$ should be a non-sparse vector. On the other hand, the reflectance term log $\mathbf{S}$ should be a sparse vector. Ideally, the feature vectors $\mathbf{F}_i$ should be sparse enough that there is no overlap between them so that they are completely independent features.

ESTIMATING ILLUMINATION USING NMFSC

Non-negative matrix factorization creates a non-negative approximation for a given set of input data that represents the data in terms of a linear combination of non-negative basis features[11]. In the context of color imagery, we will use it to represent the log image data in terms of a linear combination of log illumination and log reflectance.

Let us assume that the data consists of T measurements of N non-negative scalar variables. Denoting the (N-dimensional) measurement vectors by $\mathbf{v}^t$ ($t = 1, \ldots, T$), a linear approximation of each data vector is given by

$$\mathbf{v}^t \approx \sum_{i=1}^{M} \mathbf{w}_i h_i^t = \mathbf{W}\mathbf{h}^t, \tag{8}$$

where $\mathbf{W}$ is an $N \times M$ matrix containing the basis vectors $\mathbf{w}_i$ as its columns, and $\mathbf{h}^t$ is the vector of coefficients h_i^t. Arranging vectors $\mathbf{v}^t$ as columns of an $N \times T$ matrix $\mathbf{V}$, we have

$$\mathbf{V} \approx \mathbf{W}\mathbf{H}, \tag{9}$$

where each column of $\mathbf{H}$ contains the coefficient vector $\mathbf{h}^t$ corresponding to the measurement vector $\mathbf{v}^t$. Written in this form, it becomes apparent that this linear data representation is simply a factorization of the data matrix. Principal component analysis, independent component analysis, vector quantization, and non-negative matrix factorization can all be viewed as matrix factorization methods, with different choices of objective functions or constraints. Whereas PCA and ICA do not restrict the signs of the entries of $\mathbf{W}$ and $\mathbf{H}$, NMF requires all entries of both matrices to be non-negative, which means that the data is described in terms of additive components only.

The concept of 'sparse coding' refers to a representational scheme where only a few units are used to represent typical data vectors[12]. In effect, this implies that the majority of units take values close to zero, with only a few having significantly non-zero values.

Hoyer[12] adopts a sparseness measure based on the relationship between the L_1 norm and the L_2 norm defined as

$$s(\mathbf{x}) = \frac{\sqrt{n} - \frac{\sum |x_i|}{\sqrt{\sum x_i^2}}}{\sqrt{n} - 1}, \tag{10}$$

where n is the dimensionality of x. $\sum |x_i|$ is the L_1 norm, and $\sqrt{\sum x_i^2}$ is the L_2 norm. This function evaluates to unity if and only if $\mathbf{x}$ contains a single non-zero component, and takes a value of zero if and only if all components are equal. It also interpolates smoothly between the two extremes.

Generally, an image will contain multiple surface reflectance features, so when subwindow sample blocks are drawn from the image, each block should contain some subset of those features. NMFsc provides a way to identify a set of basis vectors to represent these surface reflectance features plus a single illumination feature. Since each subwindow is described by using strictly additive positive components, it is a linear combination of those feature vectors.

The imaging model in Equation (7) and NMFsc in Equation (8) have parallel structure, so that the imaging model can be reformatted in terms of an NMF approximation:

$$\begin{aligned} \mathbf{v}^t \approx \sum_{i=0}^{M} \mathbf{w}_i h_i^t &= \mathbf{w}_0 h_0^t + \sum_{i=1}^{M} \mathbf{w}_i h_i^t \\ &= \log \mathbf{E} + \sum_{i=1}^{M} \mathbf{F}_i h_i \end{aligned} \tag{11}$$

In this case, $\mathbf{v}^t$ corresponds to $\log \mathbf{I}$ in Equation (7) and represents the data from one of the image blocks. Since $\mathbf{w}_0$ □$_0$ takes the role of $\log \mathbf{E}$, the basis vector $\mathbf{w}_0$ is the □illumination□ basis with weighting factor □$_0$. □ represents the number of features present in the data. Since $\sum_{□=1}^{□} \mathbf{w}_{□}$□ takes the role of $\sum_{□=1}^{□} \mathbf{F}_{□}$□, the basis vectors $\mathbf{w}_i$ are the feature reflectance basis vectors with weighting factors □. The weighting factors determine how strongly the corresponding feature reflectances should appear in this image block. For instance, if □ equals to zero, it means the feature is absent from this block; if □ is large, it means the feature is strongly visible in this sample block.

