AIC2013

Bringing Colour to Life

AIC Colour 2013

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8-12 July, 2013
Newcastle upon Tyne, UK

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Volume 4

Editors:
Lindsay MacDonald,
Stephen Westland,
Sophie Wuerger

The Colour Group (Great Britain)

AIC

International Colour Association
Internationale Vereinigung für die Farbe
Association Internationale de la Couleur

programme overview

	Sunday 7th July	Monday 8th July	Tuesday 9th July	Wednesday 10th July	Thursday 11th July	Friday 12th July
07:00		Registration and Exhibition Open Registration and Exhibition Open	Registration and Exhibition Open Registration and Exhibition Open	Registration and Exhibition Open Registration and Exhibition Open	Registration and Exhibition Open Registration and Exhibition Open	Registration and Exhibition Open Registration and Exhibition Open
07:30						
08:00		**Hall One** Opening Ceremony				
08:30			**Hall One** Keynote - Fiona Jenvey	**Hall One** JUDD Award	**Hall One** Keynote - Hilary Dalke	**Hall One** Keynote - Stephen Palmer
09:00		**Hall One** Keynote - Andrew Parker				
09:30			COFFEE	COFFEE	COFFEE	COFFEE
10:00	**Lit & Phil** AIC Executive Committee Meeting	COFFEE	**Hall One** Special Symposium: Fashion		**Hall One** Special Symposium: Aesthetics	
10:30		**Hall One** Special Symposium: LED Lighting **Hall Two** Colour and Food **Northern Rock Room** Colour in Art	**Hall Two** Architectural Colour **Northern Rock Room** Colour Technology	**Hall One** Special Symposium: MCS2013 **Hall Two** Fashion **Northern Rock Room** The Colour of Culture	**Hall Two** Colorimetry **Northern Rock Room** Interdisciplinary Colour	**Hall One** Special Symposium: Human Colour Vision: From the Retina to the Cortex **Hall Two** Colour Education **Northern Rock Room** Interior Design and Lighting
11:00						
11:30				**Hall Two** Product Design and Branding	**Hall Two** Colour Difference	
12:00		**Hall Two** Colour and Wellbeing				
12:30						**Foyer** LUNCH, Posters and Exhibition
13:00		LUNCH	LUNCH*		LUNCH	
13:30				**Hall One** AIC General Assembly		
14:00		**Foyer** Posters and Exhibition	**Foyer** Posters and Exhibition		**Foyer** Posters and Exhibition	**Hall One** Special Symposium: Colour Harmony **Hall Two** Colour and Music **Hall Two** Colour Naming
14:30				Coaches depart for city excursion		
15:00	**BALTIC Terrace** Welcome Drinks + Registration Open			**Durham City** City Excursion		
15:30		**Hall One** Special Symposium: Museum Lighting **Hall Two** Colour Ergonomics **Northern Rock Room** Colour Aesthetics	**Barbour Room** Special Symposium: Sustainable Coloration **AIC Study Groups** **Northern Rock Room** Colour Imaging		**Hall One** Special Symposium: Environmental Colour **Hall Two** Colour Printing **Northern Rock Room** Colour Vision	
16:00						**Hall One:** Capstone Presentation
16:30						**Hall One** Closing Ceremony
17:00						
17:30						
18:00					Coaches depart for Alnwick	
18:30			**The Sage Gateshead** Concert			
19:00		**The Hatton Gallery** Official Congress Opening			**The Alnwick Gardens** Official Congress Banquet	
19:30						
20:00						
20:30						
21:00						
21:30						
22:00						
22:30						

* 13:00-14:15 - SDC Networking Lunch (invitees only)

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Contents

poster session 2

LED Matrix Design for Multispectral Imaging

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ABSTRACT

We propose a new method of LED matrix/panel design for use as active illumination in a multispectral acquisition system. The number and types of LEDs are first determined. The desired probability of appearance of different LEDs are then determined based on their luminous intensity profiles. The spectral sensitivity of the camera has also been accounted for. The method determines the number of different types of LEDs to form a smallest block (usually a square) in the LED matrix, and distributes them so that the LED matrix fulfills the two important design requirements: spatial uniformity and consistency of LED distribution, and that it leads to the generation of an optimal or suboptimal arrangement of the LEDs. A LED panel of any size can then be constructed by repeating the block. We confirm the effectiveness of our proposal by simulation, and also validate with real LEDs.

1. INTRODUCTION

LED lights have attracted much attention in recent years in multispectral imaging; thanks to their advantages over traditional systems with optical filters coupled with incandescent or fluorescent lights: low energy consumption, small size, long lifetime, robustness, fast switching, and narrow spectral bands. Furthermore, they are getting cheaper, and available in more and more different colors/wavelengths. In a typical multiplexed LED illumination based multispectral imaging system (LBMIS), a set of *n* different types of LEDs are selected, each type of LED is illuminated in a sequence, and a monochrome camera captures an image under the illuminated LED, thus producing a *n* band multispectral image (Park *et al.*, 2007). Such a system modulates the illumination and provides a multispectral light source. LBMISs have been proposed to be used in several applications, like color proofing (Yamamoto *et al.*, 2005), biometrics (Rowe *et al.*, 2005), medical imaging (Everdell *et al.*, 2009), and film scanning (Shrestha *et al.*, 2012).

One of the important issues in a LBMIS, which to our knowledge has not been studied so far, is the design/layout of the LED matrix. Some works have been done in the design for uniform illumination (Tan *et al.*, 2011; Zhen-min *et al.*, 2011; Su *et al.*, 2012), however they were intended for general illumination. In a typical LBMIS, a LED matrix is built from a cluster of different color (type of) LEDs. An optimal set of *n* LEDs is selected from given LEDs through exhaustive search or other appropriate selection algorithm based on certain criteria (e.g. accurate spectral or color estimation) (Shrestha *et al.*, 2012). These LEDs are lit in a sequence, and images are captured by a monochrome camera. Each color LED produces a band in an *n*-band multispectral image. The main goal of the LED matrix design for a LBMIS is the generation of a uniform and equal intensity light from the cluster of LEDs, in each band of the multispectral image. This becomes challenging as the number of bands increases, and it is further complicated by the fact that different LEDs are available with different intensity profiles. Furthermore, camera sensitivity of a monochrome camera is not flat; it is rather typically a curve with high sensitivity in green region and low sensitivity in blue and red regions. One way of achieving equal intensity multispectral bands could be by lowering the intensity of the more intense LEDs. However, this will reduce the efficiency and increase the cost, since much of the LED intensities will be unused, and this requires more LEDs and a bigger LED panel. In this paper, we propose a new method of LED matrix design based on the two important design requirements: spatial uniformity and consistency. The method takes into account all the issues discussed.

2. GENERIC LED MATRIX DESIGN

In a LBMIS, we strive for all the LEDs have the same (more or less) intensity profile. We assume that the individual LEDs of a type are of same characteristics such as uniform irradiance, luminance and directionality. Equal intensity LEDs can then be achieved by using a higher number of LEDs whose intensity is low, and fewer LEDs whose intensity is high. We define probability of appearance (POA) of a LED as the probability of appearance of that LED in a LED matrix. Let p_i be the POA of the i^{th} LED in a system with n number of LEDs, where $\sum_{i=1}^{n} p_i = 1$. The non-flat spectral sensitivity of a monochrome camera is taken into account by weighting the intensity profiles of the LEDs by the normalized spectral sensitivity of the camera. The POAs of the n LEDs are then determined using the peak values from their weighted intensity profiles. Based on the POA values, the design method is divided into three cases: Equal POAs (EPOA), Powers of 2 POAs (P2POA) and Other POAs (OPOA). EPOA is the case where POAs of all the LEDs are equal. P2POA is the case where all the POAs are powers of 2, i.e. $p_i = 1/2^l$, where l is a positive integer. The rest belongs to the OPOA. This paper addresses the first two cases, leaving the last case for future work. The proposed method is based on the three main design requirements. (1) **POA Requirement** ensures that the design satisfies the POAs of LEDs. (2) **Spatial Uniformity** criterion requires that each LED type samples the entire matrix as evenly as possible. (3) **LED Consistency** criterion states that each LED should have the same number of neighbors of a certain type of LED within a neighborhood of certain distance. The last two requirements are adapted from the ones used in multispectral filter array (MSFA) design (Miao and Qi, 2006).

The design method thus comprises of two steps.

1) **Determination of an optimal LED matrix size.** The first step is to determine a LED matrix size ($r \times c$) that distributes the n different types of LEDs fulfilling the POA requirement. For this, it may need to approximate a new set of POAs to make either P2POA or EPOA, and suggest a list of options. We choose an appropriate one based on the given acceptable tolerance. There might be a tradeoff between accurate POA values and the matrix size. We consider square matrices ($r = c$) in order to satisfy the spatial uniformity and LED consistency criteria. The number of i^{th} LED to be distributed in a $r \times r$ matrix is then given by $N_i = p_i \times r^2$, where $\sum_{i=1}^{n} N_i = r^2$.
2) **Distribution of LEDs in the LED matrix.** The next step is then to distribute all the LEDs in the LED matrix. For this we propose two methods based on whether the POAs falls into the EPOA or P2POA case. In some cases, POAs may belong to both the categories. One example is the case of 4 LEDs with $p_i = \{1/4, 1/4, 1/4, 1/4\}$. In these cases the P2POA takes precedence over the EPOA. This is because the P2POA gives smaller LED matrix size. More than one optimal distribution may be possible; one among them would be selected by proposed methods.

Distribution method for P2POA: When the POAs are powers of 2, we adapt the binary tree based (BT) method used for generating MSFAs (Miao and Qi, 2006). A binary tree of n leaves is constructed, where n corresponds to the n types of LEDs. The i^{th} LED with the POA, $p_i = 1/2^l$, will be positioned as a leaf in the binary tree at level l. LED matrix is then generated by traveling the binary tree from the root, and creating another binary tree of LED patterns starting with a checker board at the root, and then following alternately the decomposition and sub sampling steps. The final LED matrix pattern is obtained by combining all the patterns in the leaf nodes of the LED tree. Figure 1 illustrates an example with four simulated LEDs that cover the visual range of the spectrum (400nm-700nm), and with POAs $p_i = \{1/2, 1/4, 1/8, 1/8\}$. Figure 2 shows a resulting LED matrix. We assume that the LED panel is realized by surrounding the minimal size with the same pattern, one or more times as illustrated in the figure.

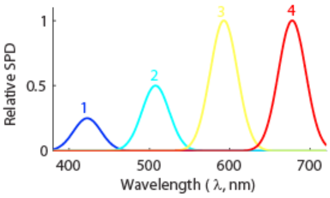
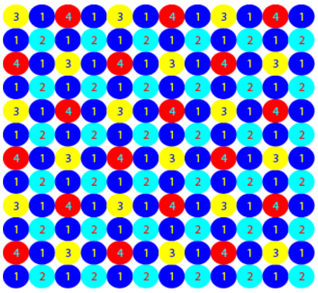


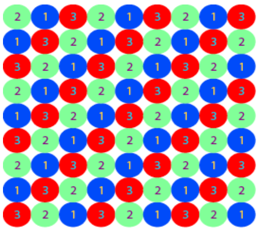
Figure 1: SPDs of four LEDs, a P2POA case.



3	1	4	1	3	1	4	1	3	1	4	1
1	2	1	2	1	2	1	2	1	2	1	2
4	1	3	1	4	1	3	1	4	1	3	1
1	2	1	2	1	2	1	2	1	2	1	2
3	1	4	1	3	1	4	1	3	1	4	1
1	2	1	2	1	2	1	2	1	2	1	2
4	1	3	1	4	1	3	1	4	1	3	1
1	2	1	2	1	2	1	2	1	2	1	2
3	1	4	1	3	1	4	1	3	1	4	1
1	2	1	2	1	2	1	2	1	2	1	2
4	1	3	1	4	1	3	1	4	1	3	1
1	2	1	2	1	2	1	2	1	2	1	2

Figure 2: matrix design for LEDs in Fig. 1.

Distribution method for EPOA: We use this method when the POAs are the same for all the LEDs (For n LEDs, $p_i = 1/n$), and they are not P2POA. In this case, we simply distribute the LEDs sequentially row-by-row from top to bottom. We use a $n \times n$ matrix, and distribute the LEDs 1 to n on the first row, from left to right in order. We distribute the LEDs on the second row in the cyclic order starting with 2 (i.e. 2, 3,…, n, 1). The remaining rows are filled similarly. Figure 3 illustrates distribution for 3 LEDs.



2	1	3	2	1	3	2	1	3
1	3	2	1	3	2	1	3	2
3	2	1	3	2	1	3	2	1
2	1	3	2	1	3	2	1	3
1	3	2	1	3	2	1	3	2
3	2	1	3	2	1	3	2	1
2	1	3	2	1	3	2	1	3
1	3	2	1	3	2	1	3	2
3	2	1	3	2	1	3	2	1

Figure 3: matrix design for 3 LEDs of EPOA.

The performance of the proposed design method is evaluated using the two evaluation metrics: *static coefficient* (*SC*), and *consistency coefficient* (*CC*), used in the MSFA design (Miao and Qi, 2006). *SC* measures the spatial uniformity of each type of LED, based on the electrostatic forces exerted on the LEDs. *CC* measures the LED consistency.

3. EXPERIMENTS AND RESULTS

The proposed design method is tested for different sets of simulated LEDs. Gaussian shaped LED SPDs are generated, with each set having different number of LEDs and intensity profiles, such that they give rise to certain P2POA and EPOA values. Table 1 shows these cases, along with the *SC* and *CC* metric values calculated from the resulting LED matrices. We have also validated the method with real LEDs used in a LED based spectral film scanner (Shrestha *et al.*, 2012). Here we use 8 LEDs selected by a forward selection method for an optimal GFC (Goodness of Fit Coefficient). The modified intensity profiles of these LEDs after accounting for the spectral sensitivity of a monochrome camera is obtained by using a simulated Gaussian shaped camera sensitivity. Figure 4 shows the normalized SPDs of the 8 LEDs enveloped by the camera sensitivity curve. The POAs of the LEDs are calculated from the modified intensity profiles, and they are then approximated to make them P2POA. This is used to design the LED matrix using the distribution method for the P2POA. The original POAs, the modified POAs and the approximated P2POAs, along with the *SC* and *CC* metric values obtained from the resulting LED matrix are given in Table 1.

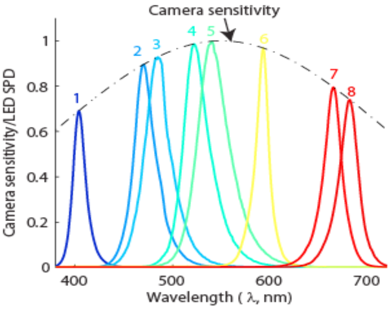
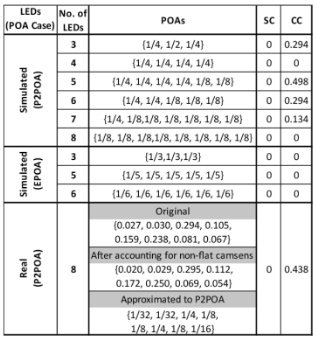


Figure 4: Normalized LED SPDs enveloped by camera sensitivity.

Table 1: SC and CC values obtained with different cases of LED matrix designs.



LEDs (POA Case)	No. of LEDs	POAs	SC	CC
Simulated (P2POA)	3	{1/4, 1/2, 1/4}	0	0.294
	4	{1/4, 1/4, 1/4, 1/4}	0	0
	5	{1/4, 1/4, 1/4, 1/4, 1/8, 1/8}	0	0.498
	6	{1/4, 1/4, 1/8, 1/8, 1/8}	0	0.294
	7	{1/4, 1/8,1/8, 1/8, 1/8, 1/8, 1/8}	0	0.134
	8	{1/8, 1/8, 1/8,1/8, 1/8, 1/8, 1/8, 1/8}	0	0
Simulated (EPOA)	3	{1/3,1/3,1/3}	0	0
	5	{1/5, 1/5, 1/5, 1/5, 1/5}	0	0
	6	{1/6, 1/6, 1/6, 1/6, 1/6, 1/6}	0	0
Real (P2POA)	8	Original {0.027, 0.030, 0.294, 0.105, 0.159, 0.238, 0.081, 0.067} After accounting for non-flat camsens {0.020, 0.029, 0.295, 0.112, 0.172, 0.250, 0.069, 0.054} Approximated to P2POA {1/32, 1/32, 1/4, 1/8, 1/8, 1/4, 1/8, 1/16}	0	0.438

The results show that both the *SC* and the *CC* values are zeros in the case of EPOA, indicating the perfect uniformity and consistency. The *SC* values for the LEDs with P2POAs are also zero. *CC* is zero when the binary tree is perfect, and the value increases with the deviations from this. Future work might investigate the possibility of incorporating mathematical models (Tan *et al.*, 2011; Zhen-min *et al.*, 2011; Su *et al.*, 2012) proposed for the uniform illumination. The method could be extended by taking into account different characteristics of individual LEDs like non-uniform irradiance, luminance and directionality.

4. CONCLUSION

We proposed a LED matrix design for multispectral imaging, based on spatial uniformity and consistency of LED distribution. POA of each type of LED is obtained from its intensity profile, taking into account the non-flat spectral sensitivity of a monochrome camera. The experiments showed that the method can generate optimal or near optimal LED matrix for a given set of LEDs whose POAs are either EPOAs or P2POAs. As a future work, it would be interesting to extend the method for the OPOA case as well.

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The Importance of Colour in Atmosphere Characterisation

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ABSTRACT

The perception of atmosphere is a function of various dimensions, like colour, illumination, surface, sound, odour, temperature as well as room structure, where colour is one of the key factors. Colour is a natural phenomenon and there are various categories and systems available describing quality and quantity of colour. In the work presented here the perception of colour on the atmospheric quality of a landscape has been analysed in a longitudinal setting. Parameters of the colour space were correlated with psychometric dimensions (human perception). An analytical tool has been used which was developed in an earlier design research project allowing the characterisation of atmosphere with six independent dimensions. Two test candidates did observe bi-weekly over a period of a year from a fixed position a specific view into nature. The natural change of light and colours through the seasons and different weather conditions led to a continuous change of the observed environmental situation. The result of this research demonstrates an unexpected correlation between colour attributes and their perception, especially relating to the opulence of the colour space. The primary attribute was the complexity of the colour variance and not the colour saturation.

1. INTRODUCTION

Along with technological progress the aesthetical sentiments and human ideals are changing. Today it seems to be important that the perception of scenes is intensifying our existence (Böhme 1993). This is in particular important for the perception of architecture that is experienced with its integrated material and comprised spiritual essence (Pallasmaa 2012). Atmospheric attributes can be e.g. sound, odour, haptic, luminance and colour.

Today we would speak of an atmospheric effect. Colours communicate to space a certain mood (Böhme 2010).

Today there is evidence that colour and light has psychological and physical effects, however many question remain still unanswered (Gilliam 1988, van Hagen 2009).

What is of interest to us in this investigation is colour in relation to the perception of atmosphere. This perception starts with objective elements like the excitation of the receptors and ends individual subjective emphasis. On the other hand there is high cultural concordance, where designer and architects can rely on. But the amount of terms for the characterisation of atmosphere is small. Therefore it seems to be important to further investigate the objective description of product appearances. (Blijlevens 2009) This can be helpful for the communication between designer/ architect and users. In this study an attempt is made to decipher the complexity of perception of atmosphere by investigating the influence of colour. As analytical tool the model according to Findeli, von Wyl and Sütterlin has been used (Findeli 2012). For colour characterisation the model was already tested in laboratory setting (von Wyl private communication). In this study the model was amended for use in the exterior space and the correlation between colour and the six atmosphere dimensions has been tested.

2. METHODS AND STRATEGY

The approach is practice oriented and shall lead to answers pertinent to design relevant solutions. Methods of social science and phenomenology as well as design instruments have been used. The analytical tool was used as described by Findeli but the terms (38 descriptors) were adapted for the description of a landscape. 5 terms of the initial list were deleted and 25 added resulting in a questionaire of 63 terms (Table 1). The six dimensions *cosiness*, *liveliness*, *grandness*, *openness*, *dispassion* and *emotional security* to characterise atmosphere remained unchanged.

Table 1. Terms of questionnaire.

Kontaktfördend (connect)	Warm (warm)	Schockierend (shocking)	Sakral (sacral)	Seelenlos (soulless)
Gemütlich (confortable)	Behaglich (cosy)	Abstossend (abhorrent)	Lebendig (animate)	Lähmend (paralyzing)
Befreiend (librating)	Formell (formal)	Funktional (functional)	Fröhlich (brightly)	Zauberhaft (enchanting)
Überraschend (surprising)	Natürlich (natural)	Dynamisch (dynamic)	Magisch (magic)	Mächtig (abundant)
Gastfreundlich (hospitable)	Anregend (brisk)	Angenehm (pleasant)	Ruhig (quiet)	Romantisch (romantic)
Harmonisch (harmonically)	Intim (intimate)	Beschützend (protective)	Kraftvoll (poverful)	Künstlich (artificial)
Deprimierend (depressing)	Nüchtern (sober)	Gepflegt (cultivated)	Friedlich (peaceful)	Bedeutsam (significant)
Geheimnisvoll (mystical)	Korrekt (accurate)	Stimulierend (excitatory)	Irritierend (vexing)	Festlich (feastful)
Surrealistisch (surrealistic)	Verspielt (coltish)	Bedrückend (oppressive)	Lustvoll (relishing)	Schummrig (dimly)
Transzendental (transcendental)	Prächtig (glorious)	Traumartig (oneiric)	Heiter (blithe)	Trostlos (desolate)
Beklemmend (disturbing)	Düster (dusky)	Schön (beautiful)	Rein (pure)	Wild (wild)
Aussergewöhnlich (dilly)	Simpel (simplistic)	Unheimlich (eerily)	Lauschig (snug)	Kalt (cool)
Beängstigend (avesome)	Klar (clear)	Exotisch (exotic)		

In preparation of the observations place and settings has been determined. Aim was to find a place where over the course of a year the only expected changes related to the weather and season. Finally a countryside has been selected with view towards a lake and mountains and grassland and forest in the foreground. Analogue to a eye-tracking method ten focus points within the landscape view have been selected based on the view directions of the two test persons. The focus points were transcribed onto a photo of this view for the subsequent colour determination.

Two test persons did observe about every two weeks over a period of a year a specific the landscape from the predetermined place in the morning with a total of 23. A photo was taken at the beginning of each observation. Later the photography was transferred onto a Mac Book. At the predetermined ten focus points the CMYK values were taken in InDesign. Two values were calculated to characterise each photo: a) average C, M, Y and K value across the ten focus points called *Saturation*, b) the corresponding standard deviations for each of the four colour values, i.e. the complexity, called *Variance*.

Following a 3-minute observation period the questionnaire had been completed. For each observation the perception of the atmosphere of the test persons was calculated resulting in one value for each of the six dimensions.

The correlation coefficient between Saturation (each CMYK value) or Variance (each CMYK value) respectively and each of the six dimension values was calculated according Bravais-Pearson (Bortz 1993).

3. RESULTS

Table 2 shows the correlation coefficient between Saturation or Variance and each of the dimensions describing the perception of the atmosphere. Saturation was significantly correlated between Cyan and the dimension grandness. Variance of Yellow was signifcantly correlated with five of the 6 dimensions, Magenta with 4, Cyan with two and Black with one.

Table 2. Correlation coefficient, significant values in bold (α = 0.05, two side testing).

			Dimensionen der atmosphärischen Wirkung (*Variance*)					
			1 Behaglichkeit (cosiness)	2 Lebendigkeit (liveliness)	3 Erhabenheit (grandness)	4 Offenheit (openess)	5 Sachlichkeit (dispassion)	6 Geborgenheit (em. security)
Satura-tion	Cyan	C	0.15	0.14	**0.36**	0.00	-0.01	0.15
	Magenta	M	-0.11	-0.01	0.14	-0.17	0.05	-0.08
	Yellow	Y	0.07	0.16	0.23	0.05	0.05	0.07
	Black	K	0.06	0.13	0.23	0.07	0.15	0.06
Vari-ance	Cyan	C	0.24	0.22	**0.35**	0.17	0.05	**0.31**
	Magenta	M	**0.33**	**0.45**	**0.42**	0.23	-0.12	**0.39**
	Yellow	Y	**0.41**	**0.44**	**0.42**	**0.30**	-0.04	**0.36**
	Black	K	0.17	0.26	**0.37**	0.13	0.08	0.17

Each of the six dimensions correlates differently with Variance or Saturation. Grandness correlates positively with the Variance of all four CMYK values, Emotional Security correlates positively with the Variance of CMY, whereas cosiness and liveliness correlate with M and Y. Openness does correlate only with the Variance of Y. Dispassion has no significant correlation.

Figure 1 shows four representative observations. The line diagram below the picture shows the ten focus points on the x-axes (starting at the top left) and their respective variance on the y-axes. The net diagram shows the value of each of the six atmospheric perception dimensions (1 = cosiness at the top, 2 – 6 following clockwise) at the respective observation. The positions for colour extraction are shown in the first picture.

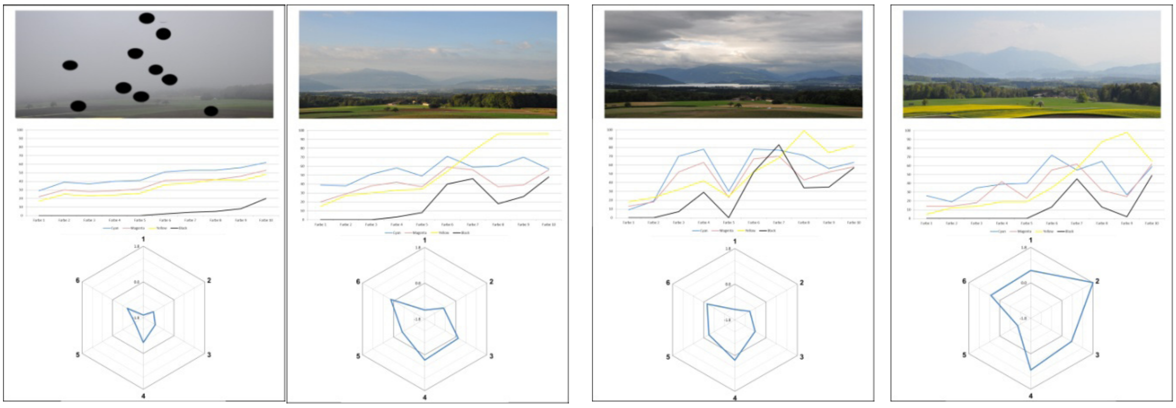

Figure 1: Variance and perception diagram for four representative observations.

4. DISCUSSION AND CONCLUSIONS

Overall the data demonstrate a positive correlation between Colour Variance, i.e. the complexity, and the perception of space atmosphere whereas the Colour Saturation seems to be of limited importance. Of the six dimensions grandness was most determined through the complexity of light and also through the saturation of Cyan. In contrary the dimension dispassion did not at all correlate with the quality of light but it might well be determined by other attributes (e.g. structure). The variance of the colour yellow, positively correlating with five dimensions, was clearly the most important. It is interesting to mention that Goethe did characterise yellow as a colour has a warming effect (van Biema 1997).

The study has its limitations. Firstly the small number of test persons, secondly the colour analysis within the CMYK colour space opposed to the larger LAB colour space. But the results are interesting for hypothesis generation and warrant further investigation. Not only will it be interesting to see whether the positive correlation of colour complexity with perception of atmosphere can be confirmed. Also the influence of other sensations on the perception of atmosphere shall be tested with the analytical model. The intuition of designers and architects could be enriched through substantiated understanding of how the character of atmosphere is determined.

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Makeup Design Suggestions by Face Image Types Based on an Analysis of Skin Colors and Makeup Colors of Korean Women

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ABSTRACT

The purpose of this study is to categorize the facial image of Korean women and to propose makeup designs by analyzing the effects of skin color and makeup color on facial image. Document studies and 2 questionnaire-type surveys were employed in the research. The subjects of the surveys were 220 students attending 20 universities in Korea. The subjects of the study were Korean women ages 20 to 24. The SPSS 12.0 statistics program was used as the analyzing method, and frequency analysis, ANOVA, MANOVA, Scheffe test, T-test, main component analysis, factor analysis using Varimax orthogonal rotation method and Cronbach's α reliability test were executed. According to the data, the effects of makeup to achieve a specific image differed according to the types of facial image, and the factors that help convey a specific image appeared to be different, too.

The results of this study can be used in practice as groundwork data for image consulting and can also be applied in beauty, fashion, marketing, advertisement, entertainment and other fields that require knowledge of the standards of Korean facial image.

1. INTRODUCTION

Facial image is a factor in nonverbal communication and affects a person's overall image, playing an important role in personal perceptions and the formation of impressions.

Facial image involves facial shape, skin color, makeup, hairstyle, clothing and many other elements. Decisions about makeup and hairstyle are based in part on physical factors, such as facial form and skin color. In order to grasp the primary influences that form the facial image, therefore, the analysis of physical factors should be given priority.

Makeup that expresses the face is an essential factor that directly affects facial image.

Analyzing the effects of facial shape and skin color on the overall image is important in deciding upon a makeup method.

Therefore, this study is trying to propose a makeup design based on facial image factors that have been materialized through a general analysis of color. This is in contrast to previous studies that have proposed an evaluation that limited the types of facial image makeup to colors.

Accordingly, the purpose of this study is to materialize the facial image of Korean women and to propose makeup designs that follow facial images by analyzing the effects of makeup color on facial image.

2. METHOD

1) Analyzing facial image and survey targets

The survey targets were restricted to 55 women ages 20-24 (mean: 21) who had not gone through plastic surgery.

The stimulus were photographed using a Nikon D-200 camera, Nikon 50mm lens, 1/60 shutter speed and 500w sun ray bulb. The distance from the subject's pupils to the lens was 182 cm. The models were instructed to make a natural expression and had their hair tied into a ponytail and their bangs pulled back with a hair band to expose all of the forehead and neck. Pictures of all sides were taken.

Three high-upper rank pictures were abstracted from each 4 image group among the 55 facial image pictures collected through a preliminary survey, and 12 final pictures were selected. Skin condition, clothing and other factors were edited using a graphic program (Adobe Photoshop) in order to suit the pictures to the survey.

The subjects of the first empirical survey of facial image were 220 men and women in their 20s, and the survey period was from May 10 to May 20, 2012. In the end, 220 copies of the survey that were judged to be appropriate for the data were used in statistics.

Respondents used a 5-point scale in the facial image evaluation of the 12 final pictures, using the following 18 adjectives: graceful, innocent, classy, intelligent, lively, lovely, cute, youthful, active, strong, man-like, characteristic, feminine, gentle, comfortable, friendly, natural, sexy. These adjectives were collected from among the adjectives used in facial and makeup-related preliminary studies and related books.

The SPSS statistical program was used to execute factor analysis, reliability analysis and correlation analysis.

2) Producing incitant of skin color-retouched image

The stimulus of skin color-retouched image was produced to compare differences in the perception of skin color-corrected images and bare-face images.

The color of each experimental subject's skin was measured during the photo shoot to obtain the CIE L*a*b* value of the skin color, which is needed when producing the incitant.

A measuring machine (Minolta CR-200) was used and the average value of four spots (forehead, both cheeks, and chin) was calculated.

Referring to the 12 personal-coloration skin colors presented in Kim Yeong In et al.'s 2006 study, four standard skin tones (bright, dark, yellow, red) were set as the CIE L*a*b* values.

The incitant of skin color-retouched image was produced with Photoshop, using abstracted CIE L*a*b* values.

To avoid changing the colors of eyes, eyebrows, lips and other parts of the face, the sphere was set to change only the skin tone.

3) Producing incitant of makeup color-retouched image

To determine the color scheme applied to the makeup color–retouched images, the main makeup color was selected in advance, and with the selected color as the base, a color scheme palette was extracted through a focus group interview of 12 masters and doctors with more than 10 years' practical experience in make up. To choose the representative coloration image for each facial image, the frequencies of 60 colors abstracted by the 12-person panel were first analyzed to extract the tone. Color abstraction was completed and 5 color schemes were selected for each of the images.

The incitant pictures with only base makeup were processed in Photoshop with the 5 colors that were extracted for each facial image to produce incitant of makeup color-retouched images.

4) Secondary subjects and analysis to verify the effects of skin and makeup color

Differences in the perception of skin color and facial images changed by makeup color were evaluated using the same 5-point survey system of 18 adjectives that was used in the first survey described in section 1. The research period started on September 10, 2012, and ended on September 20, 2012. At the end, 220 survey papers that were thought to be appropriate for the data were used in statistics. The T-test, ANOVA, Scheffe test and MDS were employed in the analysis, using SPSS12.0.

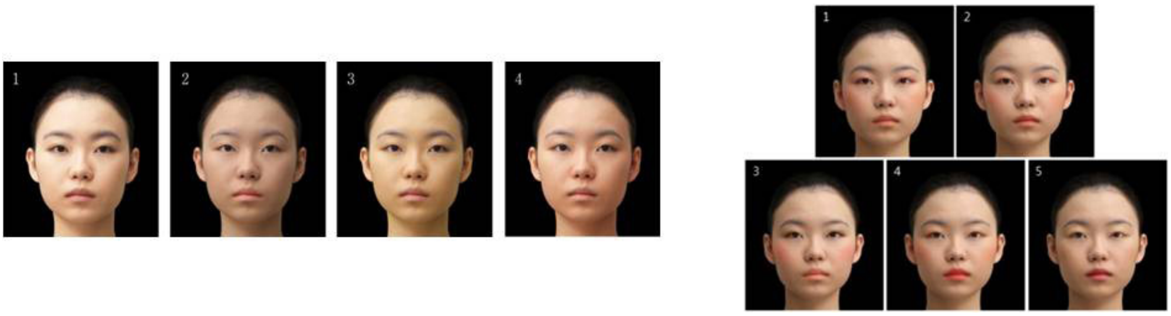

Figure 1. Examples of incitant pictures: skin color-retouched images (left) and makeup color-retouched images (right).

3. RESULTS AND DISCUSSION

1) Materialization of facial image

Facial images of Korean women in their 20s were classified into four categories: Youthfulness, Classiness, Friendliness, and Activeness. It was found that the facial impression was formed with the above 4 facial images when evaluating the facial image of Korean women in their 20s. Youthfulness and Friendliness types showed a strong resemblance, which suggests that university students in their 20s evaluate a youthful face as familiar.

2) Effects of skin-color retouch makeup

Youthful and Classiness facial types appeared with the highest frequency among faces with bright tones, and familiar and active types were most frequent among faces with red tones. When the perception of bare-face and skin color-retouched images was analyzed, a significant difference was found in Friendliness, Classiness and Activeness, while Youthfulness showed no meaningful distinction.

3) Effects of makeup-color retouch makeup

The results for the makeup-retouched version of each facial image revealed that Youthfulness occurred at a high frequency when the lipstick color was emphasized, Friendliness and Activeness occurred most often in color schemes of a similar color (setting the standard in Red and YellowRed), and an impression of Classiness was most frequent when the colors had low saturation and eye shadow in particular had low brightness. A comparison of the averages of bare-face and makeup-retouched images showed significant differences in Classiness, Friendliness and Activeness but no meaningful differences in Youthfulness.

4) Effects of makeup according to the impact factors of each facial image

Classiness and Friendliness types had the highest rising trend of image when using skin color–retouch makeup and makeup color–retouch makeup. Youthfulness and Activeness, by contrast, had no image increasing through skin-color and makeup-color retouch. Therefore, it appears that color-based makeup is effective in increasing familiarity and urbanism, while Youthfulness and Activeness are affected by factors other than skin color and makeup color.

4. CONCLUSIONS

Through an objective combined analysis of face shapes and colors, this study has systematically verified how the effects of makeup differ according to the facial image types of Korean women. Looking at the results of the study in general, many differences can be seen in how makeup creates a specific effect according to each facial image, and the decisive factors that make people perceive each type of facial image also differ. The above findings can be applied to obtain or emphasize a certain effect.

The results of this study can be used in practice as groundwork data for image consulting and can also be applied in beauty, fashion, marketing, advertisement, entertainment and other fields that require knowledge of the standards of Korean facial image.

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How the Surface Texture of a Textile Affects its Colour

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ABSTRACT

In this paper, the question of how the surface texture of a textile affects its colour is explored using 268 knitted yarn dyed fabric samples in 67 texture structures (including single jersey as the standard) and 4 colour centers (red, yellow, green and blue). Experiments show that the colour difference between the standard samples and other samples ranges from 0.09 to 1.38 with the mean of 0.57 CIELAB units. By analyzing the colour data in the CIEXYZ and CIELAB colour spaces, it is found that the colours of these samples with different texture structures in each colour center are constant in x and y channels but vary in L*, a*, b* and Y channels, i.e., the luminance values vary for samples with different texture structures but their chromaticity values are identical. It can be concluded that colour difference between textiles with different texture structures stems mainly from their variable luminance values (the CIEXYZ space) and thus lightness values (the CIELAB space).

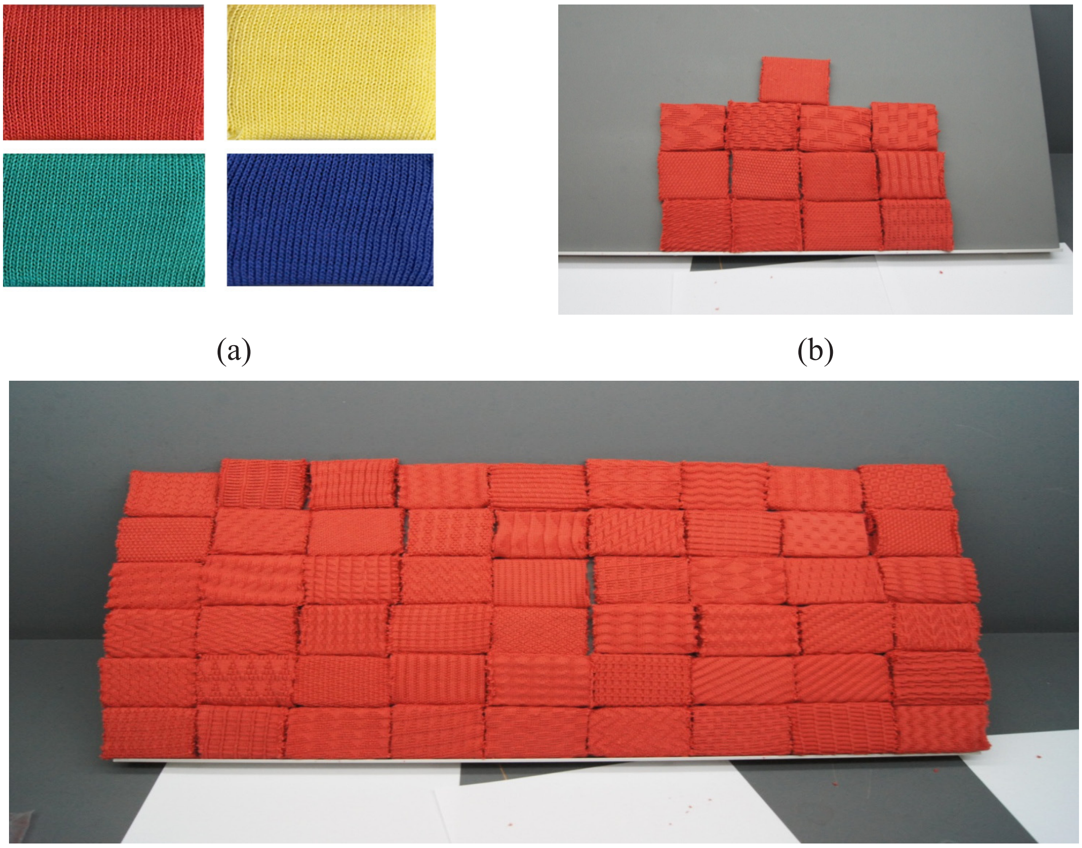
1. INTRODUCTION

There have been increasing interests in studying the relation between the texture of a textile and its colour. In former studies, a group of samples with different texture structures were collected. These samples were measured by a spectrophotometer to obtain their instrumental colours. The textures of these samples were quantified by several texture descriptors such as the half-width of histogram (Xin et al. (2005)), the autocorrelation functions (Kitaguchi et al. (2005)), co-occurrence matrices (Kitaguchi et al. (2005)) and Gabor functions (Kandi et al. (2008)). The relationship between the instrumental colours and the texture parameters of these samples was then established. As these studies focused mainly on the relation between the texture of a sample and its colour, little attention has been given to the question how the texture of a sample affects its colour. In this paper, this question is investigated.

2. METHOD

268 knitted yarn dyed fabric samples were used for experiments. The material of these fabrics was cotton. These samples included the colour centers of red, yellow, green and blue (Figure 1(a)) and 67 texture structures (Figure 1(b) and Figure 1(c)). These samples were knitted by a Shima Seiki Knitting Machine. The standard texture structures of these samples were their solid colours: single jersey (Figure 1(a)).

A MACBETH Colour-Eye 7000A Spectrophotometer was used to measure the instrumental colours of these samples in the CIEXYZ and CIELAB colour spaces. The measurement was conducted under the 1964 CIE standard observer. The specular component excluded (SCE) and UV excluded modes were applied to eliminate the influence of specular light and UV on samples.



(a)

(b)

(c)

Figure 1: The knitted yarn dyed fabric samples used in the experiment. (a) the 4 colour centers (red, yellow, green and blue) and the standard texture structures (single jersey). (b) and (c) the 67 texture structures of samples in the red colour.

3. RESULTS AND DISCUSSION

3.1 Effect of the texture on colour

Figure 2 shows the colour difference between the standard samples and other samples in each colour center. The colour difference ranges from 0.09 to 1.38 with the mean of 0.57. It can be concluded from Figure 2 that the texture structures of the knitted yarn dyed fabrics affect their colours.

3.2 How the texture of a fabric affects its colour

In order to explore the question how the texture of a textile affects its colour, the colours in the CIEXYZ and CIELAB colour spaces were analyzed. Table 1 shows the standard deviation of absolute difference of colour attributes in L*, a*, b*, Y, x and y channels. The standard deviation values of absolute difference of colour attributes in x and y channels are less than 0.0015 for all samples except those in red. However, the standard deviation values of absolute difference of colour attributes in the L*, a*, b* and Y channels are more than 0.14 for all samples.

Due to the inconsistency of unit in L*, a*, b*, Y, x and y channels, variation coefficients of the absolute difference of colour data in these colour channels are adopted to analyze the influence of the texture structure on colour in different colour attributes. The variation coefficient is a normalized measure of dispersion of data. It can be used to compare data sets with different units. The variation coefficient is defined as following,

$$c_v = \frac{\sigma}{\mu}$$

where σ and μ are the standard deviation and the mean of data.

As shown in Figure 3, the variation coefficients of colour attributes in x and y channels are less than those in L*, a*, b* and Y channels. From Table 1 and Figure 3, it can be concluded that the colour attributes of textiles different texture structures are approximately constant in x and y channels but vary in L*, a*, b*, and Y channels, i.e., the luminance values (Y channel) vary but their chromaticity values (x and y channels) are constant.

When CIE xyY colour space is used to specify colours of textiles with different texture structures, their colour attributes in L*, a* and b* channels depends on their luminance values. Thus, colour difference exists between these textiles.

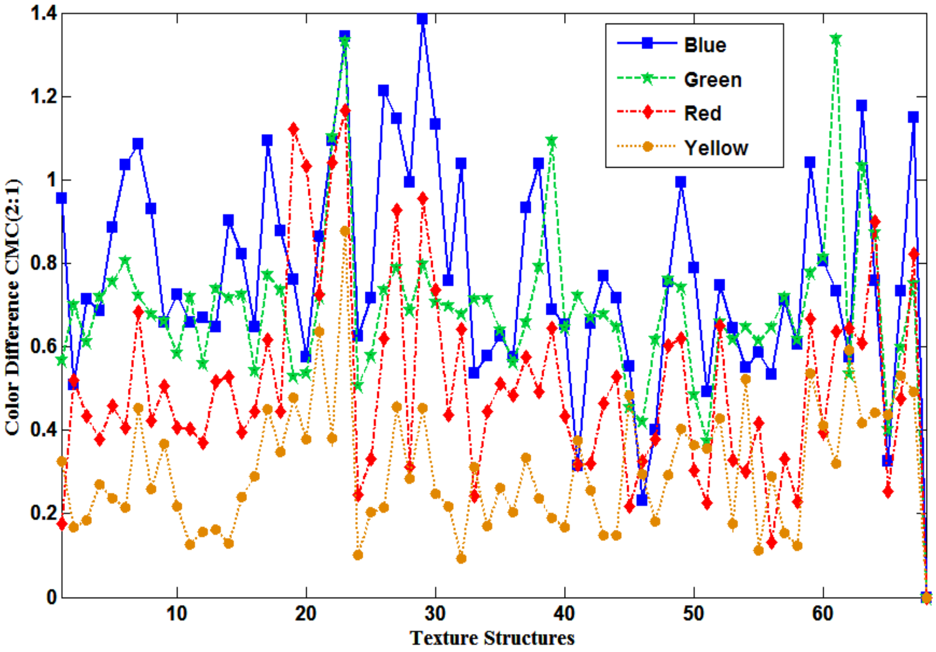


Figure 2: The colour difference between the standard samples and other samples.

Table 1. The mean and standard deviation of colour attributes in L, a*, b*, Y, x and y channels.*

	L*	a*	b*	Y	x	y
Blue	0.59	0.12	0.36	0.27	0.00097	0.00131
Green	0.67	0.35	0.14	0.61	0.00068	0.00078
Red	0.57	0.33	0.28	0.36	0.00211	0.00031
Yellow	0.34	0.14	0.58	0.66	0.00123	0.00126

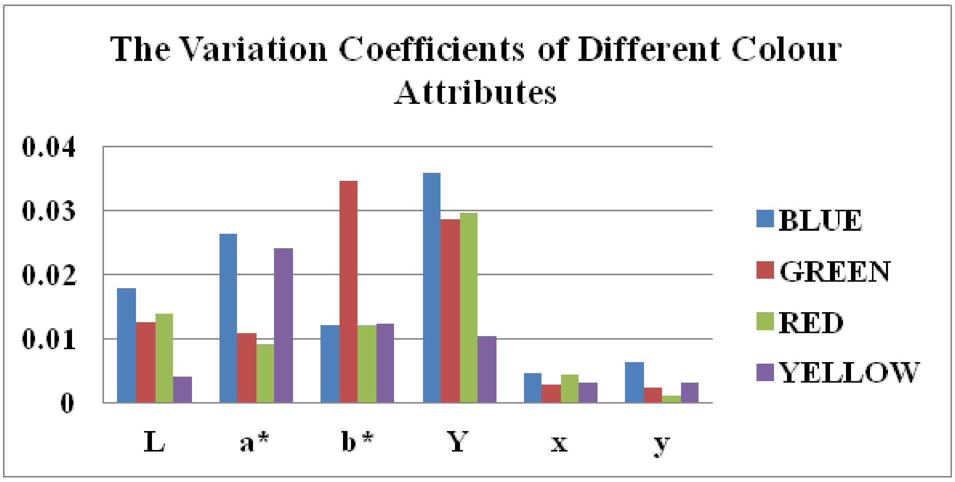


Figure 3: *The variation coefficient of difference of colour in each colour channel.*

4. CONCLUSION

This paper explores the question how the texture of a textile affect its colour. By analyzing colours of 268 knitted yarn dyed fabric samples in the CIEXYZ and CIELAB colour spaces, it is found the colours of textiles with different texture structures are constant in x and y channels but vary in L*, a*, b* and Y channels, i.e., the luminance values (Y channel) vary but their chromaticity values are approximately constant. Thus, it can be concluded that colour difference between textiles with different texture structures mainly stems from their different luminance values (the CIEXYZ space) and thus lightness values (the CIELAB space).

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A Comparative Study of the Recipe Prediction Performance of Single Constant Kubelka-Munk Derivative Models on Textiles

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ABSTRACT

One limitation of the single constant Schuster-Kubelka-Munk theory is its poor linearisation performance when relating the dyed fabric absorption properties to the applied dye concentration, particularly at higher levels of dye concentration as the fabric becomes saturated with dye. The Mrango-Owens (M-O) model, based on a modified version of the single constant Kubelka-Munk theory, improves the linearity between the fabric absorption properties and the applied dye concentration at all wavelengths across the visible spectrum, especially at higher depths of shade. This leads to a significant improvement in the accuracy of dye recipe prediction when compared to single constant Kubelka-Munk based equations (Pineo, Derbyshire-Marshall and McDonald equations). The accuracy of the predicted dye concentration from low depths of shade (e.g. 0.5%, o.w.f) to heavy depths of shade (e.g. 10%, o.w.f) is significantly improved with the majority of predicted samples having a of less than 1. The overall error of prediction for the applied dye concentration levels (o.w.f %) was reduced by 65% when compared to the single constant Kubelka-Munk based equations. This improvement in the accuracy of dye recipe prediction saves both time and resources contributing to the sustainability of the textile industry in minimizing its environmental impact.

1. INTRODUCTION

The objective for most dyers and colourists in the textile industry is to predict a textile dye recipe to match a target fabric shade at the first attempt. The Schuster-Kubelka-Munk (K-M) equation and its derivatives have been successfully applied to dye recipe prediction in the textile colouration industry. These theories relate the spectral reflectance properties of the measured samples with its absorption and scattering properties as shown in Equation 1 (Nobbs 1985). To relate the absorption and scattering properties of a textile sample to the applied dye concentration, a simplified version of the K-M equation known as single constant K-M equation was derived, Equation 2.

$$\frac{K_\lambda}{S_\lambda}=\frac{(1-R_\lambda)^2}{2R_\lambda} \qquad (1)$$

$$\left(\frac{K}{S}\right)_{\lambda,overall}=\left(\frac{K}{S}\right)_{\lambda,S}+\sum_{i=1}^{n}C_i\cdot\left(\frac{K}{S}\right)_{\lambda,i} \qquad (2)$$

where:

- Absorption and scattering coefficient of the measured sample
- Spectral reflectance value of the measured sample
- Absorption and scattering coefficient for the dyed sample, substrate and colourant respectively
- Colourant concentration

The single constant K-M equation describes the nonlinear relationship between the K/S-values and increasing applied dye concentration. Researchers suggested modifications to the K-M equation in order to improve its linearity. Derbyshire-Marshall (D-M), Equation 3, and Pineo (Equation 4) proposed modifications that accounted for the surface reflection properties of the dyed sample by introducing constants to eliminate the surface reflection properties when calculating the overall K/S-value (Derbyshire and Marshall 1980; Takatsuki and Ibaraki 1985). McDonald suggested a modification derived from Freundlich and Langmuir isotherms, modeling the nonlinear dye uptake that results from a gradual fall-off in dye exhaustion as the concentration of the dye applied to the dyebath increases, Equation 5 (McDonald 1997).

$$\left(\frac{K}{S}\right)_{\lambda} = \frac{\left[1-(R_{\lambda}-R_{0})\right]^{2}}{2(R_{\lambda}-R_{0})} - \frac{\left[1-(R_{\lambda,S}-R_{0})\right]^{2}}{2(R_{\lambda,S}-R_{0})} \qquad (3)$$

$$\left(\frac{K}{S}\right)_{\lambda} = \frac{(1-R_{\lambda})^{2}}{2(1-r)(R_{\lambda}-r)} \qquad (4)$$

$$\left(\frac{K}{S}\right)_{\lambda,overall} = \left(\frac{K}{S}\right)_{\lambda,s} + \sum_{i=1}^{n}\frac{g_{\lambda,i}\cdot C_{i}}{1+k_{\lambda,i}\cdot C_{i}} \qquad (5)$$

where:
- Spectral reflectance value of the substrate
- Surface reflectance of a fabric with infinitely high dye concentration
- Pineo's factor to account for surface reflection
- A constant that models the relationship between the amount of dye in the fibre and that in the dyebath
- A constant that models the fibre dye absorption upper limit

A perfect linear relationship between the K/S-values and the applied dye concentration is desirable for accurate dye recipe prediction. Conventional single constant K-M based equations have not been entirely successful in linearly relating the K/S-values with the applied dye concentration. The Mrango-Owens (M-O) modification of the single constant K-M equation is based on modeling the difference between the original single constant K-M K/S-curve and an imaginary linear curve. The optimized K/S-values are linear to the applied dye concentration, Figure 1. The M-O modification has been implemented for several types of dyed textile fabric materials. The performance was compared to conventional single constant K-M and the derivative equations.

$$\left(\frac{K}{S}\right)_{\lambda,m} = e_{\lambda}\cdot\left(\frac{K}{S}\right)_{\lambda,o} + f_{\lambda}\cdot C + g_{\lambda}\cdot C^{2} \qquad (6)$$

where:
- Original and modified values respectively
- the linearisation coefficients of the M–O equation
- Applied dye concentration

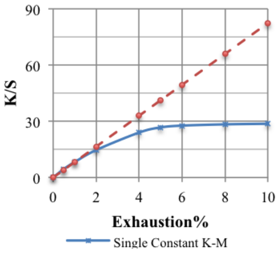

Figure 1: Single constant K-M linearisation using M-O modified values.

2. METHOD

2.1 Materials and Dyeing Procedures

In order to apply and test the performance of the M-O equation for textile dye recipe prediction, plain woven and interlock knitted bleached cotton, wool and nylon fabrics were individually dyed with different colours of reactive (Remazol and Procion), Neutrilan acid and Intra-acid dyes respectively. An exhaustion dyeing process was performed at seven different levels of applied dye concentration (0.5%-10% o.w.f.) at a 1:10 fabric-to-liquor ratio using a Mathis LaboMat RotaDyer (Nr: BFA 12 89997).

2.2 Measurement of the Spectral Reflectance Properties and Development of Textile Dye Recipe Prediction Database

A DataColor SpectraFlash (SF600) spectrophotometer measured the spectral reflectance properties of the dyed samples and their substrates (SPEXC, UVEXC). The M-O equation was implemented using MATLAB and established an almost perfect linear relationship between the applied dye concentration and the fabric's spectral reflectance properties. The predicted dye recipe was calculated from modified K/S-values, Equation 7, and additivity was achieved using the original K-M K/S-values using Equations 8 and 9. Metameric colour matches between the predicted and target samples were calculated.

$$\left(\frac{K}{S}\right)_{\lambda,m} = \sum_{i=1}^{n} C_i \cdot \left(\frac{K}{S}\right)_{\lambda,m,i} \qquad (7)$$

$$\left(\frac{K}{S}\right)_{\lambda,mix} = \left(\frac{K}{S}\right)_{\lambda,s} + \sum_{i=1}^{n} \left(\frac{K}{S}\right)_{\lambda,o,i} \qquad (8)$$

$$\left(\frac{K}{S}\right)_{\lambda,o,i} = \frac{1}{e_{\lambda,i}} \cdot \left[\left(\frac{K}{S}\right)_{\lambda,m,i} - \left(f_{\lambda,i} \cdot C_i + g_{\lambda,i} \cdot C_i^2\right)\right] \qquad (9)$$

where:

- - Recovered original K-M
- - Modified (M-O equation) for the respective colourants
- - Absorption and scattering properties of the substrate

3 RESULTS AND DISCUSSION

3.1 Linearisation Performance of K/S-curves using the M-O Equation

The linearisation of the K/S-values, as related to applied dye concentration, using the M-O equation was improved at all wavelengths when compared to the conventional single constant K-M equation, Figure 2.

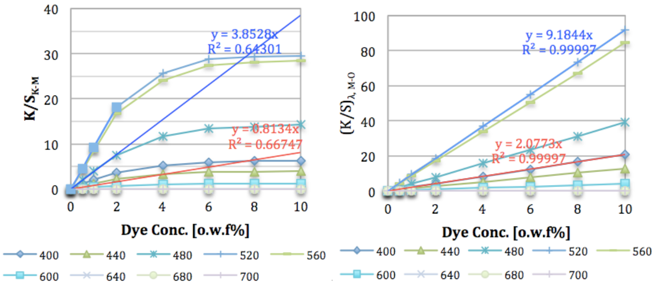

Figure 2: Linearisation comparison of values with applied dye concentration using (left) single constant K-M and (right) M-O equations (for red dyed interlock knitted nylon fabrics).

3.2 The M-O Equation Performance for Textile Dye Recipe Prediction

The M-O equation performance was compared to the single constant K-M equations. The colour differences between the target and predicted shades were calculated. The amount of applied dye required to reproduce the target shade was also calculated. Figure 3 shows the red and blue single-shade dyed interlock knitted and plain-woven cotton fabrics.

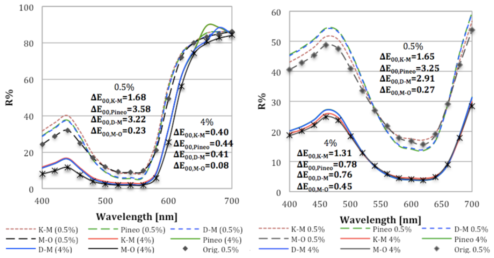

Figure 3: Comparison of spectral reflectance curves generated using single constant K-M, Pineo, D-M and M-O equations for a single dyed shade (left) red interlock knitted nylon and (right) Remazol blue plain-woven cotton fabrics.

The predicted reflectance curve using the single constant K-M equation deviated from that of the target but the M-O equation produced an almost perfect spectral match. The performance of the M-O equation for trichromatic dye mixtures showed a better prediction performance of the target recipe shade for a fabric sample dyed with the mixture of red, green and blue Remazol dyes, Figure 4. The M-O equation produced accurate spectral matches and a more accurate dye concentration prediction than the K-M equation when tested with the different dyed textile fabric materials, Figure 5.

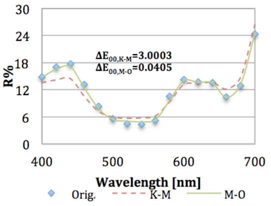

Figure 4: Predicted spectral reflectance curves for a plain-woven cotton fabric dyed with a mixture of red, green and blue Remazol dyes at 1%, 1% and 0.5% (o.w.f) concentrations, respectively.

The M-O equation accurately predicted target dye concentration and predicted a spectral match with an overall average colour difference of 0.61 (as compared to 1.85, 2.11, 1.74 and 0.61 for the K-M, Pineo, D-M and McDonald equations).

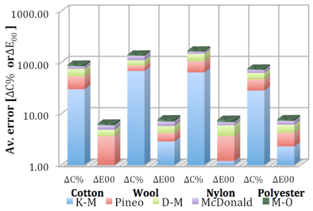

Figure 5: Dye recipe prediction performance comparison of the K-M based models for single shade dyed textiles.

The overall average error of predicted dye concentration was reduced from 47.67%, 25.98%, 25.15% and 14.64% (for K-M, Pineo, D-M and McDonald respectively) to 5.83% using the M-O equation.

4. CONCLUSIONS

The application of the M-O equation produces an almost perfect linearisation of the K/S-curves with the applied dye concentration at all wavelengths by optimizing the K/S-value using the M-O modification of the single constant K-M equation. The M-O equation accurately predicted the amount of dye to be applied to the dyebath to match the target shade reducing the error of dye concentration prediction by 60% compared to the original single constant K-M based equations. The M-O predicted spectral match performance of the target shade produced an overall average colour difference of 0.61, which was lower than the 1.85, 2.11, 1.74 and 1.07 observed from the original single constant K-M, Pineo, D-M and McDonald equations.

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Skin Color Analysis based on Pigments and Moisture Properties

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ABSTRACT

The principal factors that determine the human skin color are investigated using the surface spectral reflectance of human skin. In daily life, the skin color often changes owing to the variable moisture content in the stratum corneum (SC). We propose a new method for estimating the moisture properties (including the thickness of the SC, and the keratin concentration). We define a model equation representing the surface spectral reflectance of skin by considering the light transmission in the SC. By fitting the model euqation to the measured reflectances of skin, we estimate the moisture properties and the pigment concentrations. From the results of multiple linear regression analysis, we find that the b^* value of the $L^*a^*b^*$ chromaticity coordinates of the skin color is determined by not only the concentration of melanin pigment but also the SC properties.

1. INTRODUCTION

The quality of life, including fatigue and lack of sleep, affects the appearance and color of skin. Analysis of the skin color is useful for evaluating physical health. It is known that the principal pigments affecting the skin color are melanin and hemoglobin. The concentrations of these pigments vary little in daily life. However, a recent study (Takiwaki 1994) suggests that we must consider not only melanin and hemoglobin but also something other to evaluate the skin color. We thus focus on the moisture content in the SC, because the skin color changes as a result of daily actions such as washing the face. Although the moisture content in the SC should also be determining the skin color, to the authors knowledge, its effect has not yet been fully investigated.

In the present paper, we analyze the skin color based on the moisture properties and pigments in the skin, and determine the principal factors contributing to the skin color. First, we develop a method for estimating the pigment concentrations and moisture properties. In a previous study (Ohtsuki et al. 2012), a method was presented for estimating the concentrations of pigments (including melanin and hemoglobin) using the surface spectral reflectance of skin. Here, to predict the SC properties, we derive an equation representing the transmittance of SC. Thus, we define a new model equation representing the surface spectral reflectance from three moisture properties: the thickness, scattering coefficient, and absorption coefficient. The SC properties and pigment concentrations can be estimated by fitting the model equation to the surface spectral reflectance of skin.

Second, we estimate the above SC properties by fitting the model to the surface spectral reflectances measured from the skin of Japanese females. The principal factors contributing to the skin color are determined among the estimated parameters using the statistical technique of multiple linear regression analysis (MLRA). As a result, we can determine the b^* value of the $L^*a^*b^*$ chromaticity coordinates as an important factor for the Japanese skin color.