By taking □ sample sub-windows from the image and constructing the data matrix □, where the log RGB channels of each block are appended and stored as a column, we can then use NMFsc to solve for the basis matrix, □ □and thereby obtain the illumination basis vector and the feature reflectance basis vectors. In other words, NMFsc decomposes □ into the illumination and reflectance components that are the key to color constancy and automatic white balancing.

Equation (□) is a purely additive model, which means NMF is an appropriate approach to solving for the basis. All basis vectors, including the feature reflectance images (the □building blocks□), along with the illumination image, are required to be non-negative. This requires the input data matrix □ to be non-negative too. The model is applied to the logarithm of the original image data, so there is the possibility of both positive and negative values. Simply scaling the original image data to (0,1] ensures that all pixel values in log space will be negative or zero. Since the coefficient matrix □ is always non-negative, we negate both □ and □ to make everything completely non-negative.

NMFsc allows the sparseness for each basis vector to be controlled individually. In our model, the illumination basis vector is supposed to be non-sparse, making its components relatively similar, while the reflectance basis vectors are supposed to be sparse. In addition, with NMFsc the sparseness of each portion of a single basis vector can be controlled separately. This feature is important because in the formulation the RGB components needed to be packed into one vector. If a small sparseness value is set for the vector as a whole then the illumination basis will be similar across all the RGB channels, collectively leading to grey as the illumination estimate. To avoid this problem, the sparseness of the illumination basis vector needs to be controlled individually for the R, G, and B segments of the vector. In other words, the illumination vector must be divided into three segments and the same sparseness applied to each. For the reflectance basis vectors, a very sparse vector means that most of the entries are zeros. This property of high sparseness allows the reflectance basis vectors to be orthogonal and independent.

Hence, NMFsc is an approach for solving the illumination-reflectance model globally, in that the factorization aims to minimize the ob□ective functions based on the data matrix that includes all three channels. This is an advantage over those methods that estimate the illumination and reflectance for each colour component independently.

The proposed algorithm based on Equation (9) using the NMFsc approach is:

1. Scale the input image values to (0,1]
2. Take N sample blocks from the image
3. Take the logarithm of the RGB values in these blocks.
4. For the data from each block, concatenate the color channels into a vector.
5. Suppose there are M different surfaces appearing in N blocks (M□N)
   - 5.1. Apply NMFsc to find M□1 basis vectors
   - 5.2. Set the sparseness constraint of the 1st basis close to 0 since it represents the illumination
   - 5.3. Set sparseness constraints of the 2nd to (M□1)th bases close to 1 since they represent the surface features
6. Antilog the illumination basis
□. The average R, G, B from the channels of the antilog of the illumination basis yields the RGB color of the scene illumination.

The parameter □ represents the number of feature reflectances assumed to be present in the input image; however, the correct value of □ is unknown and could differ from image to image. Experimentally, we found that fixing □ at 5 for all images worked well.

In the above development, an image was assume to contain multiple reflectance features. An image contains □ feature reflectances with at least one feature appearing in each image subwindow. Data was collected from multiple subwindows to form the data matrix for NMFsc. However, instead of □ reflectance features, suppose that we describe the scene as a single more complex reflectance feature under a single illumination and apply NMFsc. In this case, there is only one subwindow□ the entire image□ and there will be only a single reflectance basis vector.

Equation (9) with □ □ □ combined with Equation (6) becomes

$$\mathbf{v}^{□} \approx \sum_{□=0}^{1} \mathbf{w}_{□} □_{□} = \mathbf{w}_0 □_0 + \mathbf{w}_1 □_1$$
$$= \log \mathbf{E} + \log \mathbf{S} \qquad (12)$$

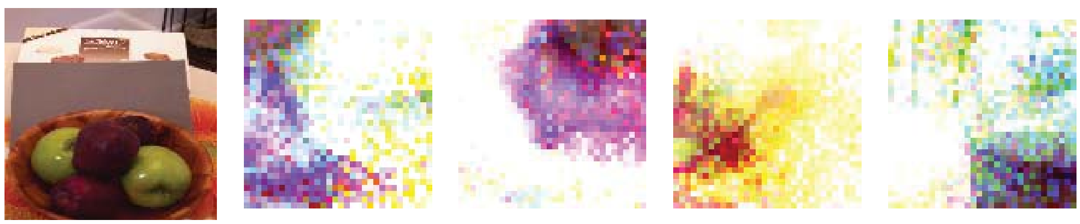
Here again, $\mathbf{w}_0 □_0 = \log \mathbf{E}$ so the basis vector $\mathbf{w}_0$ is the □illumination□ basis with weighting factor $□_0$. Similarly, $\mathbf{w}_1 □_1 = \log \mathbf{S}$ so the basis vector $\mathbf{w}_1$ is the feature reflectance basis vector with weighting factor $□_1$. The goal in Equation (12) is to split the input color image into an illumination component and reflectance component in log space. How NMFsc does the split depends on the choice of sparseness constraints for the two components.