2. METHOD

2.1 Modeling the surface spectral reflectance of skin

Figure 1 shows the optical human skin model used to define the equations representing the surface spectral reflectance of skin. This model consists of fousr layers: the SC, the epidermis, the dermis, and the subcutaneous tissue (ST). Melanin pigment in the epidermis protects the skin from damage from the sun. The pigments in dermal blood vessels are oxygenated hemoglobin (oxy-Hb), deoxygenated hemoglobin (deoxy-Hb), carotene, and bilirubin. The light path for diffused light is depicted schematically in Fig. 1. The reflectances $R_e(\lambda)$ and $R_d(\lambda)$ and the transmittances $T_e(\lambda)$ and $T_d(\lambda)$ of the epidermis and the dermis are calculated using the scattering coefficients $S_e(\lambda)$ and $S_d(\lambda)$, and the absorption coefficients $K_e(\lambda)$ and $K_d(\lambda)$. The surface spectral reflectance of skin layer $R_{skin}(\lambda)$ is obtained by integrating the reflectances of three layers ($R_e(\lambda)$, $R_d(\lambda)$, and $R_h(\lambda)$) and transmittance of the SC $T_{SC}(\lambda)$.

In this paper, we dereve a new equation of the SC transmittance $T_{SC}(\lambda)$ using theree SC properties (including the thickness of the SC, and the keratin concentration). The SC transmittance $T_{SC}(\lambda)$ is assumed to change with the moisture content of the SC. To consider the optical effects of the SC, we calculated the scattering and absorption coefficients of the SC as shown in Fig. 2. We found that the absorption coefficient of the SC at low wavelengths range is higher than that at long wavelengths. This wavelength dependence is similar to that for the absorption coefficient of keratin, which is a protein in the SC. On the basis of Kubelka-Munk theory (Kubelka 1948), we define equations that represent the transmittance of the SC using the thickness of the SC and its keratin concentration. According to this theory, the transmittance of a layer that includes several pigments can be calculated from the thickness and the scattering and absorption coefficients of the pigments. The transmittance of the SC $T_{SC}(\lambda)$ is described as follows:

$$\begin{aligned}
T_{SC}(\lambda) &= \frac{b_{SC}(\lambda)}{a_{SC}(\lambda)\sinh\left(b_{SC}(\lambda)S_{SC}(\lambda)D_{SC}\right) + b_{SC}(\lambda)\cosh\left(b_{SC}(\lambda)S_{SC}(\lambda)D_{SC}\right)} \\
a_{SC}(\lambda) &= \left(S_{SC}(\lambda) + K_{SC}{'}(\lambda)\right) \Big/ S_{SC}(\lambda) \\
b_{SC}(\lambda) &= \sqrt{\left(a_{SC}(\lambda)^2 - 1\right)} \\
K_{SC}{'}(\lambda) &= K_{SC}(\lambda) w_{SC}
\end{aligned} \tag{1}$$

where $S_{SC}(\lambda)$ is the scattering coefficient of the SC, $K_{SC}(\lambda)$ is the absorption coefficient of the SC, and w_{SC} is the keratin concentration.

Next, we express the multiple reflection in the skin using the reflectance and transmittance of the epidermis, the dermis, and the SC. The equation for the surface spectral reflectance of skin $R_{skin}(\lambda)$ is then described as follows:

$$R_{\mathrm{skin}}(\lambda) = (1-k_1)(1-k_2)\frac{T_{\mathrm{SC}}(\lambda)^2 R'(\lambda)}{1-k_2 T_{\mathrm{SC}}(\lambda)^2 R'(\lambda)}$$

$$R'(\lambda) = R_{\mathrm{e}}(\lambda) + \frac{T_{\mathrm{e}}(\lambda)^2 R_{\mathrm{dh}}(\lambda)}{1-R_{\mathrm{e}}(\lambda) R_{\mathrm{dh}}(\lambda)}$$

$$R_{\mathrm{dh}}(\lambda) = R_{\mathrm{d}}(\lambda) + \frac{T_{\mathrm{d}}(\lambda)^2 R_{\mathrm{h}}(\lambda)}{1-R_{\mathrm{d}}(\lambda) R_{\mathrm{h}}(\lambda)} \qquad (2)$$

where $R_{\mathrm{dh}}(\lambda)$ is the light returned from the ST and the dermis, and k_2 is the internal reflectance.

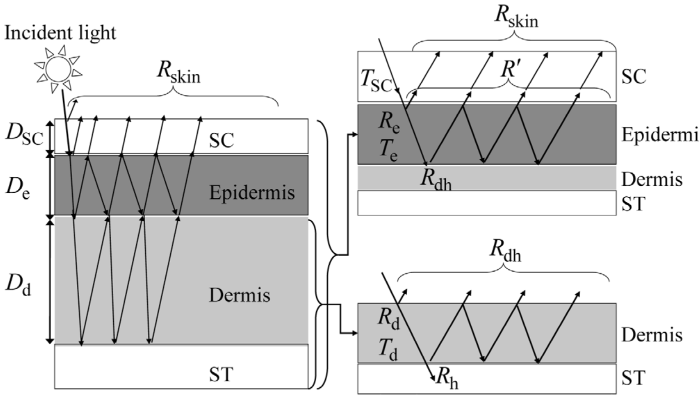

Figure 1: Optical skin model.

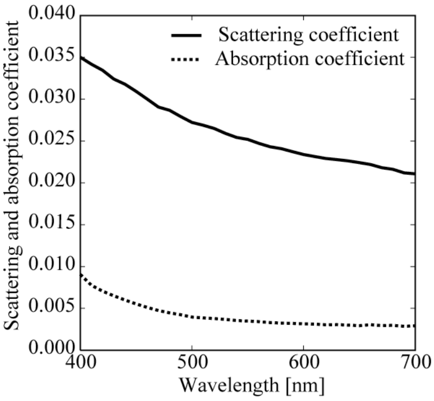

Figure 2: Scattering and absorption coefficients of the SC.

2.2 Parameter estimation

The unknown parameters are the concentrations of five pigments (melanin, oxy-Hb, deoxy-Hb, carotene, and bilirubin), the reflectance k_1, the thickness of the SC D_{SC}, the keratin concentration w_{SC}, and the thicknesses of the epidermis D_{e} and the dermis D_{d}. For the fitting computation, the reflectance and transmittance of the dermis are calculated by adjusting the concentrations of four pigments (oxy-Hb, deoxy-Hb, carotene, and bilirubin) and the thickness of the dermis. We determine the unknown parameters that minimize the root-mean square error (RMSE) between the fitted reflectance $R_{\mathrm{skin}}(\lambda)$ and the measured surface spectral reflectance of the the skin.

3. EXPERIMENTAL RESULTS

The pigment concentrations and moisture properties were estimated using the surface spectral reflectance from the skin of Japanese females. From the results, we determined the principal factors that contribute to the human skin color. First, the reflectances were measured in the visible wavelength range [400–700nm] using a spectrophotometer (CM2600-d, KONICA MINOLTA). The estimates of pigment concentrations and SC properties were obtained by the above estimation algorithm. Second, we performed MLRA to obtainn an equation that expresses the pridicted value (dependent variable) as a linear combination of several parameters (independent variables). In each MLRA, we specified the pridicted value in terms of the lightness $L*$ and the chromaticity $b*$ and $a*$. The estimates of pigment concentrations and SC properties were specified as independent variables.

The results of MLRA are summarized as follows:

1. The lightness L^* and chromaticity a^* of the skin color are determined by the concentration of melanin and hemoglobin, respectively.
2. The chromaticity b^* depends on three parameters: the melanin concentration, the SC transmittance $T_{SC}(\lambda)$, and hemoglobin concentration.
3. The skin color depends on the moisture content as well as the pigment concentration, in the sense that the SC transmittance increases with increasing moisture content.

4. CONCLUSIONS

In this paper, the principal factors that determine the human skin color were investigated using the surface spectral reflectance of human skin. First, we defined model equations that represent the multiple reflection ins the skin. A method was then devised for estimating the concentrations of pigments and moisture properties. Next, we estimated the pigment concentrations and moisture properties using the surface spectral refleactance data. From the results of MLRA, we found that the chromaticity b^* value could be determined by two factors: the melanin concentration and SC transmsittance.

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Estimation of Skin Color under Various Illuminants Using Spectrum Data

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ABSTRACT

Rapid development in virtual reality and visualization technologies makes it possible to produce numerous virtual simulation systems. In these types of systems, color representation is very important to reproduce the realistic result, and especially in virtual makeup simulation system, color representation is crucial because humans are very sensitive to skin color. Although CIELAB or CIEXYZ standard color spaces are widely used for color image processing, limitations in representing true color can occur because those are established from perceived colors by human perception under standard illuminant conditions (Jang 2013). To overcome these limitations, spectral reflectance can be used to analyze and represent true color information, where spectral reflectance represents color characteristics of a material and determines the specral distribution of reflected light that represent the color of the material (Mansouri 2008, Mansouri 2005). In this paper, we proposed a novel approach to predict and reproduce skin colors under various illuminants using spectrum data. The estimated result by using the proposed modeling method is compared to the pictures taken under actrual lightings, and the experimental result shows that the proposed method can satisfactorily estimate the perceived color of human skin when various illuminants are applied by using spectrum data.

1. INTRODUCTION

Color of an object can be determined by the characteristics of illuminants and objects. As such, if the illuminant color changes, the color of the object can be seen differently. As virtual makeup simulation which applies makeup effects to skin images has recently been gathering interests, there is a growing need to predict the skin color under various illuminants, because the appearance of skin color depends on the illuminant. However, it is difficult to predict the exact color values using only three channel color data such as RGB or CIELAB of illuminants and objects because the exact color characteristics cannot be applied. Therefore, in this paper, spectrum data, which uses higher dimensional data than 3 channel values, is used for analyzing the colors of illuminants and objects, and the observed color of objects under various illuminants is estimated by modeling the interaction between illuminants and objects using 31 dimensional spectrum data to achieve more exact and precise color information of illuminants and objects. Spectrum data, which is reflected energy values from the surface of objects as a function of wavelength, shows the color characteristics of the object which is perceived on human eyes where illuminant is reflected. In this paper, the measured spectrum data of illuminants is analyzed and the color change of the object under various illuminants is estimated by using 31 dimensional spectrum data from 400nm to 700nm.

2. METHOD

To predict the skin color under various illuminants, spectrum data of skin and illuminant is used for more exact color analysis. Here, 31 dimensional spectrum data from 400nm to 700nm with 10nm wavelength interval is used. Spectrum data of various illuminants is measured by using Konica Minolta spectroradiometer CS-1000, which is non-contact spectroradiometer. Various illuminants such as incandescent light (A), Cool White Fluorescent (CWF), Daylight, U30, and stage lights are used for the spectrum measurement. Figure 1 shows the measured spectrum data of 8 different illuminants.

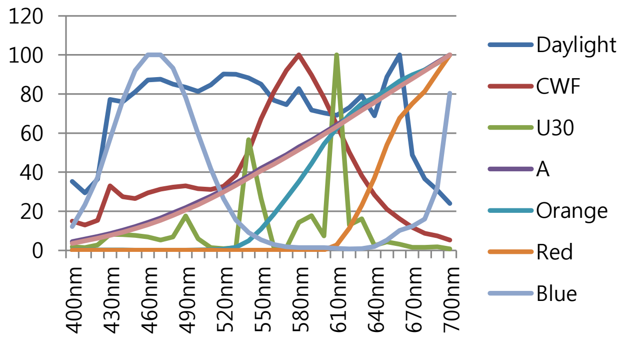


Figure 1: Measured spectrum data of various illuminants per wavelength.

The estimation process under various illuminants using spectrum data of skin and illuminant is shown in Figure 2. The spectrum data of illuminant is applied to the spectrum of skin color, and the color matching function is applied so that the estimation can generate the realistic result under various illuminants. The resulting spectrum data is achieved using input spectrum, illuminant spectrum, and color matching function.

$$EstimatedColorUnderIlluminant(\lambda) = input(\lambda) * illuminant(\lambda) * cmf(\lambda)$$

The resulting spectrum is transformed to XYZ tristimulus values, and these are transformed to RGB values for every pixel values of an image with facial skin.

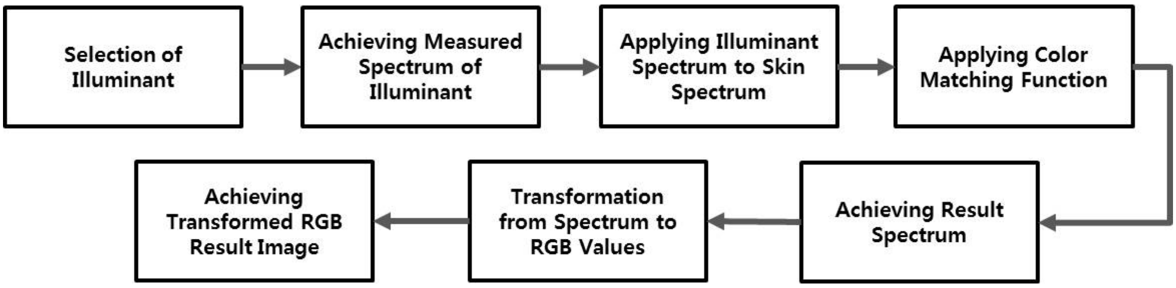
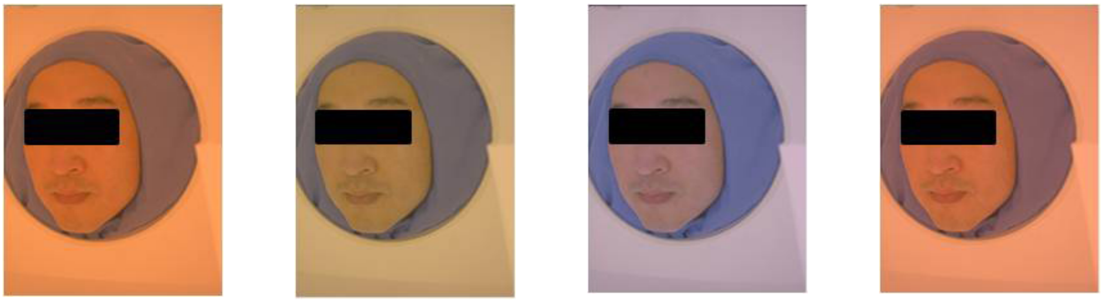


Figure 2: Flowchart illustrating the process of sample preparation.

3. RESULTS AND DISCUSSION

The experimental results using the proposed method is shown in Figures 3 and 4. Figure 3 shows the transformed facial images under incandescent light (A), Cool White Fluorescent (CWF), Daylight, and U30. The input facial images are pictures taken from the facial scanner developed to construct 3D facial model from captured images and apply virtual makeup simulation on the facial model (Lee 2012).



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

Figure 3: Transformed result of facial images under (a) incandescent light (b) CWF (c) daylight (d) U30.

Figure 4 shows the transformed facial images under various stage lights of halogen, orange, blue, and red stage light. For comparison, Figure 4 shows the photographs taken under four different types of actual stage lights. As shown in Figure 4, color values of the estimated result by the proposed method look almost the same to that of photographs taken under real illuminants, and we can see that the proposed method can properly estimate the result skin color under various illuminants.

Figure 4: Transformed facial images under four different stage lights and pictures taken under four actual stage lights.

4. CONCLUSIONS

In this paper, we proposed a novel method to predict and reproduce the skin color under various illuminant environments using spectral reflectance data. Experimental result shows that the proposed method can estimate and produce the satisfactory result of skin color under various illuminants using spectrum data.

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The Study of the Relationship among Preferable Skin Colors of Animation Films, Real Skin, and Color Chips

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ABSTRACT

Makeup expression on skin colors has become important even on animations, because many kinds of high definition media (smart phone, 2k/4k monitors and others) have developed recently. In this study, (1) the difference between preferred skin colors of the animation's facial images and the rectangle color chip without facial information, (2) the appearance of makeup skin colors on animation images, (3) the skin color appearance with point makeup colors on animation images, and (4) the comparison between the skin color appearance of animation facial images with point makeup and those of the mosaic pattern including skin color, were investigated. The results of the experiments showed that (1) preferable skin colors were affected by the existence of facial shape, (2) in spite of the animation's facial images, appropriate coloring could seem to be makeup face, (3) the skin color appearance was changed according to point makeup colors, and (4) the appearance of the skin colored mosaic patterns was almost unchanged with partial chromatic expression.

1. INTRODUCTION

Preferred skin colors play significant roles for color rendering, color reproduction, cosmetics and other many application fields. They have been so far studied from various view points, because preferable skin colors have unique properties which are different from other object colors (Bartleson 1962, Nishimura 1974, Hunt 2005). An amount of skin colors has been used in animations, however it has not been studied what kind of animation's skin colors are better.

2. EXPERIMENT

2.1. Evaluation of Preferred Skin Colors on Animation's Facial Images

The difference between preferred skin colors of the animation's facial images and the rectangle color chip without facial information was investigated (Figure 1). The purpose of this experiment is to evaluate the new method based on the spearman rank-order correlation coefficient to find preferred skin colors of animations.

Figure 1: Facial image (left) and rectangle pattern (right).

2.1.1. Stimuli

The printed facial images (Figure 1 left) with 60 kinds of skin colors, which were selected among the same Δa*b* interval 10 in the L*a*b* color space, were used as showing in Figure 2. The size of stimuli was 5.6 cm width and 4.9 cm height.

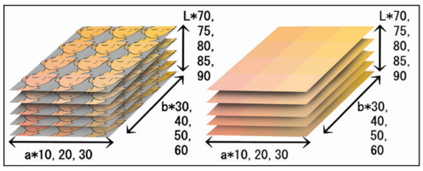

Figure 2: Stimuli in LAB color space.

2.1.2. Method

The observers (3 women, 25 to 30 years old) were asked to select the most preferable skin color from among 60 skin color stimuli, and made rank order until the worst or most awkward skin color at 1000 lx of D65 fluorescent lamp.

2.1.3. Analysis

Making rank order of preferable skin colors (Figure 3) is assumed that an observer selects preferable skin color according to the distance from his/her memory color. If they make the rank No.1, the point will be the nearest from the preferred memory color. On the contrary, the rank order of No.60 must be the farthest from the preferred point.

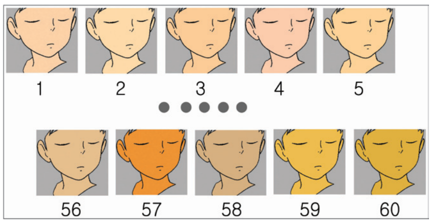

Figure 3: Example of rank-order.

In this experiment, the rank orders of No.49 - No.60 did not have any major influence on the rank correlation coefficient, therefore the ranks of No.1 - No.48 were used for the spearman rank-order correlation coefficient's calculation. The calculation method is as follows:

1) 516 points at the same interval 5 in the range (L* 65 to 90, a* -20 to 25, b* 15 to 70) were used for the calculation.
2) The assumption is that the color difference between the preferred memory color and each color point of 516 points is supposed to influence the rank order of the stimuli.
3) The color difference between the 516 points and the L*a*b* coordinate of the stimulus was calculated.
4) The spearman rank-order correlation coefficientwas calculated by the rank order of 516 points and the subjective rank order of the stimuli as shown in the following equation.

$$\rho = 1 - \frac{6\sum D^2}{N^3 - N}$$

D=difference between subject's rank of preferred skin color and 516 calculated rank

N=48(stimulus number)

2.1.4. Result

Figure 4 shows that the contour lines joined with the spearman rank-order correlation coefficient 0.5, 0.6, 0.7 and 0.8 each. These contours showed that the preferred skin color's point in the L*a*b* space could be estimated graphically in case of both the animation facial image and the rectangle color chip. As shown in Figure 4, the area for the rectangle color chips was larger than that of the animation facial images.

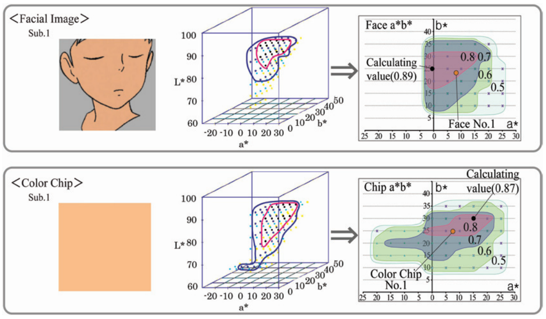

Figure 4: Contour maps according to rank-order.

2.2. Evaluation of the Animation Facial Images' Skin Color with Makeup Colors

We investigated the distinction between the makeup skin colors and the natural unpainted skin color among the animation facial images with various skin colors.

2.2.1. Stimuli

The woman's animation image was used. The size was 5.5 cm width and 8.5 cm height. 60 skin colors were selected at the same Δa*b* interval 10 in the L*a*b* space.

2.2.2. Method

The observers (4 women, 25 to 30 years old) were asked to select first 12 color stimuli which felt as best makeup skin colors, and choose next 12 color stimuli which felt as best natural (unpainted colors) from among 60 stimuli.

2.2.3. Result

Figure 5 shows the color ranges of the makeup colors and the natural skin colors. It is shown in Figure 5that both makeup colors and natural skin colors on the animation images were clearly different from the real skin data (Shiseido 123 natural skins and makeup skins) of SOCS (Color gamut of Standard Object Color Spectra Database). Especially, the makeup colors and the natural skin colors had got much higher lightness colors than real skin colors in case of the animation images.

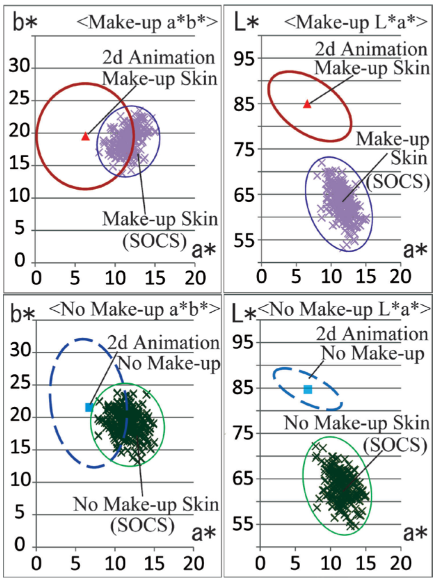

Figure 5: Comparisons between animation facial image and real skin color (make-up, unpainted natural skin color).

2.3. The Appearance of the animation facial skin colors with point makeup

Chromatic point makeup (lip, eye shadow, and cheek) is supposed to influence the appearance of skin colors on animations as well as those of real makeup faces. We investigated the skin color appearance of the animation facial images with chromatic point makeup.

2.3.1. Stimuli

Four types of point makeup images (pink, pearl, brown, and pink-brown) and one unpainted skin image were used as stimuli. The size was 5 × 21 cm (width × height).

2.3.2. Method

The observers (4 observers participated) made color matching between the middle of forehead's skin color in the stimuli and the Munsell color chart at 1000 lx of D65 fluorescent illumination as shown in Figure 6.

2.3.3. Result

Figure 7 shows the area of matched Munsell colors on an a*b* diagram. The solid black circles were the measured values of the middle of forehead's skin color in the stimuli. It was clearly shown that the skin color appearance of the stimulus was influenced by the chromatic point makeup (namely the skin color of the facial image with brown point makeup appeared yellowish, and those with pink appeared reddish). The results suggest that skin appearance of animation images would be changed by partial coloring.

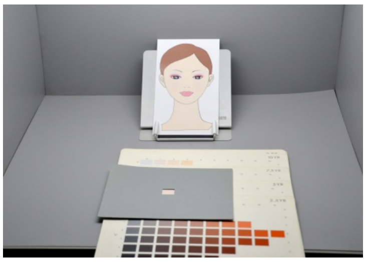

Figure 6: Color matching.

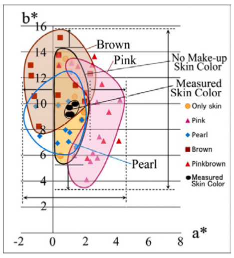

Figure 7: Results of skin color appearance according point make-up.

2.4. The relationship between the animation facial image with point makeup and the mosaic color pattern including skin color

To make clear the influence of chromatic point makeup on an animation facial image in terms of skin color appearance, we investigated the relationship between the animation facial image with point makeup and the mosaic color pattern including skin color.

2.4.1. Stimuli

Eleven colors (red, magenta, pink, orange, yellow, green, cyan, blue, violet, brown, and grey) were used as point makeup color on the animation facial images (left of Figure 8 is the same stimuli as the experiment 2.3). We used the mosaic color pattern with the same 11 colors as the facial ones' (right of Figure 8).

2.4.2. Method

The procedure of subjective color matching was the same as those of the experiment 2.3.

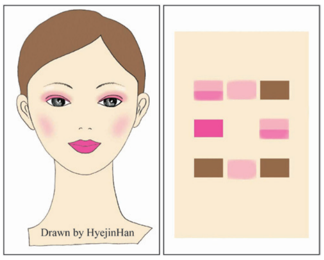

Figure 8: Point make-up facial image and mosaic color pattern.

2.4.3. Result

Figure 9 shows the skin color appearance with the various chromatic point makeup on an a*b* diagram. The results suggested that the range of appearance with chromatic partial expression on the facial image was different from those of the mosaic color pattern. In addition, the sizes for the facial image were bigger than those of the mosaic pattern. It suggests that the influence of the partial coloring will be more distinguished on the facial image than the mosaic pattern without the facial information.

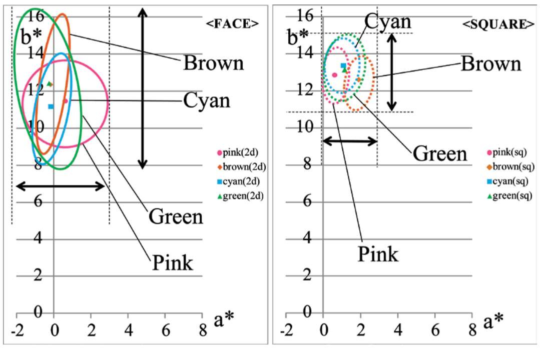

Figure 9: Results of partial coloring.

3. CONCLUSION

The preferred skin color could be graphically estimated, using the rank order correlation analysis. In spite of animations' facial image, appropriate coloring could seem to be makeup face. The influence of partial chromatic expressions is more distinguished on a facial image than a mosaic pattern without any facial information.

ACKNOWLEDGEMENTS

We thank to Konica-Minolta Corporation for supporting the measurement instruments.

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A Method to Determine the Minimum Number of Colour or Texture Measurements in Gonio-apparent Panels

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ABSTRACT

For gonio-aparent panels it is important to measure both colour and texture at different measurement geometries. Nowadays, there is only an instrument, the BYK-mac multiangle spectrophotometer, which is able to simultaneously measure six colour measurement geometries and three ones for sparkle. On the other hand, there are studies that recommend a minimum number of measurements to characterize solid colour samples with texture. However, no previous studies give recommendations to the minimum number of measurements needed to characterize the colours with special-effect pigments.

Our hypothesis is that colour panels incorporating special-effect pigments in their colour recipes will require a minimum number of measurements higher than in solid pigments panels. The objective of this work is to check our hypothesis using a BYK-mac. Therefore, we made a study of the minimum number of necessary measurements, both colour and texture, to optically characterize three types of samples (solid, metallic and interference). The parameters studied were the colourimetric values L*a*b*, which characterize the colour sample, and sparkle values SG that characterize the directional texture of the samples.

For the study, thirty samples were chosen for each type of colour recipe (a set of ninety samples). The colours were selected to cover all possible colour space. Twenty measurements were made for each sample, from which it was calculated and represented the cumulative mean value for L*, a*, b* and SG. Finally, we determined the minimum number of measurements when the cumulative mean value become constant.

The results show that the minimum number of measurements depends on both colour and texture of the sample as well as the measurement geometry.In addition, it also seems that the number of measurements depends on the lightness of the sample. However, this new hypothesis will be discussed more thoroughly in a future work.

1. INTRODUCTION

For gonio-apparent panels is important to measure both colour and texture at different measurement geometries. Nowadays, there is only an instrument, the BYK-mac multi-angle spectrophotometer, what is able to simultaneously measure six colour measurement geometries and three ones for sparkle. This device characterises colour by measuring to -15º, 15º, 25º, 45º, 75º and 110º from the specular angle. Following CIE standards these geometries are written as: 45ºx:-60º, 45ºx:-30º, 45ºx:-20º, 45ºx:0º, 45ºx:30º and 45ºx:65º, respectively. In the same way, it characterises sparkle by measuring in the perpendicular direction to the sample and with an illumination direction of 15º, 45º and 75º. Following CIE standards these geometries are written as: 15ºx:0º, 45ºx:0º and 75ºx:0º, respectively.

On the other hand, there are studies that recommend a minimum number of measurements to characterise solid colour samples with texture (Prieto, et. al. 2010). However, no previous studies give recommendations to the minimum number of measurements needed to characterise the colours with special-effect pigments.

Our hypothesis is that colour panels incorporating in their colour recipe special-effect pigments (Pfaff 2008, Klein 2010) will require a minimum number of measurements higher than in solid pigments panels. The objective of this work is to check with the BYK-mac our hypothesis. To do this, we made a study of the minimum number of necessary measurements, both colour and texture, to optically characterise three types of samples (solid, metallic and interference). The studied parameters were the colorimetric values L*a*b*, which characterise the colour, and sparkle values S_G, which characterise the texture of the samples.

2. METHOD

2.1 Sample Selection

For the study, thirty samples were chosen for each type of colour recipe. The colours were selected to cover all possible colour space, as shown in next figure:

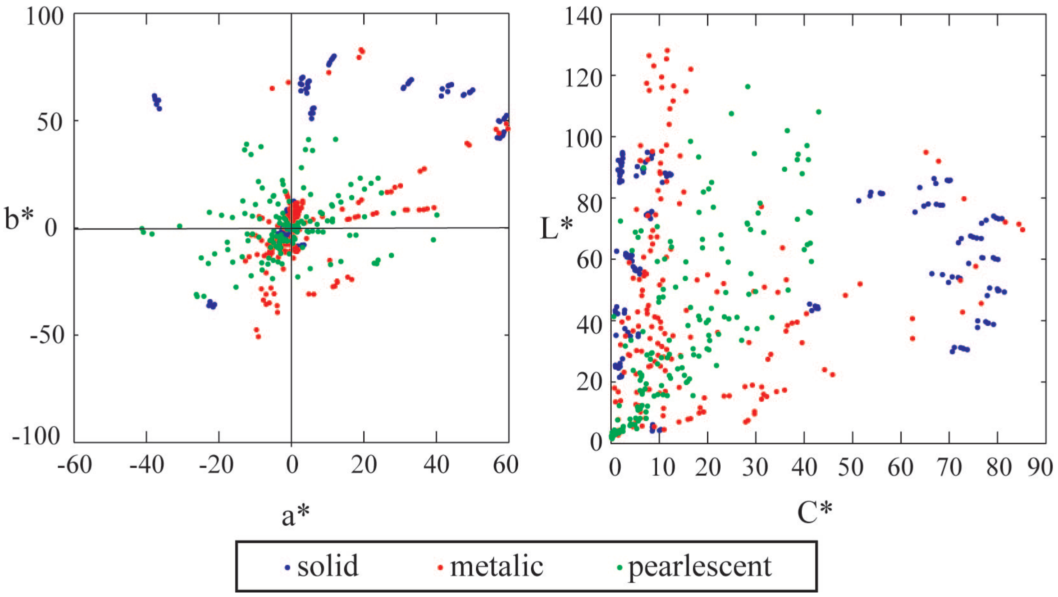

Figure 1: Sample selection represented in the chromaticity diagram.

Twenty measurements were made for each sample, from which was calculated and represented the cumulative mean value for L^* a^* b^* and S_G. We determined the minimum number of measurements with the following statistical formula (Triola, 2000) for stablising an objective method to determine the minimun number of measurements become constant:

$$n = \frac{\mathbf{N}\boldsymbol{\sigma}^2\mathbf{Z}^2}{(N-\mathbf{1})e^2 + \boldsymbol{\sigma}^2\mathbf{Z}^2} \qquad (eq.\mathbf{1})$$

where *N* is the population size, s is the standard deviation of the population, *Z* is the value obtained by confidence levels (equivalent to 1.96 for a confidence interval of 95 %) and *e* is the acceptable limit of sampling error that assume was 1 units.

Finally we obtained a table for each type of pigment with the minimum number of colour measurements for individual sample and each measurement geometry and other table with the minimum number of sparkle measurements for individual sample and each measurement geometry.

2.2 Statistical analysis

Because the number minimum of measurements did not follow a normal distribution (in fact, for some geometries we had a constant set values), we cannot use parametric statistical studies. In this case, we think the box-plot is an efficient way to get an overview of quantitative data. The bottom and top of the box are always the first and third quartiles, and the band inside the box is always the second quartile (the median). The ends of the whiskers represent the minimum and maximum of all of the data. Any data not included between the whiskers should be plotted as an outlier with a dot, small circle, or star.

3. RESULTS AND DISCUSSION

In the next figures we show the box-plot of the minimum number of colour and sparkle measurements for the set of thirty samples with solid pigments, for the set of thirty samples with metalic pigments and for the set of thirty samples with pearlescent pigments.

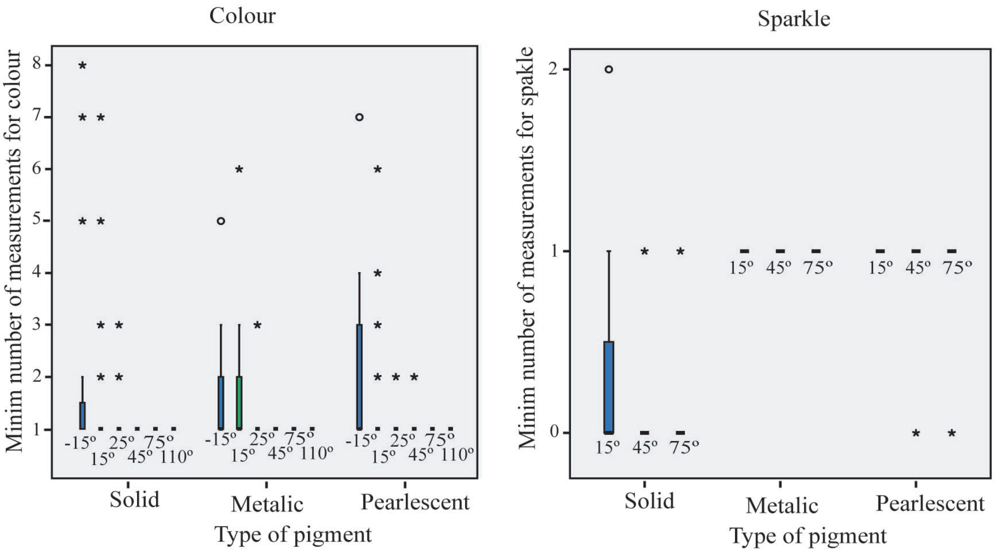

Figure 2: Box-plot of minimum number of colour (left) and sparkle (right) measurements in samples with different type of pigments for different geometry measurements.

When we can try to characterise colour, the results show that an unique measurement is necesary to determine the colour for four geometries further to specular angle (25º, 45º, 75º and 110º from specular angle), independently of type of pigment.

On the other hand, for two geometries closer to specular angle, a larger number of measurements is necessary to determine the colour for all type of samples. Although, a greater number of measurements is necesary to determine the colour for metallic samples (three measurements) that for solid samples (two measurements) and ever greater number of measurements is necessary to determine the colour for pearlescent samples (four measurements).

When we can try to characterise sparkle, the results show an unique measurement is necesary to determine the sparkle independently of type of pigment or measurement geometry.

More specifically, the results show that for solid samples none measurement is necesary, which is consistent with the fact that solid samples should not have sparkle. For solid and pearlescent samples one measurement is necessary.

In addition, although the partial dependence of the minimum number of measurements with L*a*b* are not shown in this work, it also seemed that the number of measurements will depend on the lightness of the sample. However, this new hypothesis will be discussed more thoroughly in a future work.

4. CONCLUSIONS

In particular, we can conclude that for characterization colour, the results show an unique measurement is necessary to determine the colour for four angles further to specular angle (25º, 45º, 75º and 110º from specular angle), independently of type of pigment. For two geometries closer to specular angle (-15º and 15º) two measurements are necessary for characterization colour of solid samples, three measurements for metallic samples and four measurements for pearlescent samples.

When we can try to characterise sparkle the results show that for solid samples none measurement is necesary, which is consistent with the fact that solid samples should not have sparkle. For solid and pearlescent samples only one measurement is necessary.

ACKNOWLEDGEMENTS

The Ministry of Economy and Competitiveness for the concession of the coordinated project "New developments in visual optics, vision and color technology" (DPI2011-30090-C02), and the grant FPI BES-2012-053080. Francisco Javier Burgos also thanks the Generalitat of Catalunya grant a pre-doctoral fellowship.

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Custom Colour Reference Target for Chronic Wound Photography

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ABSTRACT

This paper addresses the problem of colour constancy in chronic wound photography. It investigates the possibilities of colour accurate digital imaging of chronic wounds and discussing the practical considerations for using digital images as reliable photo documentation and source for automated wound image analysis. The problem is how to achieve a consistent and accurate colour reproduction of wounds captured under realistic conditions with different digital cameras and various lighting conditions. In order for a wound images to be useful for clinical evaluation, they need to be colour calibrated and independent of camera settings and illumination. This device-independent colour reproduction can be achieved by means of a calibrated colour reference target. For this purpose a custom colour target was developed, used and tested. To evaluate the colour correction in real conditions, the custom target was captured together with the standard Macbeth ColorChecker during a patient examination in three different clinics. Validation of color correction by custom target was carried out by calculating the colour errors and comparing against the standard target. Another validation was performed by analyzing original wound images and images corrected using custom and standard colour reference target using application for wound image analysis and consulting clinician to compare results.

1. INTRODUCTION

Digital colour imaging in medicine has been the subject of many studies and researches (Chulhyun 2008), but it has not yet become a routine in daily clinical practice in Croatia. However, some clinics have started to use the commercially available digital cameras in wound care as an acceptable and affordable tool for assessment of human wound healing process. But the problem is that un-calibrated digital images of wounds can serve only for documentation purposes. They are inaccurate and not reproducible, and thus unsuitable for medical evaluation (Rennert 2009). The value of digital photography in wound care lies in the ability to achieve repeated views over time, adding objective visual confirmation to the written record, and can provide evidence of the wound healing process and appropriate wound care (Poucke 2010). To be able to use digital photography in such a manner, some kind of calibration is required. The main aim of this research was to create a method for ensuring reproducible colour content of digital images independent of camera settings and illumination changes. Proposed metod includes the custom colour reference target and an automatic colour calibration using ICC profiles. In future work an automatic colour calibration algorithm will be developed.

2. METHOD

2.1 Custom colour reference target development

Medical application puts special requirements on colour reference target. Although not necessary being sterile since it is not placed directly onto the wound, it should be disposable. It should also be small enough to be practical to handle and position near the wound. Beside colour samples the ruler is also incorporated in the target.

Colour target consists of fourteen colored samples; four samples represents a grey ramp, following three process colours (C, M, Y) and three secondary colours (R, G, B). Those samples are made according ISO 12647-2 standard. Four colors-of-interest specific for chronic wounds are incorporated in target. They are selected from set of fifty different wound photographs. Wound expert manually marked different tissue types on each photograph. For each of four tissue types mean value of all colour samples is selected as reference colour and included into the custom target. Specific colors are shown in Table 1. While it would be ideal to print those samples with spot colors, it was necessary to meet the requirement of low cost production. Target was printed on a calibrated inkjet color printer Epson Stylus Pro 9900 using Swiss Barier Photo Mat paper. Printed target was measured with Eye-One Pro spectrophotometer under the D50 illuminant.

Table 1: Specific colours representing four tissue types.

Wound tissue types	**L**	**a**	**b**	**colour**
Granulation	43.76	46.04	27.83	🟥
Fibrin	59.08	10.88	18.87	🟫
Fibrin layer	47.21	34.49	22.62	🟥
Necrosis	24.49	-0.12	0.31	⬛

2.2 Digital image capture

For digital image capture 35mm digital SLR Canon EOS 350D with zoom lens was used. The images were stored in raw format to avoid any in-camera colour processing. Flash was not used because it may obscure essential details in the glare of moist surfaces. If necessary, an external bounce flash or ring flash would be a better solution than built-in flash, but they are expensive and not common in practice. The most difficult variable to control was the lighting in clinics and the patient's position when photographing wounds. In this study we include three different outpatient clinics for wound care. All clinics had the same light source commonly used in hospitals - fluorescent lamps. In two clinics there was a large window with white protection against daylight. Two clinics have white walls, but one had an orange wall. Figure 1 illustrates the environment of these clinics.

Figure 1: Three outpatient clinics.

While shooting the camera was held perpendicular to the wound to avoid perspective distortion. There are some cases when this is not possible, like imaging of circumferential wounds (leg, heel, toe, elbow and ankle). Custom and standard colour targets were placed in the same focal plane as the wound. Illumination in the field of view was kept as uniform possible. As a background, common practice is to use the sterile green cloth, but as this colour can affect the colours of surrounding, it would be better to use the sterile white sheet. The special care was taken to minimize any lighting flare.

2.3 Colour correction method

Raw files (12 bits) from camera were converted using Adobe Photoshop CS3 Raw converter (using camera settings) and saved in uncompressed TIFF format in RGB mode. Images of targets were then supplied to the ProfileMaker 5.0 software, which relates camera RGB signals to measured CIELAB values from target, to build a CLUT based transformation structure. Image colour correction was performed in Matlab using ICC profile generated for developed custom colour target.

3. RESULTS AND DISCUSSION

Colour correction accuracy was evaluated by comparing measured colour values at standard Macbeth ColorChecker and colour values acquired from original and corrected photographs. Table 2 represents colour difference ΔE values for photographs taken at three different clinics. In all cases ΔE_{ab} is signficantly reduced at corrected photograph. On Figure 2 improved colour reproduction is obvious on corrected image.

Table 2: ΔE_{ab} comparison of original and corrected photographs.

	Clinic 1		Clinic 2		Clinic 3	
	Orig.	Corr.	Orig.	Corr.	Orig.	Corr.
Median (ΔE_{ab})	27.19	11.35	23.52	9.61	32.44	9.22
Mean (ΔE_{ab})	26.71	13.14	23.87	10.49	33.12	8.05
Min (ΔE_{ab})	15.86	3.21	15.61	2.03	18.28	1.16
Max (ΔE_{ab})	35.81	35.91	36.69	18.43	51.60	16.31
σ (ΔE_{ab})	5.66	7.85	5.62	5.27	9.16	3.97

Figure 2: Original and corrected digital image.

Quality of colour correction is further tested by analyzing wound photographs using WoundManager software for chronic wound analysis and healing process assessment (Antonic 2012). Figure 3 represents tissue classification for original and corrected image. Classification accuracy is significantly improved for corrected photograph, which is verified by clinician.

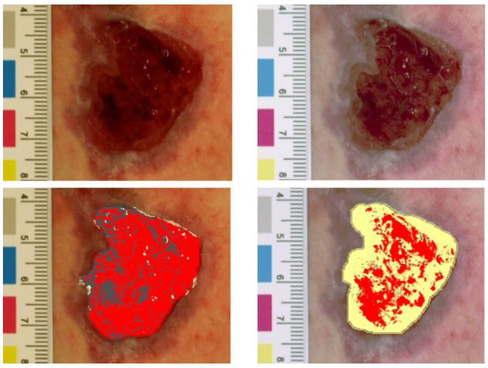

Figure 3: Tissue classification (original image - left, corrected image - right).

4. CONCLUSIONS

The results of this research have proved that it is possible to calibrate the images taken with commercially available digital camera independently of lighting conditions. Instability in colour rendering could be significantly reduced by using a simple and inexpensive colour target in the field of view when photographing wounds. This could ensure the image quality necessary for reliable assessment of wound healing process.

ACKNOWLEDGEMENTS

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Creation of Colour Chart Database of Disaster Victim's Skin: Measurement of Quasi-skins in Shock and Congested State by Healthy Young Subjects

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ABSTRACT

Our research aims to perceive the real visual environment for rescue activity and emergency medication in night time, to extract negative factors of lighting and visual objects for rescue and medical staffs, and to point out important problems to create more effective rescue and medical care at the disaster areas in the future. This paper reports collecting the spectral reflectance data and creating the colour chart database of quasi-skins in shock and congested state by healthy young subjects, in order to determine the visual conditions of disaster victim's skin under a situation like buried in rubble.

1. INTRODUCTION

Every year we see many disasters occur in various nations and regions. It is widely known that response time for saving people alive is within 72 hours (Yamane 2005), so rescue teams operate around the clock. Especially in night time, only limited light source is available in disaster sites, which makes rescuers observe situations significantly more difficult (Yoshimura 2010). Recent development of LED technology can help, but some medical relief workers warn LED lights make it difficult to for example observe skin of victim, as LED has distinct spectral distribution from incandescent or florescent lamps. Our research therefore aims to perceive the real visual environment for rescue activity and emergency medication in night time, to extract negative factors of lighting and visual objects for rescue and medical staffs, and to point out important problems to create more effective rescue and medical care at the disaster areas in the future.

We already reported the questionnaire survey results on visual problems experienced by the disaster relief workers (Akizuki 2011). Many rescue sites where the respondents work at night are routine types like fire, not non-routine types like major earthquakes. Regardless of the different site types, main problem of personal compact lighting equipment is the lack of luminous flux level. The rescue workers demand wider range of irradiation, and some of them feel bad colour rendering properties. Moreover we measured the conditions of compact lighting equipment used in the actual disaster sites (Akizuki 2011). There are great individual differences of light intensity among all equipment samples, and rescue workers are stumped about selection of their lighting equipment, so it suggests need for rule regarding expression in the brochure. Our results reveal that the rescue workers are well aware of those serious visual/lighting problems as they are on the front line of disaster relief efforts.

In order to determine the visual conditions of disaster victim's skin under a situation like buried in rubble, this paper reports collecting the spectral reflectance data and creating the colour chart database of quasi-skins in shock and congested state by healthy young subjects. Moreover the colour differences between normal healthy skins to shocked/congested skins are calculated.

2. EXPERIMENT

The skin-colour of the critical patient in shock state changes over time widely. Therefore we recreate the disaster victim's skin which is the most prominent symptom in shock with the distal ischemia portion of a healthy young subject.

2.1 Subjects

Subjects were selected from Japanese students in the University of Toyama: 22 women with an average age of 22.0±4.4, and 7 men of 21.4±1.5. They were measured their blood pressure (by M-7080IT, Omron), heart race and the percentage saturation of oxygen (by N-560, Nellcor), and checked for good health before the experiments. All subjects wore a thin shirt with long sleeves in the experiments.

2.2 Measurement Site

We set three skin states: normal healthy skin, ischemia-shocked skin, and reperfusion-congested skin by a spectrophotometric colorimeter (CM-2600d, Konica Minolta). The measurement site in this experiment is the base between first metacarpal and second metacarpal on back of a subject hand (Figure 1), which is easy to recreate skin in shock state by ischemia of the upper extremity.

Figure 1: Experimental scenery.

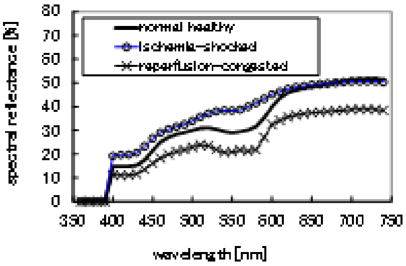


Figure 2: Typical result of spectral reflectance at three skin state.

2.3 Procedure

The procedure is outlined below.

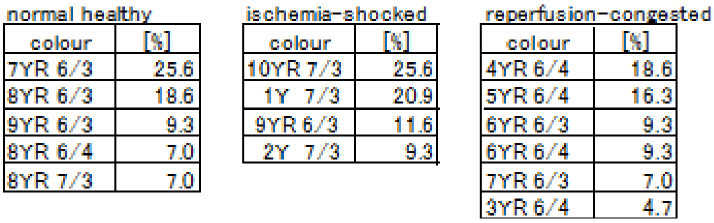
1. Before experiment: a subject sits a chair quietly for 60 seconds, put the back of his hand on a table and the normal healthy skin of the subject hand is measured.
2. After the experiment started (0 second): the subject raises his upper arm, keeps the pose for 90 seconds. The upper arm is wrapped a sphygmomanometer cuff (UM-101, AND).
3. After 90 seconds: the upper arm is brought to 200mHg pressure by the cuff, and keeps the pressure for 60 seconds. The internal bleeding is not appeared.
4. After 150 seconds: the subject slowly pulls his arm down on the table, and keeps the pose for 60 seconds.

5. After 210 seconds: the ischemia-shocked skin of the subject hand is measured.
6. After 240 seconds: the pressure is reduced to 0mmHg, and the reperfusion-congested skin of the subject hand is measured at 10 seconds intervals for 240 seconds.

3. SPECTRAL REFLECTANCE OF QUASI-SKINS

Figure 2 shows a typical result of spectral reflectance at three skin state of a representative subject; the normal healthy skin, the ischemia-shocked skin, and the reperfusion-congested skin. The spectral reflectance of the ischemia-shocked skin is whitened and higher as compared with normal skin, especially within a range of 450-600nm. On the other hand, the spectral reflectance of the reperfusion-congested skin is wholly lower than other skin state. This tendency is applicable to many subjects.

Table 1: Munsell Colour Chart Results at Three Skin States (N=43).



normal healthy		ischemia-shocked		reperfusion-congested	
colour	[%]	colour	[%]	colour	[%]
7YR 6/3	25.6	10YR 7/3	25.6	4YR 6/4	18.6
8YR 6/3	18.6	1Y 7/3	20.9	5YR 6/4	16.3
9YR 6/3	9.3	9YR 6/3	11.6	6YR 6/3	9.3
8YR 6/4	7.0	2Y 7/3	9.3	6YR 6/4	9.3
8YR 7/3	7.0			7YR 6/3	7.0
				3YR 6/4	4.7

4. MUNSELL COLOUR CHART OF QUASI-SKINS

As values attained by the colorimeter of Munsell colour chart comes as decimal number, we round off them into integer number. Table 1 shows the Munsell color chart results of two thirds of all data under the light source D65. As compared with the normal healthy skin, the ischemia-shocked skin tends to be more yellowish and have higher brightness, and the reperfusion-congested skin tends to be more reddish and have higher saturation. Getting numbers of Munsell colour chart in three skin state are 16 in normal healthy, 16 in ischemia-shocked, and 21 in reperfusion-congested.

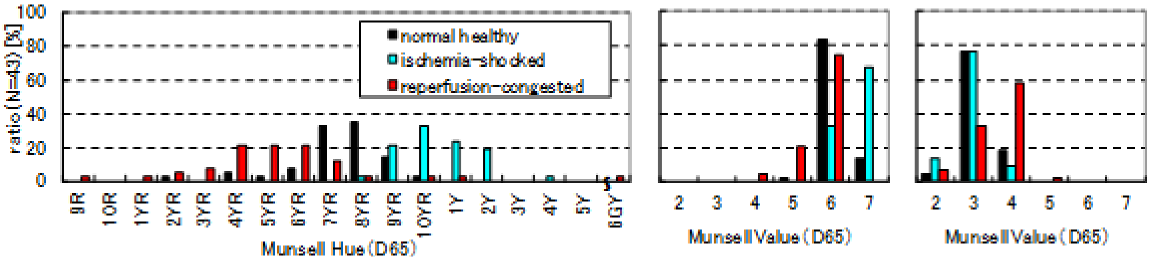


Figure 3: Frequency distribution of Munsell results.

Figure3 shows the frequency distribution assorted by Munsell Hue, Munsell Value, and Munsell Chroma. Changes by three categories of skin (“normal”-“shocked”-“congested”) are as follows; “7&8YR”-“above 9YR”-“below 6YR” by Munsell Hue, “6”-“7”-“below 6” by Munsell Value, and “3”-“3”-“4” by Munsell Chroma.

5. TRISTIMULUS VALUE YXY OF QUASI-SKINS IN SHOCKED AND CONGESTED STATE

Figure 4 shows the tristimulus value Yxy at three skin states under the light source D65. Fig.4-1 shows the cumulatice frequency distribution of Y. The highest percentile value (10-

50-90%) is of the ischemia-shocked skin (32-38-42), and the lowest is of the reperfusion-congested skin (21-28-33). Figure 4-2 shows the chromaticity coordinate xy. The reperfusion-congested skin is more reddish than the normal healthy skin, and the ischemia-shocked skin is more yellowish than the normal one.

6. COLOUR DIFFERENCE OF QUASI-SKINS

Figure 5 shows the cumulative frequency distribution of ΔE^*_{ab}(D65), which is the colour difference of the ischemia-shocked skin and the reperfusion-congested skin against normal healthy skin. The result of the reperfusion-congested skin has some large color difference, but 80% of all data is under 9. The percentile value (10-50-90%) of the ischemia-shocked skin is (3.7-6.1-8.8), and of the reperfusion-congested skin is (3.0-5.1-12.6).

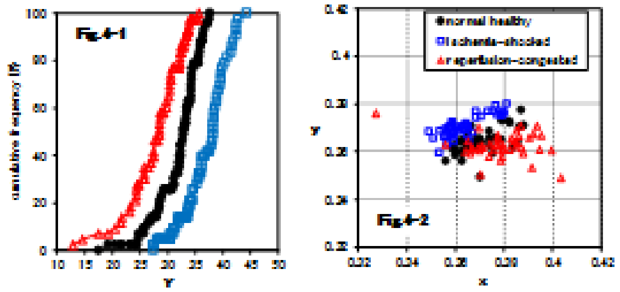


Figure 4: Yxy Results at three skin.

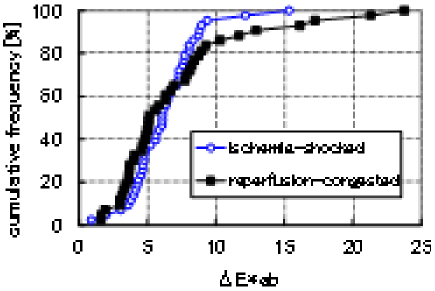


*Figure 5: Cumulative frequency distribution of ΔE*ab.*

7. DISCUSSIONS

This paper reports that normal healthy skin and shocked/congested skin have limited color difference. When the color rendering of light source is not enough under disaster environment, the color difference is further limited, making right judgement of injuries and diseases especially difficult. We conducted quantitative analysis of quasi-state of healthy young subjects' skin. It is necessary to collect real patient data to verify our results.

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Systematic Error Impact in Colour Determination of Special Effect Coatings from sBRDF Measurement

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ABSTRACT

How a systematic error in spectral Bidirectional Reflectance Distribution Function (sBRDF) measurement affects colour determination of special effect coatings is studied in this work. From experimental sBRDF measurements of three special effect coatings (Arctic Fire, Lapis Sunlight and Light Yellow & Solaris Red), other spectral BRDFs were simulated by adding to the measurement a proportional systematic error ranging from 0.1 % to 10 %. Afterwards, the colour differences between the simulated sBRDF and the experimental sBRDF were calculated in CIELAB space. The parameters lightness difference (DL^*), total colour difference (DE_{ab}^*), chroma difference (DC_{ab}^*), hue angular difference (Δh_{ab}), and hue difference (DH_{ab}^*) were evaluated for a combination of incidence angle (θ_i) and viewing angle (θ_s) within the incidence plane, from 0º to 70º every 10º. It was observed that systematic errors in sBRDF lead to significant changes in L^*, E_{ab}^* and C_{ab}^*, whereas h_{ab} and H_{ab}^* can be considered negligible.

1. INTRODUCTION

If spectral Bidirectional Reflectance Distribution Function (sBRDF) of an object is affected by a systematic error that doesn't depend on the wavelength, how the error modifies the result of its chromaticity coordinates? The answer depends on the spectral distribution of the sBRDF of the material itself. The study of this effect has been carried out for three special effect coatings and quantified taking into account parameters such as lightness difference (DL^*), total colour difference (DE_{ab}^*), chroma difference (DC_{ab}^*), hue angle difference (Δh_{ab}) and hue difference (DH_{ab}^*) in CIELAB space for a 10º observer (CIE 1964) and standard illuminant D65.

2. METHOD

Three coatings were used: Colorstream® T20-02WNT Arctic Fire which shows a colour shift from subtle turquoise through brilliant silver to metallic red hues (Merck) (Figure 1, Sample 1); Colorstream® T20-04WNT Lapis Sunlight which shows a colour shift from gold through elegant silver green to deep blue (Merck) (Figure 1, Sample 2) and Xillaric® x0428 Light Yellow & Solaris Red (prototype, Merck) which shows a colour shift from yellow to green (Figure 1, Sample 3).

The experimental sBRDF was measured, in the incidence plane, with the Spanish goniospectrophotometer (GEFE) (Rabal et al. 2012). The measurement of the distribution was carried out by varying incident polar angle (θ_i) and viewing polar angle (θ_s) between 0º and 70º every 10º. Moreover, incident azimuthal angle (φ_i) was kept fixed in 0º whereas viewing azimuthal angle (φ_s) takes two positions: 0º and 180º. q is defined respect to the coating's normal.

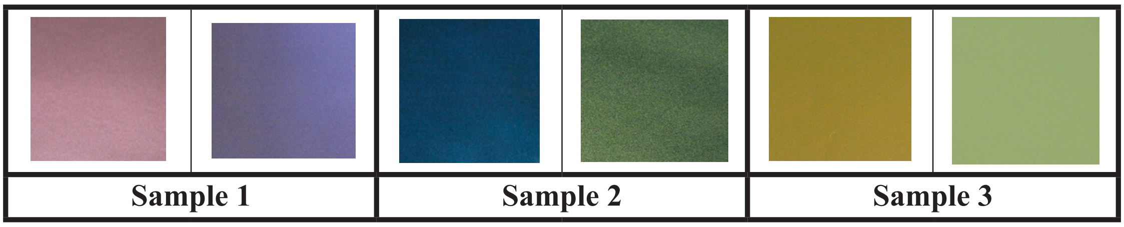

Figure 1: Pictures of the samples in two different orientations. Sample 1: Arctic Fire; Sample 2: Lapis Sunlight; Sample 3: Light Yellow & Solaris Red.

From experimental sBRDF, other spectral BRDFs were simulated by adding a proportional systematic error to the measurement between 0.1 % and 10 %. Afterwards, the chromaticity coordinates in CIELAB for the standard observer CIE 1964 and standard illuminant D65 were calculated for each spectral distribution. Then chromatic differences between the simulated spectrum and its corresponding experimental one (reference) were computed (Schanda 2007:86-87) ($\Delta = \xi_{\mathrm{Simulated}} - \xi_{\mathrm{Reference}}$, where ξ is the given chromatic attribute).

3. RESULTS AND DISCUSSION

To analyse the results, an average value and its corresponding standard deviation are calculated from the differences in every chromatic attribute, so that the average value represents the sBRDF (a given systematic error) and the standard deviation indicates how much that chromatic difference varies within that sBRDF. Figures 2 to 4 show these values for the three samples as a function of the amount of systematic error. Top graphs indicate the change of the average value of a given chromatic attribute, while the bottom ones show the variation of the standard deviation of those mean values.

Comparing the lightness differences for these three special effect coatings, a systematic error of 5 % resulted in DL^* between -1.90 and -1.17, while a 10% error resulted in DL^* between -3.88 and -2.39 (Figure 2, top-left). Clearly, Light Yellow & Solaris Red coating presents the highest DL^*, although it is much more independent on the measurement geometry than the other two coatings (Figure 2, bottom-left), since it has got the lowest standard deviation values. The total colour difference, DE_{ab}^*, increases with the systematic error: Values between 1.2 and 2 for 5% error, and between 2.5 and 4.1 for 10 % (Figure 2, top-right). Light Yelow & Solaris Red has got the highest differences as for DL^*.

The higher systematic error, the higher absolute value of the chroma difference, $|DC_{ab}^*|$ (Figure 3): Systematic errors of 5 % and 10 % resulted in a DC_{ab}^* ranging from -0.66 to -0.30, and from -1.35 to -0.62, respectively. Again, Light Yellow & Solaris Red coating presents the highest $|DC_{ab}^*|$ but it is much more independent on the measurement geometry than the other two coatings.

On the other hand, (Figure 4, top-left) the hue angle difference, Δh_{ab}, is higher in Lapis Sunlight produced, possibly, by its more complex composition, mixture of four colours: Gold, silver, green and blue. In the other two coatings, this parameter is negligible: there is not an apparent shift, likely because the added systematic error is independent on the wavelength. The hue difference, DH_{ab}^*, is determined as the positive square root value of $(DH_{ab}^*)^2$, and behaves like Δh_{ab} (Figure 3, top-right). The higher change is seen in Lapis Sunlight, being negligible for the other two coatings.

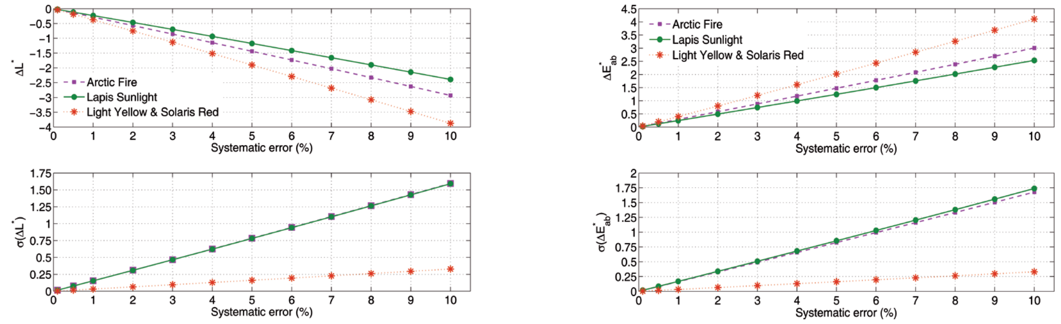

Figure 2: Lightness difference, DL*, (left) and total colour difference, DE$_{ab}$*, (right) versus systematic error for three special effect coatings. The graphics on top show the average value of every BRDF. The graphics on bottom show its standard deviation.