Since NMFsc should return two basis vectors $\mathbf{w}_□$ and $\mathbf{w}_□$, it requires an input data matrix of at least two columns. Rather than taking two distinct sample subwindows as the input data, we construct the data matrix □ with two identical columns. Each column is a vectorized version of the full input image. It is no longer necessary to estimate the parameter □ because in this case it always equals 1. Note also, that whereas the location of each pixel matters in the multiple-reflectance model, location has no effect in the single-reflectance model.

□. E□□ERIMENTS

The NMFsc illumination estimation method is evaluated on a number of different image databases. Both the multiple-reflectance-feature reflectance and single-reflectance-feature approaches are tested.

The first set of tests is with multiple features. Figure 1 gives an example.



(a) (b) (c) (d) (e)

Figure 1. The reflectance basis vectors (contrast enhanced for visualization) based on the multiple-feature reflectance model: (a) 12□x12□input image ; (b)-(e) are the reflectances basis vectors F_i using 32x32 subwindows.

Ta□le 1. Comparison of NMFsc to SoG, Max RGB, Grayworld performance. The results involve testing on the large natural image dataset, with no real-data training required. Errors are reported in terms of both the RMS angular chromaticity and distance error measures.

Method	Angular Degrees			Distance□× □□□□		
	Mean	RMS	Max	Mean	RMS	Max
GW	□69	9.3□	42.2□	5.9□	□4□	3□33
SoG	□50	□93	34.52	5.50	6.5□	2□6□
MAX RGB	9.99	11.□6	2□42	□24	□60	21.□2
NMFsc (M □5)	□66	□96	34.□9	5.59	6.5□	26.99
NMFsc (M □1)	6.□2	□15	3□2□	5.11	6.1□	32.□4

NMFsc is applied with □ □ □, sparseness of the illumination basis is set to 0.005 for the R, G, and B channels separately, and the sparseness of the feature reflectance basis is set to be 0.45. Figure 1 (b)-(e) shows the feature reflectance basis vectors (i.e., the antilog of the $\boldsymbol{w}_i$'s in Equation (11) with $1 \le □ \le □$).

The second test provides statistical results about the accuracy of NMFsc-based illumination estimation. The test set is extracted from the large dataset of natural images representing a variety of indoor and outdoor scenes under different light conditions that Ciurea et. al.[13] measured with a grayball attached to a digital video camera. The original image database includes 11,346 images. However, many of these images have very good color balance (i.e., RGB of the gray ball is gray) which could bias the testing of the illumination-estimation methods. Therefore, we eliminated from the data set the ma□ority of the correctly balanced images so that the overall distribution of the illumination color is more uniform. The resulting data set contains □661 images. The grayball appears in the lower right-hand quadrant of every original image, so for testing that quadrant is cropped from every image.

The □,661 images are tested based on the SoG, Max RGB, and Grayworld methods, as well as both our multiple-reflectance and single-reflectance methods. The accuracy of various illumination estimation methods (Shades of Gray, Max RGB, Grayworld, single-reflectance NMFsc, and multiple-reflectance NMFsc) applied to the [illegible],661 images is listed in Table 1. In the case of the multiple-reflectance based estimation, each image is resized to 64x64 pixels, and divided into sixteen 16x16 subwindows. The number of reflectance features [illegible] is set to be 5; the sparseness of the illumination and the reflectance bases are 0.001 and 0.45, respectively. The average computation time for processing one image is 0.[illegible]3 seconds. In the case of the single-reflectance based estimation, each image is also resized to 64x64. The sparseness of the illumination and the reflectance bases are 0.001 and 0.45, respectively. With [illegible], the average computational time for processing one 64x64 image is 2.43 seconds.

[illegible]. CONCLUSION

The experiments show that nonnegative matrix factorization with sparseness constraints provides a method of separating a color image into its illumination and reflectance components. The accuracy of the NMFsc method is competitive with other illumination-estimation algorithms. One possible disadvantage of the approach is that existing factorization algorithms are iterative, and in comparison to some of the other illumination-estimation algorithms, somewhat costly in terms of computation. A particularly good feature of the NMFsc approach is that it requires no training.

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