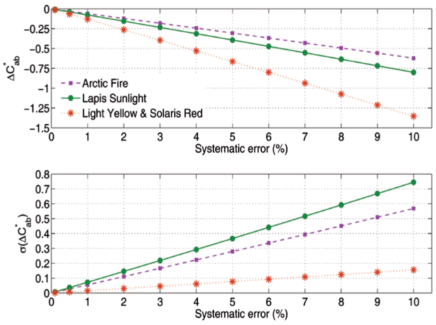

Figure 3: Chroma difference, DC$_{ab}$*, versus systematic error for three special effect coatings. The graphic on top shows the average value of every BRDF. The graphic on bottom shows its standard deviation.

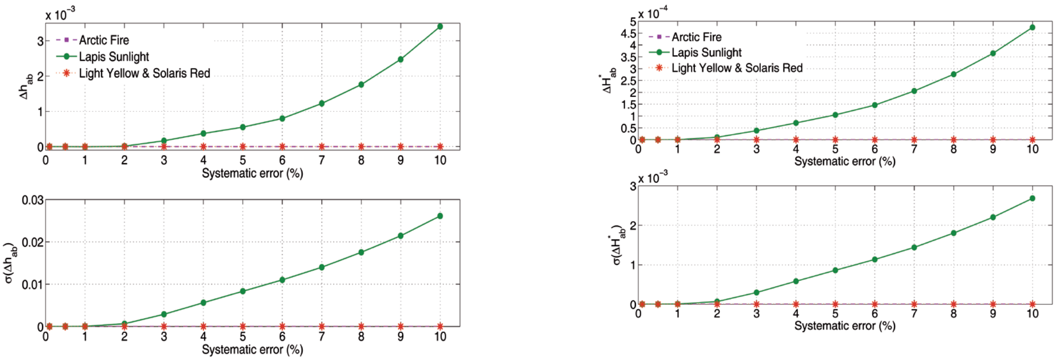

Figure 4: Hue angle difference, Δh_{ab}, (left) and hue difference, DH$_{ab}$*, (right) versus systematic error for three special effect coatings. The graphics on top show the average value of every BRDF. The graphics on bottom show its standard deviation.

4. CONCLUSIONS

The influence of a systematic error, proportional to the spectral value, in colour determination in three special effect coatings has been studied for directions within the incidence plane. It is observed that, the more systematic error, the more total colour difference, DE_{ab}*, lightness difference, DL^*, and chroma difference, DC_{ab}*, whereas hue angular difference,

Δh_{ab}, and hue, DH_{ab}^*, are not significantly affected. Furthermore, there is not a strong dependence on the measurement geometry, since the increase of the standard deviation of average values is much lower. If 1 CIELAB unit is accepted as the perceptual difference, a 2 % error already gives rise to a significant colour change. The measurement accuracy must be under that threshold.

On the other hand, it is observed that the major contribution to the colour difference arises from the lightness difference, probably due to the fact that the systematic error introduced is proportional to the spectral value at every wavelength.

It should be pointed out that Light Yellow & Solaris Red shows the highest change in L^*, E_{ab}^*, C_{ab}^*. By contrast, it shows less dependence on the measurement geometry (lowest standard deviation values).

This study should be extended to other coatings having different pigments to be more concluding. Finally, to complete this study, how a wavelength dependent systematic error would affect, should be analysed.

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Discrepancy of Whiteness in Wet State

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ABSTRACT

In the Western culture, white is the colour most often associated with innocence, perfection, cleanliness, the good and honesty. Nowadays, it is relatively easy to accomplish great whiteness and brightness of white textiles applying the FWA's, but discrepancy in hue due to applied blue or violet FWA, and wet or dry fabric indicate the need for further research in that area. The wetting and wicking have important role in textile dyeing and finishing. Textile colourists require a substrate which wets uniformly for efficient, level dyeing and printing, while in finishing good absorbency and wettability are necessary. In wet state fabrics are transparent, what change the whiteness and UV protection as well. Therefore, in this paper the discrepancy of whiteness of textiles in wet state as well as its transparency of UV light was researched.

1. INTRODUCTION

In the Western culture, white is the colour most often associated with innocence, perfection, cleanliness, the good and honesty. White materials like textile, paper, plastics, ceramics and many others are clearly preferred colour in many material fields and aesthetic application. White, besides being objectively quantifiable, is also a subjective connotation of quality which is greatly influenced by personal taste. From physical point of view it is clear that white has high level of luminosity, no saturation (achromatic one) and no hue. As Brown (2009) said: "White surfaces possess a beautiful harmony of achromaticity".

As other materials, textiles are never as white as necessary. For reaching the highest degree of whiteness, chemists tried to research the best compounds and bleaching procedure that finally succeed by using hydrogen peroxide. Chemical bleached natural textiles never reached the complete elimination of natural colour and little yellowness. At the beginning of 20th century consumers asked producers for better whiteness that resulted with historic discovering of first fluorescent compound *Esculin* by Paul Krais in 1929 for application on textiles, plastics and other materials. He extracted Esculin from wild chestnut, and applied it on flax fibers. He reported "About the new white ...". It was the new white indeed, never seen before in such high whiteness degree. This fluorescent compound and many others later synthesised add a new dimension to the white textiles giving the importance of white objects as one of basic colour in all colour system. Based on electronically-excited state by energy of ultraviolet radiation the molecules of fluorescent whitening agents (FWAs) show the phenomenon of fluorescence giving to white textiles high whiteness of outstanding brightness. It is emission process occurring from lowest excited state to the ground state of molecules reemitting the energy at the blue end of the spectrum. Grancaric *et al*. published several papers (Grancaric 1980, 1984, 1986, 2006, 2007, 2009) regarding the quenching of fluorescence. In some range of higher concentration bimolecular process which deactivates excited state of molecules appears. Recently it has been shown that FWAs have marked contribution to fabric UV protection (Reinert 1997, Grancaric 2006) giving to fabric the capability to absorb UV radiation of partially UV radiation range, from 300 to 380 nm. It is to point out that FWAs have multifunctional activity by giving the high whiteness, neutralizing the fabric yellowness, giving to the fabric the high luminosity and protecting fabrics against UV radiation.

Nowadays, it is relatively easy to accomplish great whiteness and brightness of white textiles applying the FWA's. But discrepancy in hue due to applied blue or violet FWA, and wet or dry fabric indicate the need for further research in that area. The wetting and wicking have important role in textile dyeing and finishing. Textile colourists require a substrate which wets uniformly for efficient, level dyeing and printing, while in finishing good absorbency and wettability are necessary. The only method for surface free energy measurement of hydrophilic textiles is based on thin layer wicking. In wet state fabrics are transparent, what change the whiteness and UV protection as well. Therefore, in this paper the discrepancy of whiteness of textiles in wet state as well as its transparency of UV light was researched.

2. EXPERIMENTAL

Raw cotton fabric (sample R) was used. It was plain weave fabric of 100 % cotton yarn of 20 tex and surface mass 220 g/m^2. Chemical bleaching (sample B) was performed in peroxide baths in autoclave (Scholl). Uvitex BAM (Ciba), derivate of stilbene disulphuric acid was used as FWA (sample OB) in three concentrations ($c_1 = 0{,}5$ g/l; $c_2 = 5$ g/l; $c_3 = 50$ g/l) by padding at wet pick up 100 %, in bath containing 5 g/l corn starch, 10 g/l glycerol, 20 g/l Na_2SO_4 and drying at T = 100 °C for t = 90 s. Samples were measured in dried and wet (-W) condition.

Remission spectrophotometer SF 600 PLUS CT (Datacolor) was used for measuring spectral characteristics of cotton fabrics. CIE whiteness degree (CIE_{WH}) was calculated automatically according to ISO 105-J02:1997 and Yellowing Index (YI) according to DIN 6167:1980. The discrepancy in wet state was determined through color differences of color coordinates (Δa*, Δb*, DC*, DL*, DH*) according to:

$$\Delta E^*_{ab} = \left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\right]^{\frac{1}{2}} \quad \text{or} \quad \Delta E^*_{ab} = \left[(\Delta H^*)^2 + (\Delta L^*)^2 + (\Delta C^*)^2\right]^{\frac{1}{2}} \qquad (1)$$

Varian Cary 50 Spectrophotometer was used for measurement of fabric transmission at different wavelengths. The fabric UV protection ability was determined according to AS/NZS 4399:1996. It is expressed via *ultraviolet protection factor* (*UPF*) indicating the ability of body protection by textile materials to prevent erythem [6].

3. RESULTS AND DISCUSSION

The remission and transmission spectra, whiteness degree, yellowness and UV protection properties of cotton fabrics in wet state are discussed. From measured spectral characteristics using the remission spectrophotometer, CIE whiteness degree and yellowing index, as well as remission (R_{max}) and wavelength (λ_{max}) maximums, were calculated. Results are collected in Table 2. It is evident that high effects in textile cleaning of genetic and added impurities such are waxes, protein substances, pectin and other during scouring and bleaching in peroxide baths, where pigments are removed, leads to cotton whitening. As the whiteness increase, yellowness decreases. Optical brightening due to FWA's fluorescence contributes to the fabric high whiteness and beauty in optimal range of concentration. At the low FWA concentration blue fluorescence neutralizes the yellowness of bleached fabric giving the high luminosity and "most beautiful" white. In the range of higher FWA concentration yellow colour of FWA is overcomes and fluorescence quenched in the same time with a consequence of complete different feeling far away from white and all beauty that it brings. The discrepancy in wet state occurs as well. From the CIE Lab differences shown in Table 2 it is evident that raw and bleached fabrics get darker, with negative DL* values, while optically brightened fabric get lighter, less green and yellow.

Table 1. CIE whiteness (W_{CIE}), yellowing index (YI), remission (R_{max}) and wavelength (λ_{max}) maximum and UV protection of cotton fabrics.

Fabric	W_{CIE}	YI	R_{max} [%]	λ_{max} [nm]	Mean UPF	UV prot.
R	5.7	26.89	81.74	700	26.93	20
R-W	-12.6	32.36	79.65	700	14.10	10
B	60.1	9.16	86.09	700	21.25	15
B-W	41.2	13.62	80.03	700	8.20	5
OB(0.5)	113.9	-11.08	103.99	440	58.93	50+
OB(0.5)-W	96.0	-6.27	91.99	440	22,70	20
OB(5)	115.2	-11.18	106.90	440	232.23	50+
OB(5)-W	101.2	-9.40	98.77	440	114.53	50+
OB(50)	41.6	12.45	91.60	500	439.20	50+
OB(50)-W	1.4	23.03	81.80	500	386.41	50+

Table 2. CIE Lab Difference of cotton fabrics in wet state.

Fabric	Wet fabric	DE*	DL*	Δa*	Δb*	DC*	DH*	In wet state
R	R-W	9.948	-6.06	1.44	7.76	7.88	-0,31	Darker redder yellow
B	B-W	4.109	-3.46	-0.04	2.21	2.21	-0.07	Darker yellow
OB(0.5)	OB(0.5) -W	11.489	1.05	2.38	-11.19	1.77	-11.30	Lighter less green less yellow
OB(5)	OB(5)-W	10.717	1.71	0.50	-10.57	0.82	10.55	Lighter less green less yellow
OB(50)	OB(50)-W	8.684	1.79	-6.96	4.88	7.27	4.40	Lighter greener yellow

Fabric protective ability from UV radiation (UV-R) was investigated in wet state as well. From the results of UV protection expressed through mean UPF values shown in Table 1. It can be seen that raw fabric has good sun screening properties. The reason for that is that pectin and waxes in raw cotton which absorb small quantities of UV radiation. Removing those impurities in scouring and bleaching, UV protection is lower, but still good. Therefore, for summer clothing additional fabric protection is necessary, as for fabric whiteness as well. By absorbing UV-A radiation optical bleached fabrics transform this radiation to blue fluorescence not transmitting this range of radiation what leads to excellent UV protection and high degree of whiteness. Cotton fabrics of the highest FWAs concentration have the highest

UPF. On the other hand, transmission of UV radiation through fabrics in wet state, presented in Table 2, is getting higher. Therefore, all the fabrics give off lower UV protection than in dry state. For raw and bleached cotton fabric, transmission gets so high that fabrics become non-rateable. As for optically brightened fabrics, the transmission is higher, but they still give an excellent UV protection.

4. CONCLUSIONS

Scouring and bleaching process leads to higher cotton whiteness and lower yellowness. Fabric whiteness and UV protection increase after optical brightening. The harmonic change from raw cotton fabric through its brilliant whiteness to its yellowness as the consequence of quenching of fluorescence has been seen. In the higher FWA concentration quenching phenomenon occurs resulting with negative appearance because of lower luminosity and yellowness.

In wet state, raw and bleached fabrics get darker, with negative DL* values, while optically brightened fabric get lighter, less green and yellow. On the other hand, UV transmission is higher, and therefore all the fabrics give off lower UV protection than in dry state.

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Evaluation and Computer Graphics Reproduction Way of Effect Coatings Applied Gonio-Photometric Spectral Imaging

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ABSTRACT

In this study, a gonio-photometric spectral imaging system was applied to measure colour and texture of effect coatings. It was composed of white LED illuminations, a liquid crystalline tuneable filter (LCTF), and CCD imaging device. Illuminations angle were 20, 45 and 70 degrees from normal direction, and detective direction was normal against sample, and the CCD device captures the images via the LCTF, and inside parts of the images were related with aspecular angle. This system could get highly accurate gonio-photometric imaging reflectance spectrum and colour values with various optical dimension.

The effect coating test panels for measurement were coated aluminium flake and interference micas. The CIELAB colour value, the information entropy, the number of colour occurrence, the distribution in CIELAB colour space, and sparkle, graininess index were calculated from measured spectral imaging. The analysis shows that each value was related with characteristic of effect material. Also the computer graphics reproduction images were calculated from these values of each effect material. Developed gonio-photometric spectral imaging is quite useful for evaluation and computer graphics reproduction of effect coatings.

1. INTRODUCTION

Metallic and pearlescent colours such as recent automotive and home electronics exterior coatings, cosmetics are included many types of effect materials, for example, metal flake and pearlescent pigment. Effect coatings show colour, sparkle and graininess texture, and visual perceptions related to goniometric condition of illumination and observation. The main idea of evaluation and digital imaging reproduce colour and texture is the use of combined spectral and imaging information with gonio-photometric.

2. METHOD

Gonio-photometric spectral imaging system was composed of white LED illuminations, LCTF, and CCD imaging device with Peltier cooling unit. Illuminations angle were 20, 45 and 70 degrees from normal direction, and detective direction was normal against sample, and the CCD device captures the images via the LCTF from 420 to 700nm with each 10nm and 400 dpi resolution. Especially, it was considered the best way of objective lens angle and CCD device resolution to get highly sharpness for all measured area of effect coatings. Finally, this system could get highly accurate gonio-photometric reflectance spectrum and colour values with wide aspecular angle from 3.5 to 80.8 degrees (see Figure 1). Spectral imagings were checked positioning differency on peripheral part of images between each wave legth, and confirmed high accuracy all over the images with no pixcel shift.

The effect coating test panels were prepared one aluminium flake (Toyo Aluminium) and eight interference micas (Merck). Each panel was mixed with FW200 carbon black and coated on white and black substrates by spray application. The thickness of base coat layer was 20 micron, and top coat layer was 35 micron and formulations are shown in Table 1. The information entropy was calculated by Shannon equation and the number of colour occurrence was counted number of L*a*b* unit cube which covered colour value of each pixels.

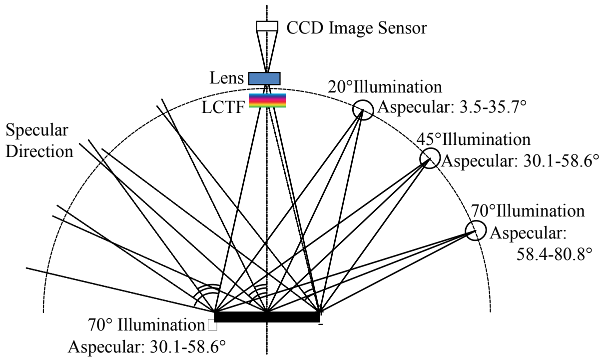

Figure 1: Optics Geometry of Gonio-Photometric Spectral Imaging.

3. RESULTS AND DISCUSSION

As an example, the measuring result of Xirallic Crystal Silver with FW200 carbon black pigment is shown in Figure 2. The distribution in CIELAB colour space calculated from measured spectral imaging of 20 degrees illuminant is shown in this figure. Right side shows the frequency of occurrence projected to L*-a* plane, and left side shows the frequency of occurrence to projected a*-b* plane at L* = 15 with optimal colour area.

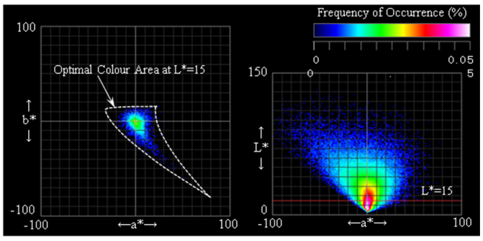

Figure 2: The distribution in CIELAB color space of Xirallic Crystal Silver.

The important point to note is measured colour occurrence area has quite wide distribution with all over the optimal colour area. This result suggests that rescent effect materials need spectral imaging measurement to get high accurate L*a*b* value of spakle and grain texture. The information entropy and the number of colour occurrence of each panels are shown in Table 1. Especially, Xirallic Crystal Silver interference pigment has large number of colour occurrence of 20 degrees illumination. On the other hand, Alpate 7670 alminium flake has also large number, but small value of difference between 20 degrees and 70 degrees normarized by 45 dgrees illumination. And the information entropy and number of color occurrence with L* value at 20 degrees illumination are shown in Figure 3.

Table 1. Measured results of effect sample.
IL.:Illumination, C.B.:FW200 Carbon Black, I.E.:Information Entropy, N.C.:Number of Color Occurrence, C.S.:Crystal Silver, ClrStrm. A.F. :ColorStream Arctic Fire

Sample	Formulation	20° IL.		45° IL.		70° IL.		$\frac{20^\circ - 70^\circ}{45^\circ}$	
	Effect/C.B. (%)	I.E.	N.C.	I.E.	N.C.	I.E.	N.C.	I.E.	N.C.
Alpate7670	0.5/0.3	11.03	12648	8.15	5218	5.03	2752	0.74	1.90
Futura Green	1.0/0.3	8.30	9067	5.22	2745	2.98	1409	1.02	2.79
Futura Trqs.	1.0/0.3	8.36	6739	4.23	2470	2.24	1176	1.45	2.25
Futura Lilac	1.0/0.3	8.63	4494	4.89	1491	2.87	785	1.18	2.49
Futura Blue	1.0/0.3	8.51	5493	4.73	1939	2.87	989	1.19	2.32
Futura Violet	1.0/0.3	8.66	4896	5.12	1808	3.50	874	1.01	2.22
Futura Indigo	1.0/0.3	8.74	5966	5.23	2070	2.80	1006	1.13	2.40
Xirallic C. S.	1.0/0.3	10.05	20503	5.14	5679	2.49	2218	1.47	3.22
ClrStrm. A. F.	1.0/0.3	10.30	14052	6.06	4585	3.51	2109	1.12	2.60

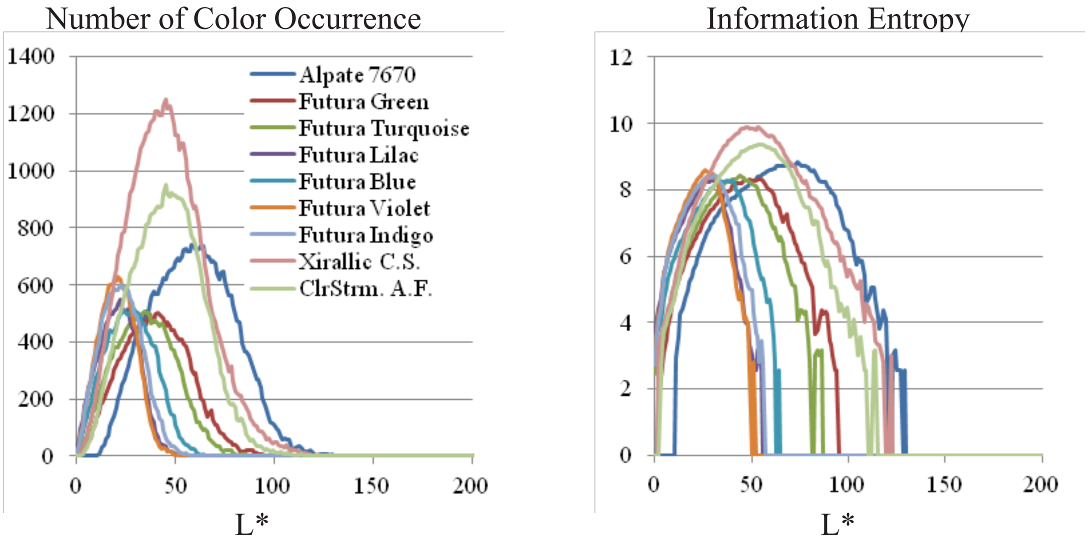

Figure 3: Measured Result at 20 degrees illuminant of Effect Samples.
Left: Number of Color Occurrence, Right: Information Entropy.

Computer Graphics rendering images were calculated from distribution in CIELAB colour space. The distribution is same as the probability density function with aspecular angle of optical dimension. The reproduce images were created on oval shape surface with specular reflection and sparkle, graininess images of effect materials by combined with randomize and probability density function (see Figure 4).

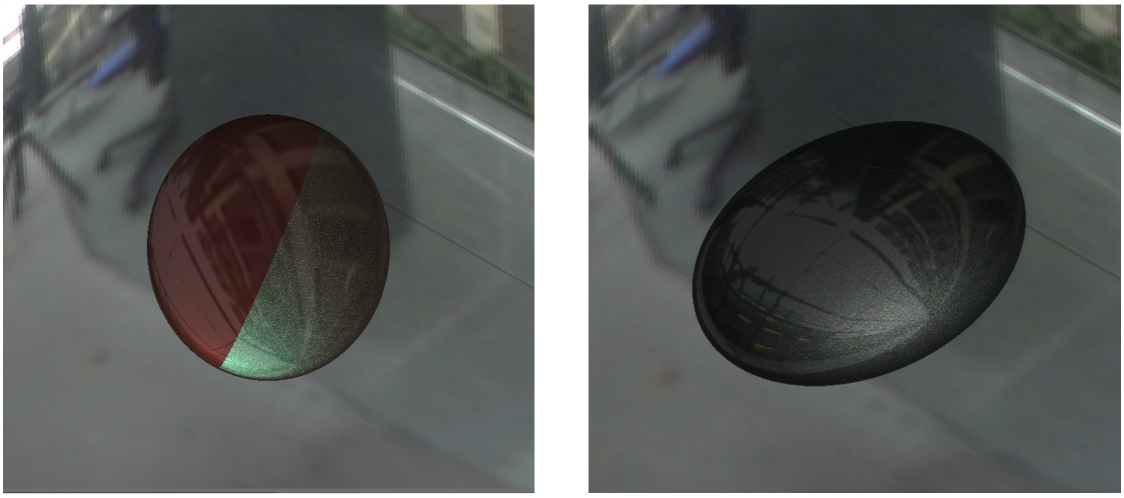

Figure 4: Computer graphics reproduce image.
Left side is coated solid paint and double layers coated combined with solid and green interference mica paint on oval shape object. Right side is coated Xirallic Crystal Silver with FW200 carbon black absorption pigment on oval shape object.

4. CONCLUSIONS

Developed gonio spectral imaging system was composed by LCTF, CCD image sensor, and LED illumination. It was confirmed interference pigment had a very wide colour area. Developed system can get various and high accurate gonio-photometric spectral imaging information by short measuring time with no movement and simple structure. And this system has possibility to get high dimensional information such like distribution in CIELAB colour space. CG rendering images were created by probability density function in CIELAB color space combined with randomize function.

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Instrumental and Visual Correlation between a Multiangle Spectrophotometer and a Directional Lighting booth

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ABSTRACT

Colour differences between what we see and what we measure entail a very complex topic. In this work, we deal with this issue for the case of special effect pigments. With this purpose, the instrumental and simulated visual results obtained for the same pairs of samples were compared. Instrumental evaluation was performed by the BYK-Gardner's multiangle spectrophotometer, BYK-Mac, and simulated visual evaluation was simulated with a goniospectrophotometric system composed by the tele-spectroradiometer PR-650 from Photo Research, Inc. and the directional lighting booth, Byko-spectra effect from BYK-Gardner. The set of samples were constituted by 13 pairs of three different kinds of pigment: solid, metallic and pearlescent. They were analysed at six geometries: 45as-15, 45as15, 45as25, 45as45, 45as75 and 45as110. The colour differences between samples of the same pair were quantified by means of AUDI2000 colour difference formula. In general, both devices behave very similar, although the set formed by the tele-spectroradiometer and the lighting booth shows higher colour differences and in some cases unacceptable from an industrial point of view. Despite the observed similarity, these two instruments do not show any firm correlation. Therefore, more goniochromatic samples must be analysed in order to strengthen the tendencies revealed by this study.

1. INTRODUCTION

Several devices are designed for colorimetric analysis of materials, either spectrophotometers or colorimeters, but the final decision is visually taken. This statement affects the whole colour science; however, this work is focused on goniochromatism. Materials that contain special effect pigments need more complex evaluations than solid pigments due to their lightness variations (metallic materials), hue and chroma (pearlescent materials) as a function of illumination/observation angle (Maile et al. 2005, Pfaff 2008).

Therefore, this study consists of finding the correlation between instrumental and simulated visual assessments of special effect and solid pigments. By this way, we will be able to know and quantify how much closer or further these techniques are.

2. METHOD

Both evaluations, visual and instrumental, were performed by means of two different goniospectrophotometric systems. In instrumental evaluation, the BYK-Gardner's gonio-spectrophotometer, BYK-Mac (Figure 1, left), was used to measure the samples. On the other hand, simulated visual evaluation was carried through the system composed by the PR-650 telespectroradiometer of Photo Research, Inc. and the BYK-Gardner's directional lighting booth Byko-spectra effect (Figure 1, right). The goal of this second gonio-spectrophotometric device consists of simulating a typical visual evaluation by placing inside a booth a couple of coloured samples and measuring them at each geometry.

Figure 1: Left: gonio-spectrophotometer BYK-Mac;
Right: Gonio-spectrophotometric system formed by the PR-650
tele-spectroradiometer and the Byko-spectra effect lighting booth.

The set of samples included 13 pairs of three different kinds of pigments: solid, metallic and pearlescent. Every pair was composed by samples of the same colour but different batches; due to that fact, colour differences were very small. Regarding measuring geometries, they were fixed by the gonio-spectrophotometer and the lighting booth: 45as-15, 45as15, 45as25, 45as45, 45as75 and 45as110.

Colour differences between samples of the same pair were calculated by means of AUDI2000 colour difference formula (Dauser 2012). It was especially designed for goniochromatic materials, in other words, it takes into account the colorimetric variations that these materials show as a function of illumination/observation angle.

$$\Delta E_{AUDI2000} = \sqrt{\left(\frac{dL_{\gamma}^{*}}{k_{dL} S_{dL_{\gamma}}}\right)^{2} + \left(\frac{dC_{\gamma}^{*}}{k_{dC} S_{dC_{\gamma}}}\right)^{2} + \left(\frac{dH_{\gamma}^{*}}{k_{dH} S_{dH_{\gamma}}}\right)^{2}} \qquad \text{(Eq. 1)}$$

where dL_{γ}^{*}, dC_{γ}^{*} and dH_{γ}^{*} are lightness, chroma and hue differences, respectively. In the denominator, lightness $\left(S_{dL_{\gamma}}\right)$, chroma $\left(S_{dC_{\gamma}}\right)$ and hue $\left(S_{dH_{\gamma}}\right)$ weighting functions and also lightness $\left(k_{dL}\right)$, chroma $\left(k_{dC}\right)$ and hue $\left(k_{dH}\right)$ parametrical factors can be found. These last factors do not depend on the observation angle because this dependency is considered by the weighting functions.

3. RESULTS AND DISCUSSION

Table 1 shows the maximum and mean colour differences calculated by AUDI2000 colour difference formula of each pair and for the six geometries and sorted according to the instrument. Samples that present higher maximum and mean values belong to the pearlescent group, as *Dark grey* and *Gold*. The results obtained through the system formed by the tele-spectroradiometer and the lighting booth reveal higher colour differences for solid and metallic colours. However, colour differences related to pearlescent samples are higher for gonio-spectrophotometic measurements.

Table 1. Maximum and mean ΔEAUDI2000 values of each sample for the six geometries and as a function of the instrument.

Sample	BYK-Mac		PR-650 + Byko-spectra effect	
	Maximun $\Delta E_{AUDI2000}$	Mean $\Delta E_{AUDI2000}$	Maximun $\Delta E_{AUDI2000}$	Mean $\Delta E_{AUDI2000}$
Red	1.33	0.97	2.12	1.17
Yellow	1.32	0.84	3.47	2.02
White	3.41	2.62	8.57	6.78
Cream	0.98	0.76	2.57	1.98
Green B	6.91	6.11	5.87	4.65
Violet	1.36	0.81	2.22	1.39
Green	1.3	0.82	2	1.24
Grey	2.48	1.58	3.91	2.27
Blue	1.15	0.85	4.8	3.82
Dark grey	3.63	2.92	3.5	2.81
Light blue	6.86	3.16	4.66	3.08
Gold	4.89	4.22	5.24	4.73
Light grey	14.5	4.35	8.83	3.53

On the other hand, Figure 2 shows three plots which represent each kind of pigment; they are the most representative examples of each one.

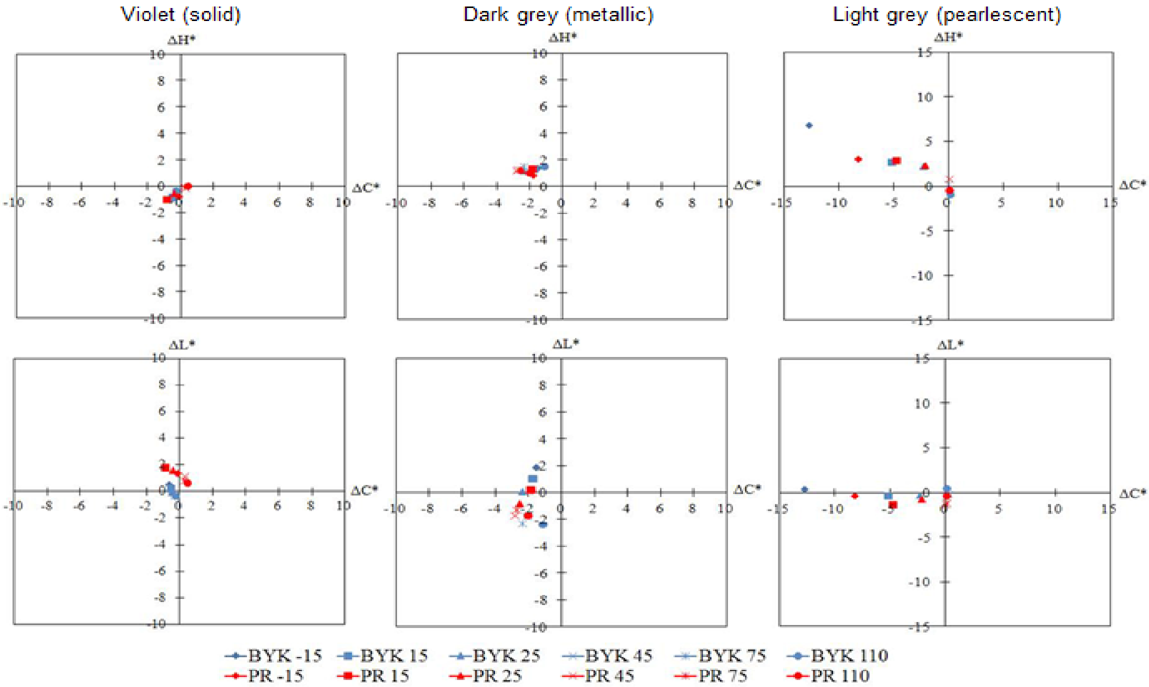

Figure 2: Partial colour differences of one solid pair, one metallic pair and one pearlescent pair.

As the results show, both systems present similar behaviour for solid colours and colour differences are very small, closer to zero in some pairs. Regarding metallic samples, they exhibit higher lightness differences, mainly in 45as-15 and 45as110 geometries for the

BYK-Mac. Nevertheless, in the case of PR-650 plus booth, the higher the aspecular angle, the higher the colour differences. Finally, hue and chroma differences shown by pearlescent pairs are higher for angles closer to specular reflection. In this case, colour differences calculated by means of gonio-spectrophotometric results are higher than the ones obtained by the tele-spectroradiometer plus lighting booth set.

4. CONCLUSIONS

Summing up, both devices behave in a similar way but there is no strong correlation between colour differences calculated by AUDI2000 colour difference formula. Solid pigments clearly correlates but effect pigments show more differences between samples. Future work will be focused on analysing a larger set of goniochromatic samples, deeply studying the different behaviour of each sort of pigment related to each measurement system and the light source of each device.

ACKNOWLEDGEMENTS

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Collecting Color Evaluation Words to Develop the Analysis Model of Color Image for Color Cosmetics

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ABSTRACT

This study is a basic research for developing color image analysis model for color cosmetics and intended to collect the colors of color cosmetics and color evaluation words. A total of 140 colors of color cosmetics were studied for the following four areas of face: 29 face colors; 55 eye colors; 37 lip colors; and 19 cheek colors. In addition, the colors were arranged freely and a total of 43 words associated with the color images were collected, including 'Calm', 'Feminine', 'Strong', 'Gorgeous', 'Lively', 'Cute', 'Conservative', 'Lovely', and 'Come-Hither'. This study is meant to be used for future research by selecting words approporate to be used as color image words for color cosmetics after verification of experts in related fields.

1. INTRODUCTION

It is well-known that colors have major impact on sensitivity of customers about the design among the various factors. Therefore, people are getting more interested in and doing research on how to come up with color arrangements that conform well to sensitivity of customers and design concept. To understand sensitivity of customers, and to reflect this knowledge in design, we need color image analysis model for each design fields, which provides quantitative interpretation of color sensitivity of image adjectives used in the design fields. This study is a basic, prerequisite research for developing color image analysis model for color cosmetics, and researched the colors of color cosmetics and selected color evaluation words accordingly.

2. METHOD

This study was carried out in the following two ways. First, colors of color cosmetics were classified into four categories of different areas of face and studied through colorimetry. Second, color evaluation words were collected regarding the studied colors through experiment.

2.1 Research into Colors of Color Cosmetics

The study was focused on color cosmetic brands with abundance of colors for the following four different areas of face. The colors released in 2012 were divided into four categories of face, eye, lip and cheek and studied through colorimetry. It was done using a colorimetry equipment (NCS color Scan 2.0) created for product development with the help of practitioners of the brands. However, finish power and colorless lip gloss that create no colors on skin were excluded.

2.2 Selection of Color Evaluation Words

To choose color image words, four categories including face color, eye color, lip color, and cheek color were presented to the subjects as shown in Figure 1. Then, they were asked to arrange the colors of different categories freely to be used for make-up. The subjects were asked to give words associated with the colors they arranged on their palettes, which was repeatedly done until they ran out of words to evaluate them. However, non-color factors such as makeup technique, gloss, and glitter were excluded from the study. The subjects were 7 graudate students in their 20s to 30s who were prolific users of color cosmetics and trained to participate in the experiment.

3. RESULTS AND DISCUSSION

3.1 Results on Color Cosmetics Colorimetry

A total of 140 colors of cosmetics were studied for the following four areas of face: 29 face colors; 55 eye colors; 37 lip colors; and 19 cheek colors, and the colorimetry results were presented through NCS color code and sRGB D65 2° as shown in Table 1. Face colors were predominantly high-brightness, low-chroma YR line, and eye colors encompassed the widest range of colors, including high-brightness, high-chroma, and mid-brightness, high-chroma. Lip colors were represented by RP, YR lines such as high-brightness, high-chroma, high-brightness, mid-chroma, and mid-brightness, high-chroma. Cheek colors, on the other hand, featured mostly mid-chroma, high-brightness of RP, YR lines.

3.2 Selection of Color Evaluation Words

Table 2 shows the 43 color image evaluation words selected based on free arrangement of 140 colors of color cosmetics. The subjects primarily gave words such as ‘Calm’, ‘Feminine’, ‘intense’, ‘bright’, ‘cheerful’, ‘cute’, ‘unpretentious’, ‘lovely’, and ‘sensual’ for relevant color image words.

Table 1. The colorimetry results

FACE	▨	▨	▨	▨	▨	▨	▨
	R20B-S1015	R60B-S3010	Y50R-S1002	Y30R-S1505	Y50R-S1505	Y60R-S1505	Y60R-S1510
	230,199,206	210,204,223	229,222,215	220,207,190	218,204,191	222,196,178	222,196,178
	▨	▨	▨	▨	▨	▨	▨
	Y60R-S1010	Y50R-S1510	Y40R-S1510	Y40R-S1010	Y50R-S1515	Y50R-S2010	Y70R-S2005
	235,206,189	225,195,174	225,199,173	237,210,182	225,188,160	213,184,164	205,190,18
	▨	▨	▨	▨	▨	▨	▨
	Y30R-S2010	Y40R-S2010	Y30R-S2020	Y40R-S2020	Y80R-S1010	Y80R-S1510	Y80R-S1515
	213,192,165	210,182,157	217,180,139	213,170,135	233,206,197	219,193,183	224,184,172
	▨	▨	▨	▨	▨	▨	▨
	Y60R-S1515	Y60R-S2010	Y40R-S3010	Y30R-S3010	Y50R-S2020	Y50R-S3020	Y40R-S3020
	227,187,165	210,181,165	187,160,138	187,164,139	212,166,138	197,150,122	187,146,115
	▨						
	Y20R-S3040						
	190,139,73						
Lip	▨	▨	▨	▨	▨	▨	▨
	R50B-S2002	R-S2010	R10B-S1020	R10B-S1030	R30B-S1030	R10B-S2020	Y90R-S2030
	198,195,197	204,182,179	231,187,191	233,170,178	226,172,195	205,163,168	211,142,136
	▨	▨	▨	▨	▨	▨	▨
	R-S2030	Y90R-S2040	Y90R-S3020	R-S3020	Y80R-S3030	Y90R-S4020	R30B-S1040
	210,142,143	209,126,121	185,138,132	181,139,139	185,119,108	162,118,114	223,148,184
	▨	▨	▨	▨	▨	▨	▨
	R10B-S1040	R-S2040	R10B-S2040	R30B-S2040	R20B-S3030	R20B-S3040	Y70R-S3040
	226,145,156	208,122,125	203,120,135	195,122,156	176,117,136	173,94,116	188,110,86
	▨	▨	▨	▨	▨	▨	▨
	Y60R-S3040	Y90R-S2050	R-S1050	Y80R-S3040	R10B-S1050	R-S1060	R10B-S2050
	194,115,83	207,105,9	231,126,129	188,105,92	233,128,144	226,100,111	197,97,113
	▨	▨	▨	▨	▨	▨	▨
	R30B-S1050	R10B-S1060	R20B-S2050	Y90R-S3040	R-S3050	Y60R-S2050	R30B-S1060
	224,126,173	227,98,123	202,96,131	182,99,93	171,75,83	214,121,82	219,94,158
	▨	▨					
	R50B-S4040	R20B-S1070					
	117,74,125	211,57,113					
Cheek	▨	▨	▨	▨	▨	▨	▨
	Y30R-S1510	R-S1015	R-S1510	R-S1515	Y70R-S1510	Y90R-S2020	R-S2020
	222,200,171	233,195,192	233,195,192	219,185,181	220,193,179	215,164,156	206,163,163
	▨	▨	▨	▨	▨	▨	▨
	Y50R-S2020	Y70R-S2020	R10B-S2020	R40B-S1030	R30B-S2030	Y80R-S3020	R-S3020
	212,166,138	213,165,147	205,163,168	219,174,206	203,147,170	187,141,131	181,139,139
	▨	▨	▨	▨	▨		
	Y70R-S2030	Y80R-S2030	R10B-S1040	R30B-S1040	Y80R-S2040		
	221,150,129	216,144,129	226,145,156	223,148,184	216,128,113		

Table 2. Color image evalution words

color image evaluation words	response ratio	color image evaluation words	response ratio
calm, feminine, strong	86%	intellectual, natural, Chesterfieldian, chic, animated, fresh, cybertic, cosmo, neat, graceful, clear, classical, rhythmical, characterful	29%
gorgeous, lively, cute	71%		
conservative, lovely, come-hither	57%	transparent, casual, pure, stately, gentle, confident, soft, cool, bright, unusual, lofty, sweet, noble, light	14%
fancy, elegant, sexy, classy, fascinating, clean	43%		

4. CONCLUSION

A total of 140 colors of color cosmetic brands were selected, which were divided into four areas and used for colorimetry. The colors had different characteristics in terms of shade and tone for each area of face, and mostly featured a wide range of brightness and chroma of RP, YR lines. A total of 43 words were selected after the 140 colors were arranged freely and associated color image words were examined.

The words will be used for future research by selecting appropriate ones as color image words of color cosmetics after verification of make-up experts. In addition, colors of top color cosmetic brands of various countries will be studied for more objective and universal research and selection of image words and for collection of color evaluation words with subjects of various age groups.

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Basic and Advanced Colorimetry Methods for Displaying Microscope Image Appearance

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ABSTRACT

The reproduction of image appearance in cross media is a challenging task due to the inherently different nature of different media. When it comes to medical microscopy this image matching becomes critical since an inaccurate reproduction might lead to an erroneous interpretation. In this paper, a new color management solution is proposed for displaying microscope images preserving the image appearance observed through the eyepiece of the microscope and via the display. For this purpose, the 24 samples of the Macbeth ColorChecker were measured through the eyepiece of the microscope and their appearance was reproduced to an LCD display. A basic calibration procedure was tested and compared with more complex solutions implementing different chromatic adaptation transforms or color appearance models. For the evaluation, a psychophysical experiment and different advanced colorimetry metrics were used. The results yield that there is a clear improvement in the image appearance when advanced colorimetry methods are included in the workflow.

1. INTRODUCTION

Nowadays, there is a huge transfer of visual information between different devices. Additionally, the range of different devices is expanding since new display technologies and cameras are produced. Therefore, there is continuous need for innovative solutions, improvements and optimizations in various cross-media reproduction applications. In order to achieve an accurate reproduction for cross-media applications one should be able to reproduce the image appearance in a different range of media and viewing conditions.

This is the problem faced when trying to match the image appearance of a sample viewed through the eyepiece of a digital microscope and of its image reproduced on a display. The increasing usage of digital microscopes requires new methods of color management suitable for these devices. A digital microscope offers the advantage of observing and storing the information digitally by a digital camera that captures the image of the specimen. In many medical applications the appearance of the sample must be preserved accurately since it might be critical for the correct interpretation of the sample. Moreover, in order for different researchers and laboratories to communicate with each other the image on their displays should be the same with the one observed through the eyepiece. The difference in the appearance is usually not because of the optics of the eyepiece but because of the different nature and viewing conditions in the two media.

The precise reproduction in this problem cannot be achieved by only using basic colorimetry. This is because basic colorimetry can only provide predictions of color matches under identical viewing conditions for the reference and the reproduction (Fairchild 1996). However, advanced colorimetry methods can accommodate the differences in the viewing conditions, such as the level of luminance, the surround relative luminance, the chromaticity of the white point, the gamut of the display and camera.

2. METHOD

The operation of a digital microscope can be described by the following steps. The light coming from the sample can be split in two different rays. One will be observed through the optics of the eyepiece and the other will be captured by the camera. Then the captured image will be projected on a display. The final goal of this research is to match the simulated response of the human eye observing through the eyepiece with the response of the eye while observing via the screen. Our proposed method is based on the transformations required between these two stages as can be seen in Figure 1.

2.1 Transformation Steps

The different steps where a transformation is needed can be separated as follows: the XYZ tristimulus values measured through the eyepiece, the RGB tristimulus values of the camera that captures the image, the RGB values of the display that displays the image and the XYZ values that can be measured on the display. If only basic colorimetry is considered, the tristimulus XYZ values of the display should be matched with the tristimulus XYZ values of the eyepiece. Under this assumption, the problem can be considered as a simpler calibration problem between the camera and the display. However, this approach does not take into account the different viewing conditions in the two different media. Hence, even if all the tristimulus values are matched, the stimuli appearance will be still perceived differently. Therefore, a Color Appearance Model (CAM) has to be applied in order to relate the tristimulus values with visual attributes of the color sensation (lightness, chroma, hue) in the different stages. This means that if $JCh(XYZ_{eyepiece}) = JCh(XYZ_{display})$ after applying a CAM for the two viewing conditions, the visual match between the two stimuli can be achieved.

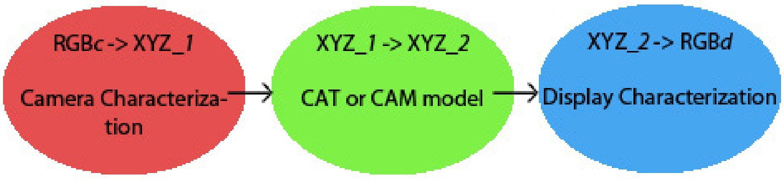

Figure 1: Schematic of the proposed methodology.

For the above purpose, the XYZ tristimulus values of the 24 samples of the Macbeth ColorChecker were measured using a spectroradiometer in the position of the eye at the eyepiece of the microscope. Moreover, the images of the samples were captured by the digital camera of the microscope. Thus, the RGB values of the camera for each sample were computed. For the measurements in this paper a microscope Nikon Eclipse MA200 and a camera Nikon D80 were used. The RGB values of the camera are highly dependent on the camera. Therefore, in order to correlate the RGB values of the camera with the XYZ values measured through the eyepiece a third-order polynomial-fitting between the data was applied. This procedure is mentioned as the camera characterization. A normal procedure for LCD display characterization was implemented in order to correlate the desired XYZ values emitted by a screen with the RGB values that drive the monitor. For this purpose a LUT table was built for all the possible combinations of RGB values. In order to match the appearance three different models were used and tested. Two of them implemented only a Chromatic Adaptation Transform between the XYZ tristimulus values in each device. Thus, in this case only the difference in the white point of each device was considered. Two different CATs were tested: the CAT02 (Fairchild M.D. 2005: 177) and a modification of the Von-Kries adaptation (Fairchild M.D. 2005 : 181). The more complex implementation took into consideration more advanced phenomena applying the RLAB model which was built for cross-media applications.

Thus, the absolute luminance of the light source, the relative luminance of the surround and the discounting-the-illuminant mechanism were now considered. In this case the JCh attributes of the XYZ values in the eyepiece were computed. Then the corresponding JCh values of the display that would provide the same sensation were calculated and inverted back to the XYZ values that should be emitted by the display.

2.2 Psychophysical Experiment

In order to test the different color management systems a psychophysical experiment was performed. The 24 samples were evaluated by 15 normal vision observers by observing each sample in the eyepiece and simultaneously four different versions of the sample on the screen. The first version was with CAT02 implemented, the second with Von-Kries implemented, the third with RLAB implemented and assuming complete chromatic adaptation in the eyepiece (D=1) and the fourth with RLAB model implemented and assuming incomplete chromatic adaptation in the eyepiece (D=0.5). The position of each patch on the display was random for each sample.

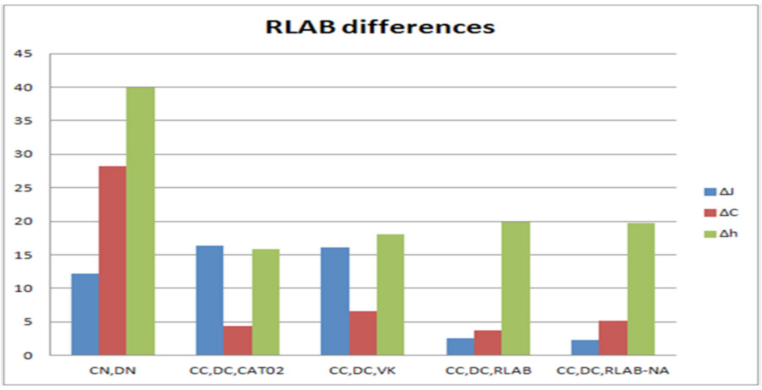

Figure 2: Color appearance attribute differences in RLAB.

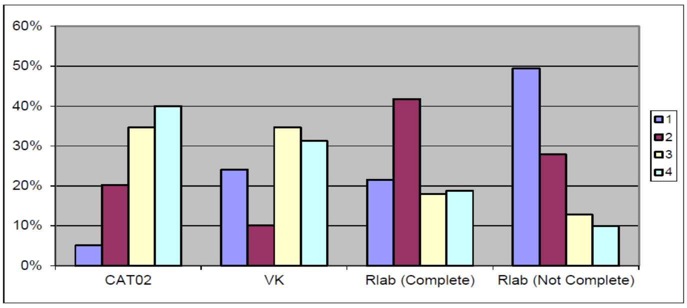

Figure 3: Ranking of the best match by the observers.

3. RESULTS AND DISCUSSION

In order to examine carefully the performance of each different model applied, the mean absolute differences for the 24 samples in the RLAB space were computed. The results for the attributes of Lightness (L) Chroma (C) and hue (h) are shown in Figure 2. From left to right are presented the results of the non-corrected case (Camera-No, Display-No), the corrected case for the CAT02 (Camera-Corrected, Display-Corrected), the corrected case for Von-Kries, the corrected case for RLAB with D=1 and the corrected case for RLAB with D=0.5, respectively. The Δh is expressed in degrees. The same calculations were done in the CIECAM02 space and the results were similar.

In Figure 3 the results of the psychophysical experiment are presented. Each observer ordered the samples according to which one was closer to the original observed through the eyepiece. Only the four corrected versions of the Figure 2 were used in this experiment in order to get a closer look in the improvement of each model. As it can be seen in both Figures 2 and 3 the correction that applied the RLAB model achieved a significant improvement in terms of color appearance. The RLAB with the incomplete chromatic adaptation for the eyepiece (which is closer to reality) provided the best choice for the observers. Furthermore, even the simple CAT transformations that only take into account the difference of the white point in each device are able to improve noticeably the performance of a color management system that only assumes the basic calibration procedure of camera and display characterization as can be seen in Figure 2.

4. CONCLUSIONS

In this paper, a new method for color management in displaying microscope images is proposed. This method can be applied to different microscopes by characterizing each camera and display individually. Xiao et al. (2012) proposed a method for displaying microscope images that does not take into account the difference in the viewing conditions. Moreover, they evaluated their results according to color difference formulas. These metrics were designed in order to evaluate small color differences of color samples observed under the same viewing conditions. Therefore, they should not be used in cases where the samples are viewed under different light sources. In a microscope the sample is observed through the eyepiece under the light source of the microscope and on the screen under the light source of the screen. Hence, the evaluation in a color appearance space can provide more meaningful results. Our research has shown that advanced colorimetry methods are critical in cross media applications and according to the desired complexity a CAT or a more complex CAM can be applied in order to increase dramatically the appearance match between the display and the eyepiece. Further research in this field can be held in order to include the implementation of an image appearance model such as iCAM (Kuang, Johnson and Fairchild 2007) in order to test complex stimuli in terms of image appearance and not only uniform color samples.

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Study on the Skin Color of Cable Home Shopping based on Six Domestic Broadcasters

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ABSTRACT

This research is a study on skin color for domestic cable home shopping broadcasters. We analyzed five product families; household goods, home appliances, foods, fashions, and cosmetics; for six home shopping channels; Home and Shopping, GS Home Shopping, CJ O Shopping, NS Home Shopping, Hyundai Home Shopping, Lotte Home Shopping. Skin color analysis is a very important element for image quality estimation method. The current broadcasting video is captured for the skin color experiment. After then, the female host forehead and the both cheeks skin color is extracted for skin analysis. The result of the comparison of the colors of the broadcasters is 'Home&Shopping', 'GS Home Shopping' is located in the YR-family, 'CJ O Shopping' is located in Y and YR that is mainly used the yellow color family. 'NS home shopping' and 'Lotte Home Shopping' has been seen in the distribution of R-family and YR-family, which use red color family. 'Hyundai Home Shopping' is Y, YR, and shows broad distribution R series. The results in comparing among the product family did not show a distinctive difference between them.

1. INTRODUCTION

We are living in the period of variety of multimedia TV channel. We are interacted by many variety of video and have been exposed to visually upcoming colors. The roll of color on media is useful not only for information-providing contents, but also for the consumption contents which is the home shopping area (HyangSun Shin, 2010). The purchase is normally caused by the usability of the product. However, with a touch of color, there are many ways to enhance that satisfaction. Skin color is an important element for memory color. This is directly related to preference color. According to Daechul Kim, Wangzun Kyung, Youngho Ha (2012) color standard of video is human, especially the face and skin color. Skin color is showing frequency on the TV screen and memory color is indicated important role for preference of audience and preferred color reproduction. In this study, the contents are limited to the five product families and six domestic home shopping channels.

2. METHOD

We analyzed five product families; household goods, home appliances, foods, fashions, and cosmetics; for six home shopping channels; Home and Shopping, GS Home Shopping, CJ O Shopping, NS Home Shopping, Hyundai Home Shopping, Lotte Home Shopping. We followed the step-by-step experiments. Figure 1 shows the experiment process.

The First step: five products (household goods, home appliances, foods, fashions and cosmetics) six domestic home shopping channels (home&shopping, GS home shopping, CJ O shopping, NS home shopping, Hyundai home shopping) set limited to range.

The Second step: we captured the female show host face image among the five products for all six domestic home shopping channels.

The third step: the face captured image went through a mosaic image filter and skin colors were extraction. The standard extracted skin color is the home shopping show host's forehead and both cheeks.

The fourth step: extracted data are represented in AdobeRGB and converted CIELAB values. Next each home shopping channel is compared and analyzed each other and among product families.

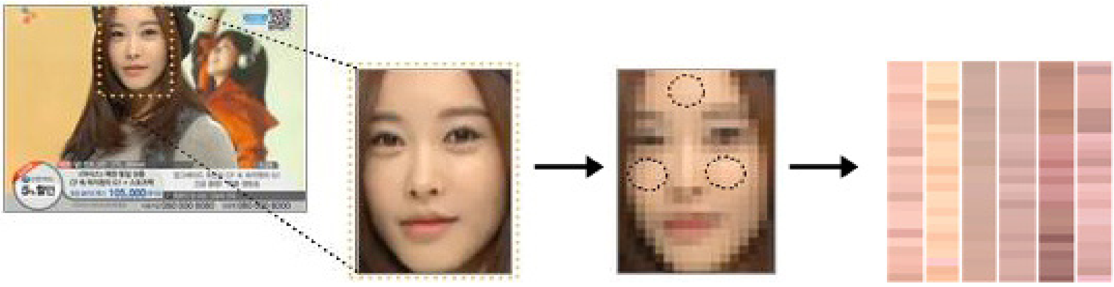

Figure 1: Flowchart illustrating the experiment *process.*

3. RESULTS AND DISCUSSION

3.1 Hue (color) comparative analysis of each broadcaster

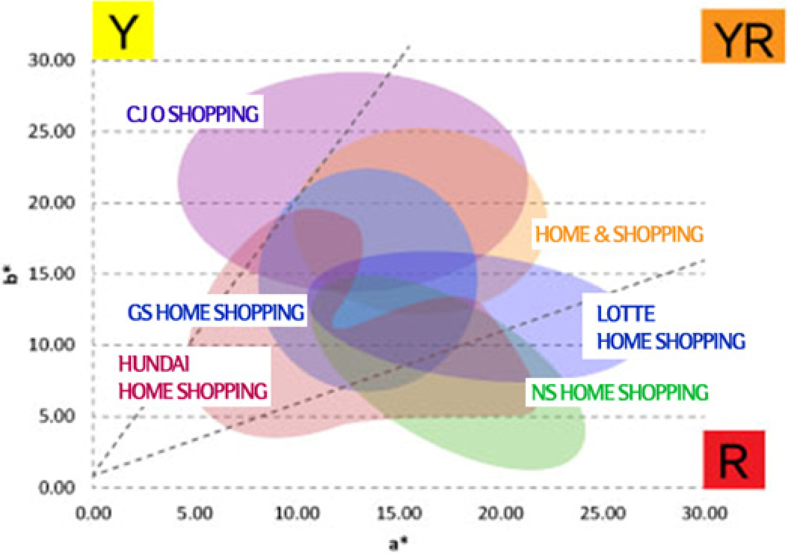

Figure 2: Hue compare by broadcasters.

Figure 2 shows the hue comparison of broadcasters on a*-b* plane. Home Shopping broadcasters as a whole showed the skin color to distribute within the scope of the R-YR family. Within the results, 'Home&Shopping' are distributed in YR-family that is close to Y-family. Among the comparison between products, the location of the household goods, home appliances, food, and cosmetics appears relatively close while fashion is slightly different. Fashion is into the R range of 10~20 compared to the other family are widely distributed. The 'GS Home Shopping' is located evenly in the YR-family. Especially, fashion shows a diverse range of color. 'CJ O Shopping' compared to other home shopping is located the Y-family and widely distributed. Not only has that, but also shows that each product's rang of color appeared relatively wide. ‘NS Home Shopping’ is located in the R range of colors. The skin color is located towards the R-family and shows that skin color is pink. The ‘CJ O Shopping’, ‘NS Home Shopping’ has a range of the color of their own group. The ‘Hyundai home shopping’ has variety of colors. Home appliance, food group have shown the tendency of YR-family close to the Y-family. Fashion, cosmetics, household goods are YR-family color close to the R-family. ‘Lotte Home Shopping’ has variety of colors. The location is close to the R-family color is the color of the YR-family.

3.2 Tone comparative analysis of each broadcaster

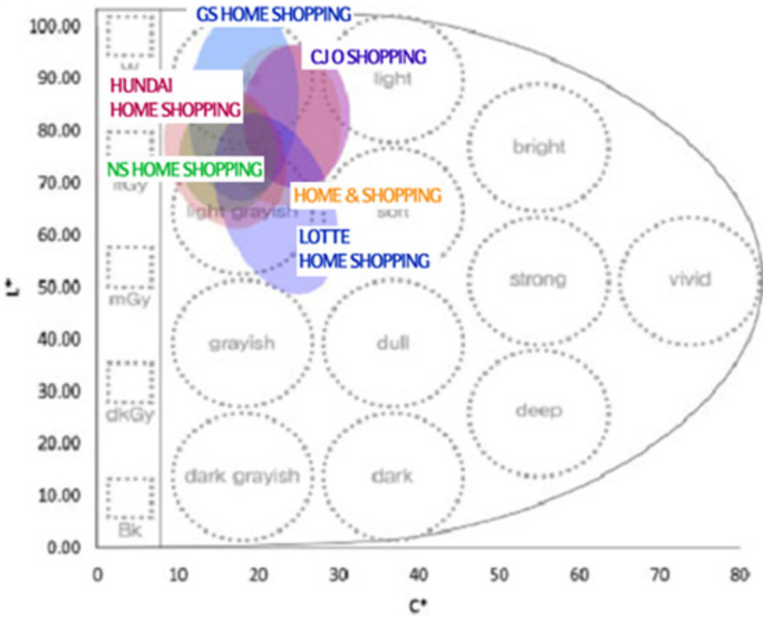

Figure 3: Tone Compare by broadcasters.

The tone of five product families and six home shopping channels are analyzed. In a whole view, the broadcasters are located on ‘pale tone’ and ‘Light Grayish tone’ region. The results are shown in figure 3. In result, ‘Home&Shopping’, ‘GS home shopping’, ‘NS home shopping’, ‘Hyundai home shopping’ show same range of tone which is ‘pale’, “light greyish’. ‘CJ O shopping’, ‘Lotte home shopping’ are wider by tone range. ‘CJ O shopping’ more shows ‘light tone’ and ‘Lotte home shopping’ shows more ‘Soft Grayish tone’. The tone for each broadcaster is listed in Table 1.

Table 1. Tone Compare by broadcasters.

Home shopping Broadcasting Center	Home & Shopping	GS Home Shopping	CJ Home Shopping	NS Home Shopping	Hundai Home Shopping	NS Home Shopping
Tone	Pale, Light Grayish	Pale, Light Grayish	Pale, Light Grayish, Light	Pale, Light Grayish	Pale, Light Grayish	Pale, Light Grayish, Soft Grayish

4. CONCLUSIONS

In this paper, study on six domestic cable home shopping broadcasters' skin color was analyzed. The female show hosts' skin color was used to specify the range of skin color by broadcasters. The results of a comparison of the colors by the broadcasters 'Home&Shopping', 'GS Home Shopping' has distribution within the YR-family, 'CJ O Shopping' has distribution in Y-family and YR-family that mainly used the yellow color family. 'NS Home Shopping' and 'Lotte Home Shopping' has been seen to show the distribution of R-series and YR series, use red color family. 'Hyundai Home Shopping' has distribution in Y, YR, R-family. It supposed that a standard of the skin color for broadcasters does not exist. The results of the comparison of tone by the broadcasters, all six broadcasters commonly used 'Pale', 'Light grayish tone'. It seemed that the skin colors of the broadcasters are not that exaggerated colors that are high in saturation or in tone. We can infer the pursuit color of each cable broadcasters through this study. It is not determined each product of color, but the color of broadcaster itself.

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Colour Emotional Visualisation

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ABSTRACT

This work is concerned with visualisation of colour emotion. Colour emotion relates to psychological responses and symbolic meanings of colour. However, which colours explicitly are relevant to certain emotions such as warm and cool is difficult to gauge because everybody owns different feelings and various cultural backgrounds. Nevertheless, the emotional effect of colour is important to achieve successful designs. In this work, the definition and the importance of colour emotion in design are illustrated. Specifically, which colours are actually associated with certain emotional words is explored through experimental work. This paper will present the result of a colour survey conducted within one cultural context. A total of 16 participants were given a task to draw freely using a set of coloured paints that were provided to represent 6 word terms (constituting 3 bi-polar characteristics: warm-cool, heavy-light, and masculine-feminine). Previous experiments in this field used scaling to obtain participants' responses to colours displayed on a screen or asked participants to choose one of several colour patches (such as munsell or pantone) to correspond to a word. However, this work is not constrained by a small number of samples and engages the participant in a creative task which might allow a closer relationship between colour and emotional response. Moreover, the drawings produced provide interesting visualisations *per se* of the semiotic (or emotional) responses. The colours of the drawings were analysed using MATLAB software to extract quantitative colorimetric data and with respect to previous models of colour emotion (e.g. those of Ou *et al.* 2004). Broadly speaking this new work supported the models of Ou *et al.*

1. INTRODUCTION

Colour semiotics is concerned with the meanings that colours are able to communicate. Colours can evoke strong emotional responses in viewers and can also communicate meanings and or concepts through association. There seem to be at least three different origins for colour semiotics. Firstly, there is the emotional or visceral impact of colours. Colours can have a strong emotional impact and can even affect our physiological state. For example, red colours have been cited to raise blood pressure and affect muscular strength. We fear the dark. Perhaps these effects are *innate* and have been present since the earliest days. Secondly, there are *socio-economic* origins. In western society purple became associated with wealth and royalty because purple dyestuff was expensive and was adopted by organizations and individuals to communicate the idea that they were wealthy and powerful. Thirdly, some colour meanings may be *cultural* in origin. The association of red with good luck in China and the link between pink and blue with gender in western society may originate in and be reinforced by cultural behaviour and shared understanding. Colour semiotics can have a powerful effect and hence the appropriate use of colour can impact greatly on the success of a design (particularly one that has a branding or marketing requirement). However, how robust are these colour associations and to what extent do they depend upon the context in which the colour is used? Colour meaning has been shown to depend upon other aspects of visual appearance such as gloss and texture. Some authors suggest that social groups that share common purposes around colour are often relatively small and specialized and, indeed, that colour *per se* (that is, without context) does not even elicit a response but the particular meaning or significance of colour is context-bound and varies from one person or situation to another (Grieve 2001). Despite this, most robust studies that have explored colour semiotics have done so for colour patches viewed in the abstract sense, devoid of context. The colour science community often use the term colour emotion instead of colour semiotics and study bi-polar pairs of semantic words such as 'soft-hard'; in these circumstances although some effects of culture have been found they have been weak effects. Even the medium (e.g. digital display or hardcopy) has been shown to have little effect of the emotions or meanings that observers attribute to different colours (Suk and Irtel 2010). Gao *et al.* (2007) studied observers from seven countries who were asked to rate 214 colour samples each in terms of 12 bi-polar word pairs and found only small differences between the nationality groups. However, experiments that are carried in the laboratory necessarily suffer from a number of limitations. For example, such studies typical involve relatively few participants (~30) and therefore cannot easily address questions about the wider robustness of findings. However, a further limitation is that the studies tend to be quite clinical and it would be interesting to see whether the same sort of findings would result from studies carried out in a more creative environment; this was the purpose of the current study.

2. METHOD

Participants were provided with eight water-based colorants (red, yellow, green, blue, orange, black, white and violet) and given facility for mixing the eight primaries to produce a wide range of colours. The participants were asked to use the inks (and associated brushes provided) to create a visualization of each of six words; the words formed three sets of bi-polar characteristics: warm-cool, heavy-light and masculine-feminine. Each participant therefore produced 6 images (approximately 20 cm by 20 cm) and a total of 16 participants were involved. Therefore, for each of the six words being studied a set of 16 images was produced. An example of the 16 images for the word 'feminine' is presented as Figure 1.

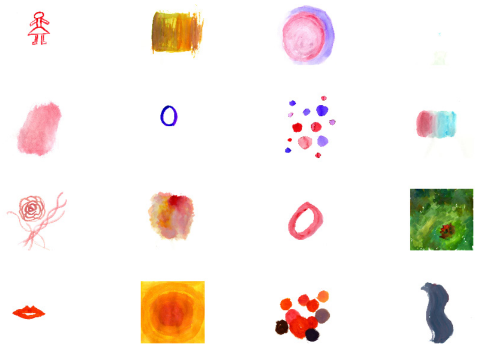

Figure 1: The sixteen images produced to represent the term, feminine. Each image was created by a different participant.

Each of the images was scanned and the resultant digital images were assumed to be in sRGB format. The images were processed using software written in the MATLAB programming environment to perform a cluster analysis in RGB space. The MATLAB command *kmeans* was employed which implements the k-means clustering method (MacQueen 1967); this is a method of cluster analysis which aims to partition *n* observations into *k* clusters in which each observation belongs to the cluster with the nearest mean. A total of 15 clusters were extracted from each of the six sets of images. In all cases the most populous cluster was white and this is because the participants drew their images on a white background. The first (white) cluster was removed from the analysis since whether or not the participants intended the background to be representative of their compositions was ambiguous. This left 14 clusters for each word term and these were ranked in terms of how many pixels each contained; the most prominent 8 clusters were used in subsequent analyses.

3. RESULTS AND DISCUSSION

In Figure 1 it is evident that although participants have used colour to represent the term feminine, they have also used form and imagery (for example, the red lips on the left-hand side of the bottom row). Participants also used symbolism in their representations of other words. Figure 2 shows the colours of the eight more populous clusters that were generated from the k-means analysis of the pooled images for each of the six word terms.

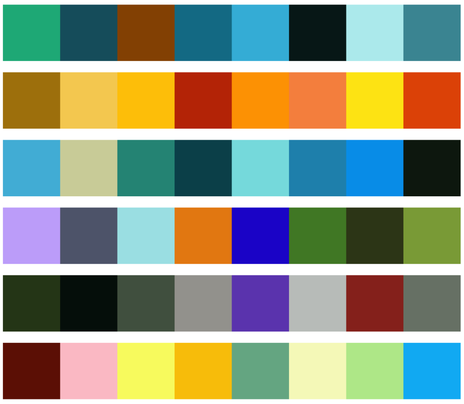

Figure 2: The eight most prominent cluster for each word. Each row contains cluster for one word (from top downwards: cool, warm, masculine, feminine, heavy, light) and the most prominent clusters are on the left in each case.

Each row in Figure 2 represents the clusters that were derived from one of the six sets of images (from top downwards: cool, warm, masculine, feminine, heavy, light). The sRGB values of the colours (Figure 2) were converted into CIELAB colour coordinates and were then used with equations developed by Ou et al. (2004) that predict warm-cool and heavy-light responses. Figure 3 shows the predictions from Ou's model for the heavy-light response for the colours from Figure 2 that were extracted from the light and heavy images respectively (for Ou's model the more positive the value the heavier and the more negative the lighter the colour). In general, the model's predictions are good. The mean lightness index (averaged over all eight colours) is -0.74 and the mean heaviness index is 1.03. However, there are some inconsistencies.

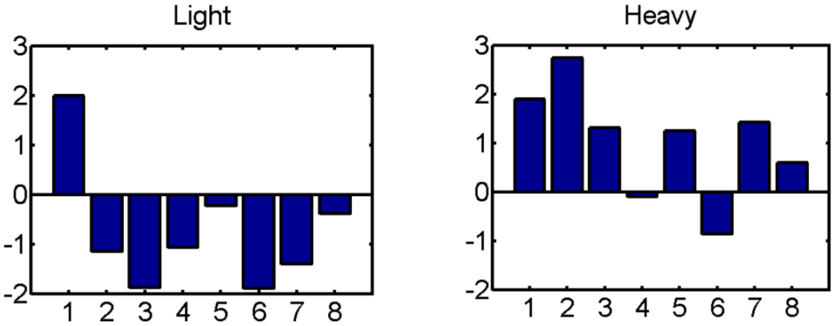

Figure 3: Ou prediction of heavy-light for light colours (left) and heavy colours (right) for each of 8 colours (denoted 1-8 on the abscissa). According to Ou's model more positive scores (plotted as the ordinate in this case) are heavier and more negative scores are lighter.

4. CONCLUSIONS

This work concerned psychological responses and symbolic meanings of colours. A total of participants engaged in a creative task and the images that were produced were analysed. A model developed by Ou *et al.* (2004) was used to predict the heavy-light associations of colours that were extracted from the heavy and light images using k-means clustering. Broadly speaking the new data were consistent with Ou's model.

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The Impact of Color and Lighting Combination on Perceived Brand Identity: A Case Study of Bank Branches in Thailand

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ABSTRACT

This research examines the impact of color and lighting combinations on the perception of bank's brand identity and built environmental quality. A total of 144 architecture students participated as research participants. Computer visualizations of bank branches interior space with a total of six color and lighting combinations were randomly shown to each research participant. The simulated spaces were evaluated in terms of room impression, mental concept, and brand identity using the seven-point scale semantic differential technique. An analysis of quantitative data showed that perception of brand identity and environmental quality changes due to color and lighting combinations. A significant difference was found between interior space with general lighting and accent lighting, especially on unique-common (t(143)=2.29, *p<.05*) and dramatic-relaxed (t(143)=4.05, *p<.001*) scale. The results also showed that interior space with "cool" lighting system installation decreases the perception of uniqueness and gives the feeling of low budget. In addition, the results showed that uniqueness score of interior space with yellow and purple theme is significantly higher than space with blue and no color (white) theme (F(3,429)=18.95, *p<.001*).

1. INTRODUCTION

Current commercial banking business in Thailand is highly competitive. Creating distinguish identity for the bank environment is the main strategy to promote transaction. From the literature review, the store environments influenced the image determination of the brand in the buyer's mental concept (Stern et al, 2001). It was shown that the color and light affected the environments in-the store, and also influenced buyer behavior (Kotler, 1973; Quartier et al., 2008).The different light characteristics with lighting arrangements, and color temperature gave different feeling (Areni & Kim, 1994; Summers & Hebert, 2001; Morgan, 2008). Different characteristics of light could also display the type of store and communicate the store's identity, the price of products (IESNA, 2000; SLL, 2009, Schielke, 2010). While previous studies showed that color and light area fundamental factors that could create identity, the impact of color and light on perceived identity of bank branch has not been thoroughly investigated, especially in Thailand. Therefore, this study examines the perceived identity of bank with the different color and lighting combinations.

2. METHOD

Six scenes of bank branches interior space, including the waiting area and counter service, were simulated with computer visualization program. In each simulated scene, the characteristic of interior colors (yellow, blue & purple), lighting arrangements (general & accent lighting) and correlated color temperature of light (warm white & daylight) were mixed and matched.

Room A-C: Different Lighting Arrangements

A) Shop with General Lighting (DL) *B) Shop with General and Accent Lighting (DL)* *C) Shop with General Lighting (WW)*

Room D-F: Different Colors

D) Shop with General Lighting (DL) and Yellow wall (R:254 G:195 B:67, H:41 S:74 V:99) *E) Shop with General Lighting (DL) and Blue wall (R:18 G:80 B:155, H:213 S:88 V:61)* *F) Shop with General Lighting (DL) and Purple wall (R:121 G:56 B:149, H:282 S:63 V:58)*

Figure 1: Summary of simulation scenes and the details.

In this study, a total of 144 architecture students aged between 18-29 years participated in this research in which the simulated scenes were randomly shown to each research participants. Research participants rated their level of perception and emotion on a seven-point scale semantic differential scaling method. A total of 11 word pairs on sensation, from Schielke's study, were translated into Thai terms to represent the room impression, mental concept, and brand image. The impact of color and lighting combination on perceived brand identity and environmental quality were analyzed with statistical test including paired-sample T-Test and Analysis of Variance to measure the.

3. RESULTS AND DISCUSSION

Summary of results from the experiment is shown in Table 1 and Figure 2. From the results, significant difference was found between the room with general lighting and accent lighting, especially on unique-common (t(143)=2.29, $p<.05$) and dramatic-relaxed (t(143)=4.05, $p<.001$) scale. The results also showed that the room with daylight colored light makes the room look less unique and gives the feeling of low budget. In addition, the results showed that uniqueness score of the room with yellow and purple theme is significantly higher than space with blue and no color theme (F(3,429)=18.95, $p<.001$).

3.1 Perception on characteristics of interior environments (Room Impression)

The perception of bank's room impression is represented through 5 pair words including P03, P04, P05, P06, and P08. It was found that light influenced perceptions and emotions. The general lighting alone made the room look spacious, natural, bright, and high-contrast, while providing general lighting together with the accent lighting made the store look confined, unnatural, and darkness. The warm white light makes room look cramped and diffuser than daylight. In addition, the results showed that color also influence the perception on characteristics of the room. For example, blue and purple made the room look wide, bright, and technical.

3.2 Emotion, feeling and mental concept (Mental Concept)

The perception of emotional is represented through 3 pair words including P01, P02, and P07. Based on the data, the warm white light gave the relaxation feeling. The color also makes emotional and psychological environment within different as well. The blue and purple make room look brighter and feel more relaxed than a regular light yellow. But yellow makes room look more stylish and unique.

Table 1. Mean (m.) and standard deviation (s.d.) of reported level of perception and emotion.

	A)		B)		C)		D)		E)		F)		Total	
	m.	*s.d.*	*m.*	*s.d.*	*m.*	*s.d.*	*m.*	*s.d.*	*m.*	*s.d.*	*m.*	*s.d.*	*m.*	*s.d.*
P01 attractive-unattractive	-0.82	1.45	-0.17	1.63	-1.20	1.38	-0.61	1.85	-0.53	1.74	-0.74	1.69	-0.23	1.62
P02 dramatic-relaxed	0.32	1.61	-0.39	1.50	0.06	1.46	-0.01	1.53	0.47	1.67	0.22	1.39	-0.04	1.53
P03 spacious-confined	-0.88	1.73	-0.22	1.61	-0.10	1.48	0.01	1.46	-0.51	1.79	-0.43	1.53	0.17	1.60
P04 uniform-differentiated	-0.70	1.49	-0.08	1.69	-0.17	1.62	-0.17	1.54	-0.51	1.73	-0.28	1.60	0.22	1.61
P05 natural-technical	-0.30	1.64	0.80	1.63	-0.16	1.68	0.47	1.54	0.22	1.78	0.64	1.61	-0.07	1.65
P06 bright-dark	-0.67	1.82	-0.55	1.47	-0.10	1.59	-0.24	1.59	-1.15	1.64	-0.97	1.54	0.08	1.61
P07 cold-warm	-0.46	1.55	-0.66	1.59	0.72	1.61	0.26	1.68	-0.69	1.49	0.19	1.61	-0.23	1.59
P08 contrast- diffuse	0.13	1.50	-0.58	1.38	0.01	1.32	-0.31	1.64	-0.06	1.52	-0.22	1.54	-0.04	1.48
P09 traditional-modern	0.70	1.43	0.65	1.36	0.48	1.27	0.97	1.48	0.80	1.26	0.60	1.35	0.17	1.36
P10 low budget-high class	0.13	1.59	0.40	1.38	1.35	1.31	0.92	1.42	0.63	1.43	0.86	1.37	0.22	1.42
P11 unobtrusive-expressive	0.00	1.45	0.38	1.50	0.95	1.85	1.10	1.55	0.56	1.47	1.02	1.49	-0.07	1.55

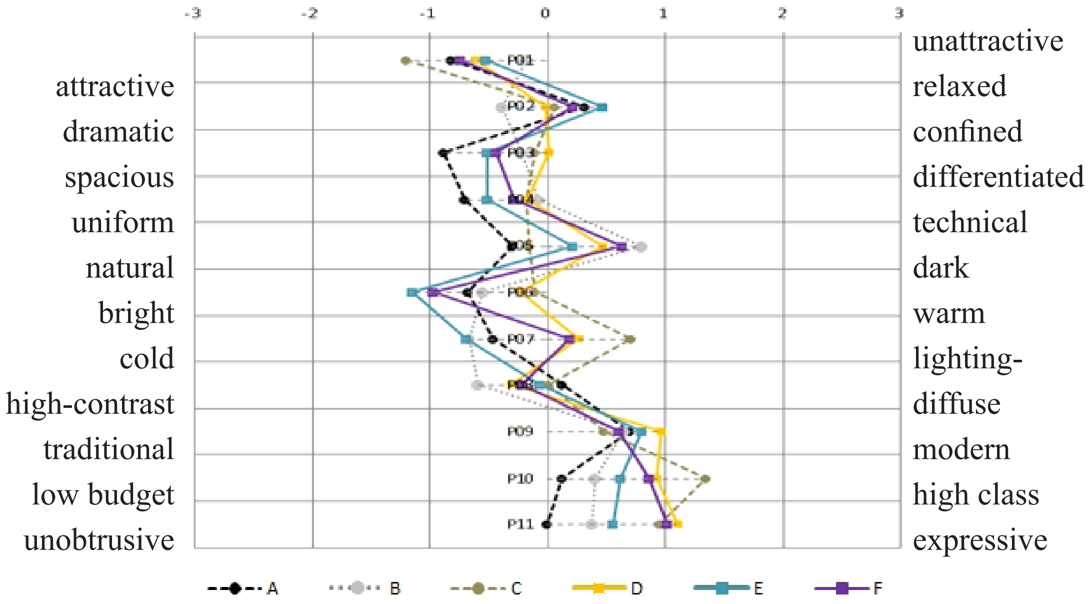

Figure 2: Trends of the level of feelings and emotions on different environments.

3.3 Brand Image

The perception of bank's brand identity is represented through 3 pair words including P09, P10, and P11. It was found that providing general lighting together with accent lighting in warm white light made the store look modern, high class and expressive. While daylight color made the store look ordinary. The color significantly influenced brand image perception in the dimensions of low budget-high class, and unobtrusive-expressive when comparing with the environment, both colorless and the three colors.

4. CONCLUSIONS

The goal of this study is to examine the perceived identity of bank with the different color and lighting combinations. The results showed that color and lighting combinations affected the perception of bank's brand identity and built environmental quality. For example, general lighting alone made the room looks spacious, natural, and bright. It was also found that building users indicate the type of store and the product price from light and color. The warm white light made the store look cramped, and soft light made the store look modern and expressive.

As a pilot study, however, other color and lighting combinations such as room with other hues/intensity have not been investigated. This study suggests that future research should examine other the key variables to develop a better understanding on the impact of color and light on bank's brand identity and environmental quality.

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Colour Emotion and Product Category

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ABSTRACT

The present study aims to investigate colour emotion in various categories of product design, including food, clothing, housing and transportation. Images of these four categories, each manipulated in colour, were presented as the stimuli in a psychophysical experiment using the categorical judgement method. The experimental results show that the food images had the most different trend than the other product categories in terms of colour emotion responses, especially the like/dislike response.

1. INTRODUCTION

Most of existing studies of colour emotion have focused on the use of contextless colour patches as stimuli in the experiments (Ou et al. 2004a-c; Gao et al., 2007; Ou et al. 2012). It was unclear, however, whether the results from such research could also apply to real-world product design. To address this issue, the present study looked into colour emotion in various contexts, in terms of 4 product categories, food, clothing, housing and transportation, which may reflect the most common daily activities.

2. METHODS

A psychophysical experiment was carried out, using digital images of various product designs, rather than colour patches, as the stimuli. The digital images consisted of 4 product categories: food, clothing, housing and transportation. The 4 categories can reflect the most common daily activities. For each of the 4 categories, 2 product images were selected, resulting in 8 original product images: cupcake, cocktail, female T-shirt, male T-shirt, house exterior, house interior, car exterior and car interior.

The authors' previous colour emotion studies (Ou et al. 2004a-c) used 10 bipolar semantic scales, also called "colour emotion scales" in this paper: warm/cool, heavy/light, modern/classical, clean/dirty, active/passive, hard/soft, tense/relaxed, fresh/stale, masculine/feminine, and like/dislike. These were the most frequently used scales in early studies. For consistency, and for comparing the present experimental results with the previous findings, the present study continued to use these 10 scales in the psychophysical experiment. Each scale consisted of 6 levels (or categories) of intensity. Taking warm/cool as an example, the 6 levels included "very warm", "warm", "a little warm", "a little cool", "cool" and "very cool".

To see whether and how product colours can affect the observer's affective responses, the experimental images were generated from the 8 original product images mentioned above, each manipulated by colour for the main part of the product in each image, using the Matlab software. The authors' previous colour emotion studies (Ou et al. 2004a-c) used 20 colours, which were selected from the NCS Colour Atlas and covered a reasonable range of hue, lightness, and chroma in CIELAB colour space. These 20 colours were again used in the present study in order that the present experimental results can be compared with the previous findings. Table 1 summarises CIELAB values of the 20 colours. A total of 8 (original product images) × 20 (colours) = 160 test images were generated for use in the experiment, as shown in Figure 1.

Table 1. CIELAB specifications of the 20 colour samples used in this study.

Sample	1	2	3	4	5	6	7	8	9	10
NCS notation	R-1080	Y-1070	G-2060	R90B-3050	R70B-3060	Y60R-5040	G80Y-4040	B50G-5040	R70B-5030	R-1020
Sample	11	12	13	14	15	16	17	18	19	20
NCS notation	Y-1030	B30G-1040	R60B-1040	G50Y-4020	B50G-5030	R50B-5020	N-9000	N-7000	N-3500	B-0502

Figure 1: The 160 test images.

An Eizo ColorEdge CG241W liquid crystal display (LCD) calibrated by an i1 Display was used in this study to present the experimental images. The display was set to have the sRGB colour gamut. The display peak white had the correlated colour temperature of 6500K with a display luminance of 70 cd/m^2. During the experiment, the display was placed at a desk, situated in a darkened room. The only light source was the display itself, which shows the 160 test images, one at a time in random order.

Thirty observers, including 15 males and 15 females, took part in the experiment. All observers were at the age rage of 18 to 30 years and have passed Ishihara's test for colour deficiency. The observers were all citizens of Taipei, Taiwan, and were either staff members or students at the National Taiwan University of Science and Technology.

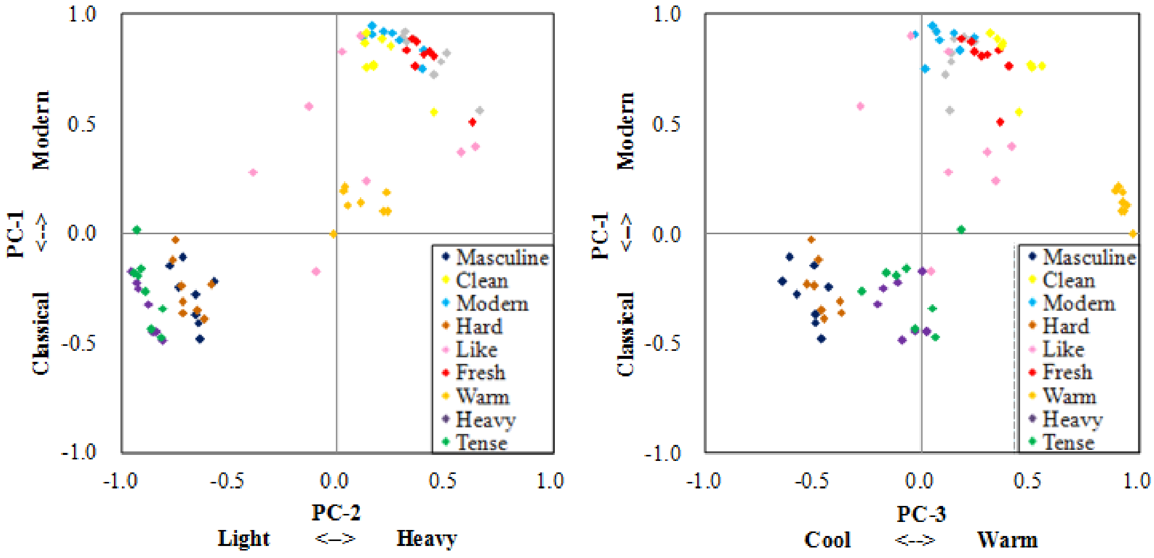
During the experiment, each observer was asked to sit in front of the experimental display, with a viewing distance of about 50 cm. Each observer rated the 160 test images using the 10 colour emotion scales. The categorical judgment method was used for data collection. All observers did the experiment twice so that a repeatability test can be performed.

3. RESULTS

Two measures were used to examine the reliability of the experimental data: inter-observer variability and intra-observer variability. Table 2 shows the results of inter- and intra-observer variability. As the table demonstrates, observers had the lowest inter-observer variability for tense/relaxed (1.64) and hard/soft (1.67). This suggests that the two scales had the most consistent observer responses. In terms of intra-observer variability, on the other hand, heavy/light (1.42) and clean/dirty (1.43) are the lowest. The result suggests that observers' responses were most repeatable for heavy/light and clean/dirty.

Table 2. Inter-observer and intra-observer variability for this study.

	Like/ dislike	Warm/ cool	Hard/ soft	Active/ passive	Clean/ dirty	Modern/ classic	Fresh/ stale	Feminine/ masculine	Heavy/ light	Tense/ relaxed
Inter-observer variability	1.83	1.71	1.67	1.83	1.79	1.71	1.80	1.82	1.78	1.64
Intra-observer variability	1.65	1.46	1.70	1.56	1.43	1.65	1.53	1.48	1.42	1.54



(a) *(b)*

Figure 2: Principal component plots: (a) PC-1 (modern-ness) versus PC-2 (weight) and (b) PC-1 (modern-ness) versus PC-3 (warmth). Each dot represents a product category.

To investigate the interrelationship between observers' responses for the 10 colour emotion scales, based on the 8 product categories, principal component analysis was carried out using the SPSS statistical analysis software. Figures 2 (a) and (b) illustrate the interrelationships between each scale on the basis of the component loadings, with each coloured dot representing the observer response to test images. There are 80 coloured dots in either graph. Dots of the same colour represent the observer response for a specific colour emotion scale. The distance between any two dots of the same colour in the graph can be seen as the dissimilarity of the two product categories; the closer the two dots are located, the more similar the two product categories were rated by a specific colour emotion scale. As the two graphs demonstrate, like/dislike is the only scale that show a wide spread of 8 dots (i.e. the 8 pink dots), suggesting a strong impact of product category on colour emotion for the like/dislike scale.

4. CONCLUSION

In this study, a psychophysical experiment was carried out to investigate the influence of product category on colour emotion. The principal component analysis shows that among the 10 colour emotion scales, only “like/dislike” shows a wide spread of data points in the principal component plot, indicating a strong impact of product category on colour preference for product images, as demonstrated in Figures 2 (a) and (b).

5. ACKNOWLEDGEMENTS

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The Impact of Colour on the Effectiveness of Threat Appeals in Social Marketing Campaigns

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ABSTRACT

Research has established that colours can influence the effectiveness of ads. The current study focuses on a specific type of ads, namely threat appeals, which are often used in social marketing campaigns to inform people about possible (health) risks and to convince them to adopt the recommended behaviour or to take preventive measures. The objective is to examine how the colour used in the background of such a threat appeal can influence its effectiveness. More specifically, we want to find out whether the usage of less or more pleasure-evoking colours will affect threat and efficacy appraisals, evoked fear and the behavioural intention to do something to avert the threat. Moreover, we want to test whether the impact of the background colour on the effectiveness of threat appeals is moderated by the threat level presented in the threat appeal. To this aim an experimental study is conducted with a 2×2 full factorial design, manipulating the level of threat and the background colour (yellow versus blue) in a flu awareness campaign promoting preventive flu shots. The findings confirm that the background colour of the threat appeal does indeed have an impact on its effectiveness, regardless of the level of threat presented in the message.

1. INTRODUCTION

Research has established that colours can influence a person's attitude towards an ad and its subsequent effectiveness (Gorn et al. 1997; Lichtlé 2007). In this study we focus on a specific type of ads, namely threat appeals, which contribute to raising awareness about unhealthy behaviours or potential dangers and are often used in social marketing campaigns. By describing the negative consequences of risks, social marketers try to convince the receiver of the message to adopt the recommendation prescribed. As threat appeals communicate a rather negative message, the impact of colour may be different than for commercial ads, which most often convey a positive note. As recent research even warns about a possible backfiring effect when using colour cues in negatively framed messages (De Bock et al., 2012); this study aims to ascertain how colour can contribute to more effective threat appeals.

2. RESEARCH OBJECTIVE & HYPOTHESES

2.1 Research Objectives

The objective of this study is to examine whether the colour used in the background of a threat appeal can influence its effectiveness. More specifically, we want to find out whether the usage of less or more pleasure-evoking colours will affect threat and efficacy appraisals, evoked fear and the behavioural intention to do something to avert the threat. Moreover, we want to test whether the impact of the background colour on the effectiveness of threat appeals is moderated by the threat level presented in the threat appeal.

2.2 Theoretical Underpinnings and Hypotheses

According to the Dual Mediation Hypothesis (MacKenzie et al. 1986) positive attitudes evoked by peripheral cues in the message, such as its background colours, impact the effectiveness of the message, both through a direct transfer of the positive attitude, as well as indirectly through cognitions (i.e. acceptance of the arguments in the message). Thus applying pleasant background colours can enhance the effectiveness of a health message. The Elaboration Likelihood Model (Petty and Cacioppo, 1986) claims that such peripheral cues are more effective if the message is not elaborately processed, but rather peripherally, due to lacking motivation or opportunity to process the message, which is often the case with marketing communications. For high level threat appeals, however, it is reasonable to assume that the message may be processed more thoughtfully (through the central route), which may reduce the impact of peripheral cues in the message, such as colour. Moreover, unlike commercial ads, which most often convey a positive note, threat appeals communicate a rather negative message and recent research warns about a possible backfiring effect when using colour cues in negatively framed messages (De Bock et al., 2012). According to the theory of Conceptual Fluency a mismatch between the valence of the content of the message (negative in case of severe threat appeals) and a prime (such as a pleasant background colour) may decrease processing fluency (Shapiro 1999), which may lead to less positive attitudes and decreased acceptance of the message. This leads us to formulate the following hypotheses:

H1– A threat appeal displaying more (versus less) severe consequences of a seasonal flu leads to (a) more perceived severity, (b) more perceived susceptibility, (c) more evoked fear and (d) a higher intention to get a flu shot.

H2 – The more (versus less) pleasant background colour blue (versus yellow) in a threat appeal leads towards (a) more perceived severity, (b) more perceived susceptibility, (c) more evoked fear and (d) a higher intention to get a flu shot.

H3– For severe (versus mild) threat appeals the positive impact of a more (versus less) pleasant background colour (blue versus yellow) may be moderated or even reversed.

3. METHOD

An experimental study is conducted with a 2×2 full factorial between subjects design, manipulating threat and background colour in a flu awareness campaign promoting preventive flu shots. The health risk chosen for the threat message was the hypothetical seasonal flu RNA5, which could be lethal (high threat) or just unpleasant like any other seasonal flu (no real threat). For the background of the threat appeals two different background colours were selected for their divergent pleasure eliciting properties: i.e. *blue* 5B, chroma 8, value 6, which is generally found to be a quite pleasant hue and *yellow* 5Y, chroma 8, value 6, which is experienced usually as rather unpleasant (confirmed in a pre-test). These hues were also specifically selected as they are noted to evoke a similar amount of arousal (Valdez and Mehrabian 1994). A convenience sample of 93 respondents was randomly exposed to one of the four threat messages (i.e., they either saw the low threat/high threat condition with either the blue or yellow background). An online questionnaire assessed the respondents' threat and coping appraisals by means of the Risk Behaviour Diagnosis Scale (RBDS) (Witte et al. 1995). Besides perceived severity, susceptibility, self- and response efficacy, also evoked fear and the respondent's intention to get a flu shot were gauged.

4. RESULTS AND DISCUSSION

A one-way MANCOVA analysis was performed with level of threat and ad background colour as fixed factors and a dummy for nationality as covariate[1]. Significant multivariate main effects are revealed for background colour (Wilks' λ = .853, F (4, 85) = 3.667, p =.008, partial eta squared = .147), as well as for level of threat (Wilks' λ = .563, F (4, 85) = 16.463, p <.001, partial eta squared = .437). No significant interaction effect was apparent (p =.278).

Anticipated main effects are confirmed for level of threat. After seeing a more (versus less) threatening threat appeal respondents reported perceiving the threat as more severe ($M_{\text{high threat}}$ = 3.833 vs. $M_{\text{low threat}}$ = 2.075160, p <.001) and feeling more susceptible to the threat ($M_{\text{high threat}}$ = 3.426 vs. $M_{\text{low threat}}$ = 2.455, p <.001). The stronger threat appeal also evoked more feelings of fear ($M_{\text{high hreat}}$ = 2.976 vs. $M_{\text{low threa}_t}$ = 2.074, p <.001) and a higher intention to get a flu shot ($M_{\text{high threat}}$ = 3.349 vs. $M_{\text{low threat}}$ = 2.049, p <.001). The results confirm H1a H1b, H1c and H1d.

Univariate results also revealed three significant main effects for ad background colour. Respondents seeing a blue (versus yellow) threat appeal reported a higher perceived severity (M_{blue}= 3.187 vs. M_{yellow}= 2.721, p =.032), confirming H2a and a higher perceived susceptibility (M_{blue}= 3.220 vs. M_{yellow}= 2.660, p =.004), confirming H2b. While evoked fear did not differ depending on the background colour used in the threat message (H2c), the intention to get a flu shot did appear to be significantly higher after seeing a message with a blue (versus yellow) background (M_{blue} vs. M_{yellow}= 2.449 = 2.949, p =.048), confirming H2d. As we could not discern any significant interaction effects, this means that the revealed impact of colour in the threat appeals under investigation was not moderated by the level of threat, disconfirming H3.

5. CONCLUSIONS

Threat appeals presented against a more pleasing blue colour were found to have a more positive impact on respondents' threat appraisals (i.e., severity and susceptibility) than when displayed against a less appealing yellow background. They appeared moreover to lead to higher intentions to follow the recommended behaviour prescribed in the message. According to our findings this effect does not appear to be moderated by the level of threat in the message. These results illustrate the importance of colour in the design of threat appeals. The usage of colour should therefore be considered thoughtfully in order to maximize their effectiveness.

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[1] We included a dummy for nationality as covariate because there was a significant difference between Belgian and UK respondents with regard to their perceived susceptibility (t(91)= 8.971, p=.005, M_{BE}= 3.242, M_{UK}= 2.595).

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Comparison and Analysis of Expressive Methods of Identity Color (Image Color) between Global Prestigious Brands and Contemporary Brand

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ABSTRACT

Having a concern for brand standardization due to the flood of trends, contemporary fashion needs a color scheme fit for a brand identitty, which in turn needs a color identity to make people remember the brand. This study thus set out to investigate color identity establishment for fashion brands based on the importance of image and color schemes to exhibit a brand identity in color schemes of brands. The study examined the characteristics, color images, and recent collections of prestigious and contemporary brands that seemed to succeed in image and color schemes and further compared and analyzed their methods to express identity colors. A fashion brand can display its color identity only with one color or establish its color identity by expressing its image colors through certain color tones and arrangements. There are differences in methods of expressing an identity according to the backgrounds, histories, and approaches toward consumers of brands. Color schemes can develop according to the brand characteristics.

1. INTRODUCTION

In fashion, color is the most important essence. Not only do colors reflect the social and cultural characteristics of the times, but they also reflect individual tastes, personalities, and cultural backgrounds as an important means of image and visual expression. In the information society, brands and consumers easily get in contact with trends. Consumers try to purchase products to make them look better, and brands need to try to have images and values to differentiate them from others.

Many brands are recently concerned with standardization. Brands need a color scheme fit for their identities and further a color identity to make consumers remember them in order to differentiate consumers and meet their needs. A brand should establish its image color, which does not change every season but always reminds consumers of the brand, before making a product season color plan. This study analyzed the cases of brands that seemed to succeed in image color scheme and compared and analyzed the methods for prestigious and contemporary brands to express their identity colors ultimately to search for and propose ways to establish a color identity fit for the situation of each brand.

2. METHOD

This study compared and analyzed prestigious global brands, which offer high-culture products and boast a heritage and high quality, and contemporary brands, which are cheaper than the designer and bridge lines and reflect the trends in vogue, in terms of image color scheme methods. A survey was taken with 20 fashion experts involved in a Korean fashion brand to identify the brands with good image color expressions. As a result, there were Hermes, Chanel, and Marni in the category of prestigious global brands and DKNY, Marc by Marc

Jacobs, and Vanessa Bruno in the category of contemporary brands. Used in case analysis were literature, photos, and Internet data. NCS was employed to analyze image colors. Analysis was conducted according to the uses of NCS colors (N,Y,R,G,B) and L. Sivik's NCS Characteristic Area. After analyzing ten or more seasons for some brands, the investigator judged that latest three to four seasons would be enough for brand image color expression and decided to analyze four seasons of each brand for convenience.

3. RESULTS AND DISCUSSION

Cases of prestigious global brands and contemporary brands that succeeded in image color scheme to establish an identity were compared and analyzed. As a result, all of them had their own color characteristics to establish a color identity and used different expressive methods from each other for planned image colors.

3.1 Prestigious Global Brands

The analysis results of prestigious brands show that each brand had a distinct image color scheme and expressed its image color in its logos, packages, websites, and VMD as well as its products.

Hermes presents 'Orange,' which reminds consumers of the wagon and leather, as its brand image color and expresses it in all of its elements. There are distributions of its color points around YR and R in its collections for all seasons (see Fig. 1). Chanel plans 'black,' which originated in modernism, and 'white' as its brand image colors and accurately presents its image colors across its logos, packages, websites, VMD, and collections(see Fig. 2). Marni plans a certain color tone as its image color. While choosing colors to reflect a trend, it mainly uses toned ligh grey, deep, toned dark grey, grayish chromatic, and dark deep tone in all of its elements (see Fig. 3).

3.2 Contemporary Brands

The analysis results of contemporary brands show that they as brands that were launched according to the trend needs used a mono tone in logos, packages, websites, and VMD as well as products mainly to highlight the products. Their identity colors were expressed to use a tone rather than color.

DKNY uses a mono tone in the elements other than products, in which it chooses strong point colors according to seasons based on the mono tone (see Fig. 4). Marc by Marc Jacobs shows a variety of colors and tones, expressing its logos and packages simple in a mono tone and its stores and webpages soft in a middle tone (see Fig. 5). Vanessa Bruno plans its seasons around tone light grey, light clear, dark deep, tone dark grey, and grayish chromatic and usually uses grey for elements other than products, creating an overall soft color image (see Fig. 6).

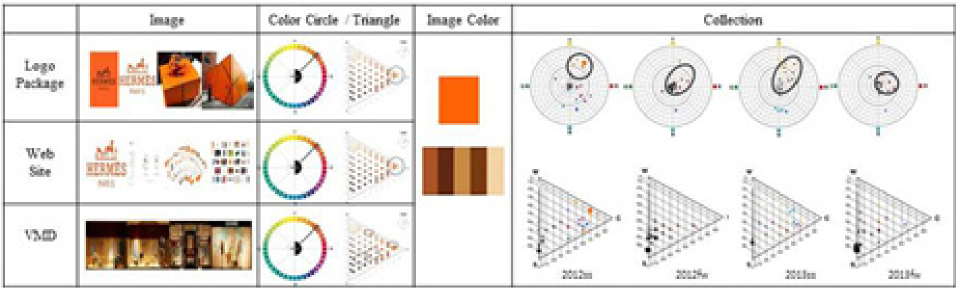

Figure 1. Color identity establishment of Hermes.

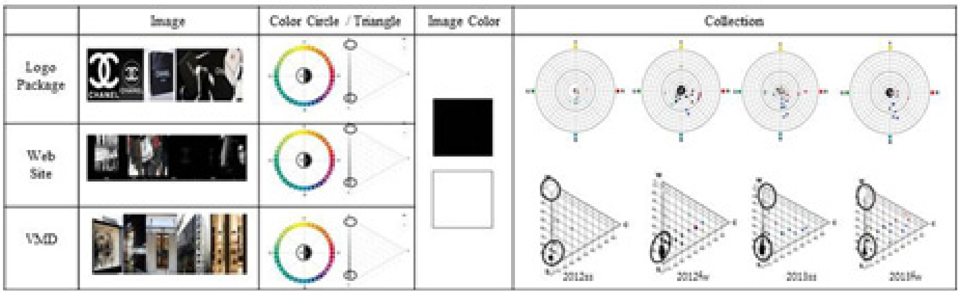

Figure 2. Color identity establishment of Chanel.

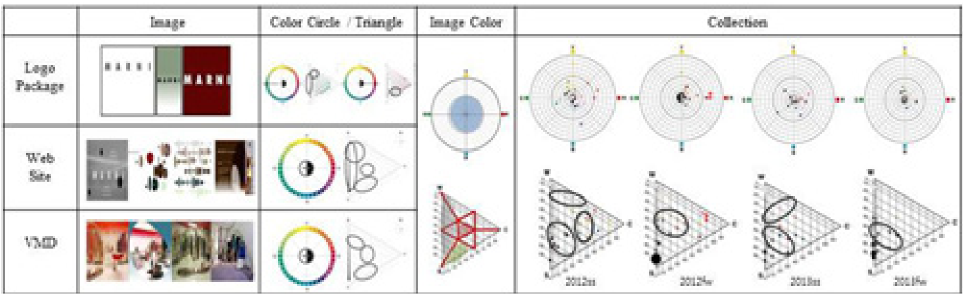

Figure 3. Color identity establishment of Marni.

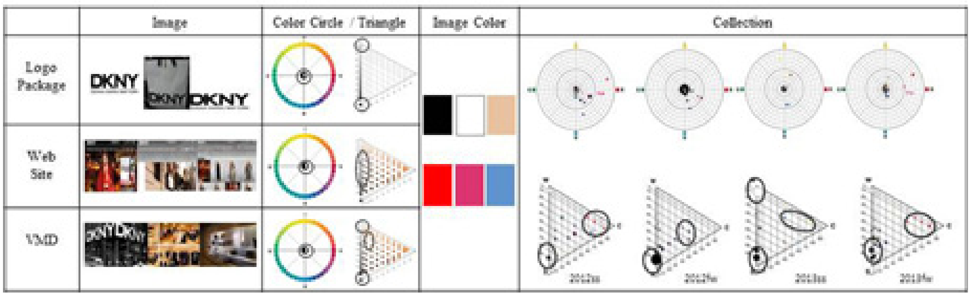

Figure 4. Color identity establishment of DKNY.

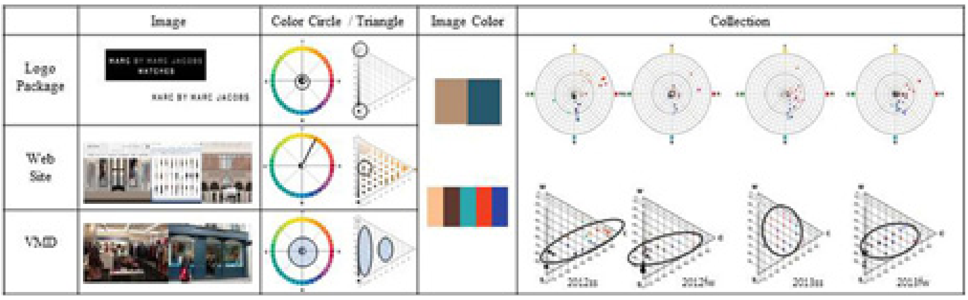

Figure 5. Color identity establishment of Marc by Marc Jacobs.

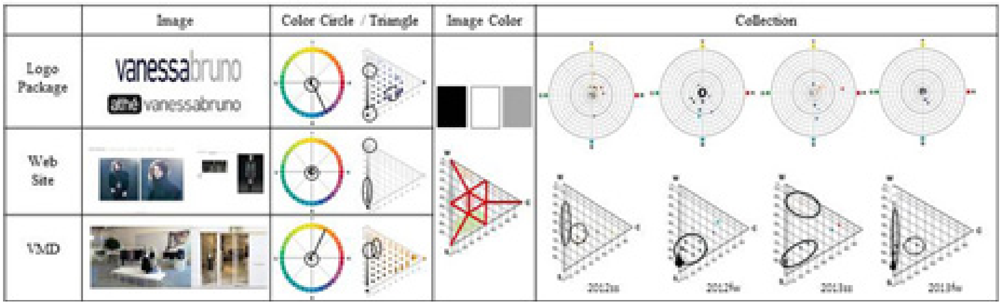

Figure 6. Color identity establishment of Vanessa Bruno.

4. CONCLUSIONS

In contemporary times in the middle of brands flood, identity is extremely important for consumers to recall a brand. This study thus compared and analyzed some prestigious and contemporary brands with a success story of color scheme for color identity establishment in terms of methods to express an identity color. The findings led to the following conclusions: first, a brand's image color to express its identity is expressed via all the components of a brand rather than just one element. Second, prestigious brands have their image colors established in their heritage and characteristics and express their identity colors through various elements. Given the characteristic of being born out of trends, contemporary brands have the most powerful image color expressions through products and utilize the other elements as a means of highlighting products in many cases. Finally, in term of ways to express a color identity, prestigious brands display diversity through products, logos, packages, store organization, and marketing, whereas contemporary brands usually focus on presenting it in a tone through products and marketing.

The characteristics of fashion allow a fashion brand to express its color identity with one color and further present its image colors and establish its color identity through certain color tones and arrangements. Methods of expressing an identity can vary according to the backgrounds, histories, and approaches towards consumers of brands. Color schemes can develop according to the brand characteristics. Fashion brands in the middle of increasing standardization should be able to plan an image color to express themselves, establish a color identity, and solidify a brand identity, thus creating high value added.

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Relationship between Color Design of Package and Consumers' Image:
In the Case of Shampoo Container in Japan

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ABSTRACT

We suggest in this paper color combination of shampoo container which contributes to the transmission of brand image to consumers. First of all we picked out words which indicate features of existing shampoos and its brand image and considered the relation between those words and colors concerned to them. In the second place we measured the colors of shampoo containers which are sold currently in Osaka and Nara Prefecture of Japan by the visual colorimetry and classified the result of the visual colorimetry into the base color, the assorted color and the accent color. We showed then the words to the subjects whose each evokes image and searched the imaged color of the words. The result of the research was as follows and it was very interesting. The image of the base color of shampoo containers approximated to the image which the subjects expected for a shampoo. The subjects liked the base color of the similar value and chroma as for assorted color and accent color. The same hue was liked when an accent color and an assorted color made contrast tone. The color combination of assorted color and accent color affected the image of a shampoo container. The way to transmit product's concept and image effective to the consumers was clarified in the consideration of the relationship between product's brand image and color of the products. This result is useful for marketing of putting new shampoo as a product on the market.

1. INTRODUCTION

Image of good is made from elements, such as a commercial message, as a form of a packing container and color, because consumers who buy goods are affected by the design. When a consumer selects a specific good from a group of goods, color plays there important role. It is a shampoo container that is very remarkable under various goods in a supermarket or a drag store. Multifarious shampoos of various manufactures sell in the stores in Japan. Facing this situation consumers decide to select a shampoo container referring to the price of the good, the quality of the good and its power to appeal. We understand that an effect of color as the power to appeal affects the consumer's interest. Colors of the goods should not be used for attractiveness only. If the color is used effectively to a package, the image of a good is made which corresponds to the consumers liking. There was the precedent study on Shampoo container to promote consumer's purchasing activity with the point of Kansei Engineering (Jeong, Koh and Toyoguchi 2006). Jeong et al. showed that yellow, orange, purple, and red were not liked etc., although white and blue shampoo containers were liked. But a shampoo of red (2006) container and purple (2007) container is put on the market from the major company in Japan, and these containers hold a high position of the popularity rank of the shampoo (shampoo-ranking 2013). There are many colors used to the shampoo container on the market. That is, the color design of a shampoo container is very important in order to offer the image which matched consumers' liking. We made furthermore a multicolor stimulus on the base of the data about the color combination of the existing goods.

2. METHOD

We picked out words which indicate features of the existing shampoos and its brand image and considered the relation between those words and colors concerned to them. We measured then the colors of shampoo containers by the visual colorimetry and we classified the result into the base color, the assorted color and the accent color. After that we examined the relation of the colors.

2.1 The words evoking image of the existing goods

The words showing the characteristic of a shampoo, an image, etc. were extracted from the homepages of the seven well-known makers of Japanese cosmetics and daily necessaries. Furthermore, we excepted the similar words of the extracted words and newly categorized. We examined the color which correspond to the color name. (Japan Color Research Institute 1993). These words which make image of the existing shampoo are applied to the color combination in this study.

2.2 The color combination of the existing shampoo container

We measured visual the color of the shampoo container with color charts[1] (Figure 1) at the supermarket and the drugstore in 7 places of Osaka and Nara Prefecture of Japan. And we categorized those colors into the base color, the assorted color, and the accent color. We clarified each relationship according to the difference of hue, and the difference of the tone. In addition, we investigated the appearance ratio of hue and a tone about base color, assorted color, accent color, etc. The size of area was disregarded about the appearance ratio.

2.3 Preparation of model stimuli

We extracted the words from the reference (Japan Color Research Institute 1993), and the words of 2.1. Subjects chose colors from color samples[2] which were suitable for each words. Subjects were 19 to 23 years old, they were five men and 54 women. The spectrophotometer was used for the measurement of color (CM-2600d, product made by KONICA MINOLTA, Inc.).

2.4 Production of the color combination about shampoo container, and examination of the image

As for the stimulus, the base color, the assorted color, and the accent color were horizontally made at proportion of 7:2:1. In addition, the determination of the position of the assorted color and the accent color refered to the existing goods (Figure 2). Subjects were 33, and they were 18 to 23 years old women.

[1] Practical Color Coordinate Sysytem, Color chart (199a), Japan Color Research Co., Ltd.

[2] JAFCA Color Code 40 (JCC 40), Japan Fashion Color Association

3. RESULTS AND DISCUSSION

About 70% of shampoo containers showed the color combination of 3 colors and 4 colors (Figure 3). The most chosen base color of shampoo container in the stores was tint color and white. As for assorted color tint tone and black were chosen. And as for accent color vivid tone, white, and black were chosen (Figure 4). Warm color such as red, reddish orange and orange were chosen as base color. Achromatic color tends to be used as assorted color and accent color.

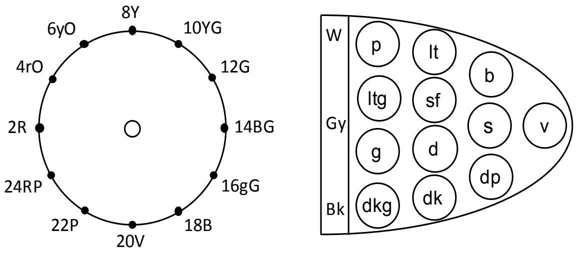


Figure 1: Practical Color Coordinate System.

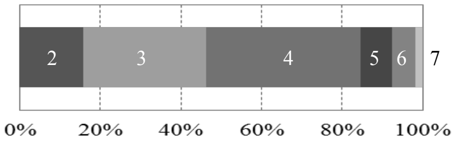


Figure 3: Number of colors in the color combination.

Figure 2: Color combination of a stimulus.

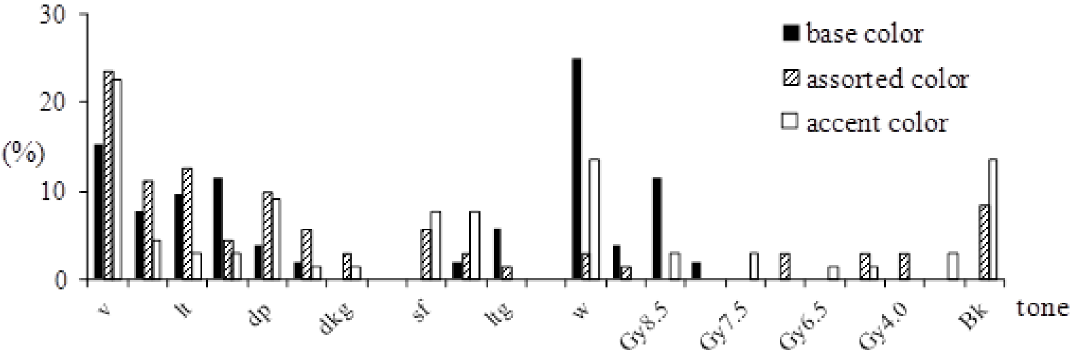


Figure 4: Tendency of the color tone of shampoo containers.

Table 1. The most favorite color combination of shampoo container.

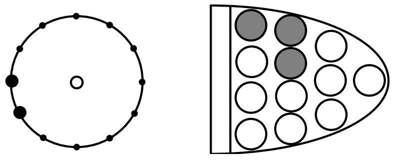
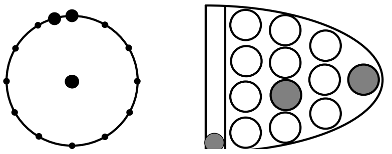
Pretty	Muncell notation	PCCS notation	
Base color	4R 8.0/3.5	p2+	
Assorted color	6RP 6.5/7.5	lt24+	
Accent color	6RP 5.5/6.0	sf24	

Table 2. The least favorite color combination of shampoo container.

Brilliance	Muncell notation	PCCS notation	
Base color	2Y 7.5/13.0	v7	
Assorted color	5Y 6.0/6.0	d8	
Accent color	N1.5	Bk	

60%-70% of the subjects chose the color chart of JCC40 YE1 (2.6Y 7.8/13.4) for the word “brilliance”, and chose the color chart of JCC40 YE2 (5.2Y 8.5/5.6) for the word “creamy”. On the other hand, as for the words “beautiful” and “elegant” there are no specific color that matches the image of the subject. The most liked base color of shampoo container was JCC40 PK2 (4R 8.0/3.5), and the assorted color and the accent color had both similar hue and similar tone (Table 1). The most disliked base color of shampoo container was JCC40 YE1 (2Y 7.5/13.05), as for assorted colors they had adjacent hue and contrast tone, and the accent color had Bk (N1.5) (Table 2).

4. CONCLUSIONS

If the color is used effectively to a package, the image of good which corresponds to the consumers liking is made. The subjects liked the base color of the similar value and chroma in the same way as assorted color and accent color. The same hue was liked when an accent color and an assorted color made contrast tone. The color combination of assorted color and accent color affected the image of a shampoo container. The way to transmit product’s concept and image effective to the consumers was clarified in the consideration of the relationship between product’s brand image and color of the products. This result is useful for marketing of putting new shampoo as a product on the market.

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Colour Palettes in Healthcare Brand Logos

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ABSTRACT

Colour plays a part in strategic decisions related to brand communication and differentiation; it is central to creating and sustaining corporate image, it can stimulate emotional and cognitive consumer responses and influence persuasiveness. Healthcare logos represent particular companies or brands and can carry forward messages for the respective companies or brands. In this work an overview of the general understanding of colour in brand logos and for the healthcare logos is carried out. Cluster analysis is used to identify the colours that are used in UK healthcare brands. For cold, cough and flu products, in particular, the ten most prevalent colours used were identified and their ability to represent concepts that were identified by consumers as important was explored. Generally, the colours were found to represent the concepts with the orange, dark blue and bluish green colours being particularly effective. Other colours (yellow, blue and red) were less effective and resulted in more varied responses from the participants and the poorest scores were found for black and pink.

1. INTRODUCTION

Logos are designed for a company, product or service to create recognition to make audiences feel safe and trusting of a particular company (River 2003). Especially, corporate brand logos have a great impact and meaning to present their brand identities that become a visual language to communicate with the consumers (Lupton 1996). Marketing research indicates that colour is the largest single factor in a decision of whether or not to make a purchase and consumers recognise specific brands of products by their colours (Bleicher 2012).

Colours in logo designs tell a story and send a message (even convey emotion) that are experienced on many levels: conscious and unconscious, sensory and intellectual often all at the same time (Holtzschue 2006). Colours in healthcare brand logos seek to represent trust and create a positive impression in consumers' minds. For designing healthcare brand logos, it is particularly important to choose the right colours for representing the health-related attributes. Therefore, this paper reviews the general understanding of colour in healthcare brand logos; the purpose of healthcare logos and the most popular colours that are used. It then investigates and analyses the current colour palettes of the UK healthcare brand logos as the next step. In this paper, colour palettes of some examples of UK healthcare brand logos are explored and anaysed. Especially, for cold, cough & flu sector of UK healthcare brand logos, a colour experiment is conducted by using the extracted colours (colour palettes) to investigate how the colours represent colour semiotics of the most considerable factors for buying medications within this sector.

2. COLOUR IN HEALTHCARE BRAND LOGOS

The healthcare industry is vast and encompasses healthcare equipment and services, biotechnology, pharmaceuticals and related life sciences (Lidstone and Maclennan 1999). To design healthcare logos, design elements (such as colours or fonts) are significant factors that must be carefully considered to symbolise the healing of an entity (Hosking and Haggard 1999).

The purpose of healthcare brand logos is to convey the message of its product or service that can be effectively rendered. It has to represent the trust of the concerned people and leave behind a positive impression in their minds. Furthermore, the healthcare brand logo design embodies a particular company or brand that carries forward the message of the respective companies or brands.

Healthcare brand logos are known to incorporate blue, green, red and grey. Blue, green and red carry a note of vitality and freshness; they are very bright colors and have an inspiring feeling into which one can delve. In general, green and blue are the most preferably chosen colours for healthcare logo designs to render a look of cleanliness and wellness (Beckwith 2000). The colours also indicate hospitality to be assured of getting and includes the note of care and concern in almost all healthcare brand logos (Dalke and Matheson 2007). For healthcare logo designs, colors such as white, black, brown or beige are also sometimes used to provide a professional look to a healthcare logo and some more soothing colour can also deliver healing attributes and the message of care.

3. METHOD

In this study, five different healthcare sectors were chosen to collect the logos which were 1) Condom & sexual health (11 brands) 2) Cough, cold & flu (57 brands) 3) Diagnostics & electrical health (42 brands) 4) Incontinence (13 brands) 5) Sleep, stress & energy (42 brands). Logos from each of the sectors were collected and put together to form a single image (collage) representing the sector. Figure 1 illustrates the image that was generated for the 57 brands' logos of the cough, cold and flu sector within the UK market.

Figure 1: Example image for the cough, cold & flu healthcare sector.

Each of the digital images were assumed to be in sRGB format. The sRGB values were converted to CIE XYZ and then CIELAB space. The images were processed using software written in the MATLAB programming environment to perform a cluster analysis in CIELAB space. The MATLAB command *kmeans* was employed which implements the k-means clustering method (MacQueen, 1967); this is a method of cluster analysis which aims to partition *n* observations into *k* clusters in which each observation belongs to the cluster with the nearest mean. A total of 11 clusters were extracted from a set of images. In case the most populous cluster was white and this is because of the white background and this cluster was ignored leaving 10 colour clusters per image. Each cluster was represented by a centroid in CIELAB space and each of the centroids was converted back to sRGB space for display (see in Figure 2).

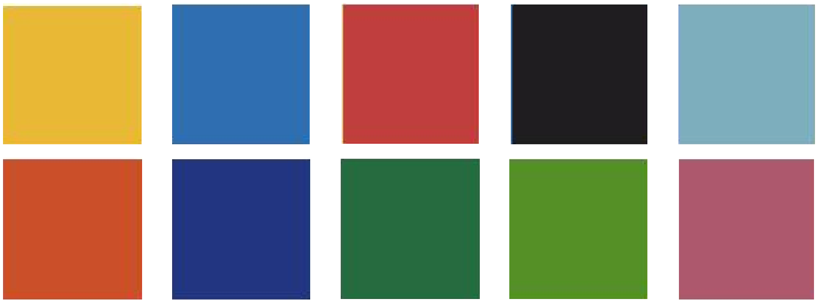

Figure 2: Centroid colours for Cough, Cold and Flu sector.

This experimental study took two-stages; firstly, respondents (15 people) were asked to identify the most important factors when they buy medications for cold, cough & flu; secondly, 10 of these respondents were then further recruited to the colour semiotics experiment. The participants for the experiment were recruited from the School of Design students of Leeds University and they were experienced in colour and design. First of all, the five most considerable factors for buying cold, cough & flu medications were noted as effectiveness, cost, healthy, safety and brand. In the colour experiment part, participants were presented with colours (Figure 2) and asked how much each of these colours represent the five distinct factors; effectiveness, cost, healthy, safety and brand. The questionnaire was designed using a five-point Likert scale (strongly disagree =1 to strongly agree = 5). In the case of "brand' factor, for example, if the colours can be associated with some brands, participants would answer rather strongly agree.

4. RESULTS

In Figure 3, for each of the ten colours the mean scores are given for each of the factors that were identified by consumers as being important. Generally the mean scores for the factors were 3 or more indicating that the participants agreed, at least somewhat, that the colours represented all five factors. However, the strongest association was found for 'safety'. Two colours (pink and black) on average gave weaker associations and three colours (orange, dark blue and blusish green) gave the strongest associations. The factors 'cost' and 'brand association' scored poorly for the yellow colour; however, the 'brand association' factor, in particular, showed high variability in response from the participants (not shown in the Figure). The strongest associations were found for 'healthy' (bluish green) and for 'safety' (light blue and bluish green). For the blue colour, the 'brand association' scored highly followed by 'safety' and 'healthy'. Similarly, 'brand association' was the highest score for the red colour. All five factors gave low scores for the black colour and 'healthy' was the highest level in case of the light blue colour. In the case of the orange colour, 'brand association', 'effectiveness' and 'safety' scored particularly strongly. The factor 'safety' was positioned peak for the dark blue colour and 'healthy', 'effectiveness' and 'cost' factors are followed within the high levels. For the bluish green colour, the 'safety' and 'healthy' occupied the top positions with the reasonable agreement between participants and the 'cost' and 'effectiveness' were also high points ranking being similarly with the dark blue colour. For yellowish green, 'safety' and 'healthy' were graded the highest.

	🟨	🟦	🟥	⬛	🟦	🟧	🟦	🟩	🟩	🟪
	yellow	blue	red	black	light blue	orange	dark blue	bluish green	yellow green	pink
Effectiveness	3.10	3.00	3.50	2.40	3.00	4.00	3.70	3.50	2.80	2.00
Cost	2.70	3.50	3.30	3.00	2.90	3.40	3.50	3.50	3.20	2.60
Healthy	3.40	3.60	3.10	1.90	4.10	3.50	3.80	4.10	3.70	1.80
Safety	3.50	3.70	3.10	2.30	3.90	3.80	4.00	4.20	3.80	1.90
Brand association	2.40	3.80	3.80	2.40	2.90	4.00	3.40	3.50	3.40	2.00
Pooled Mean	3.02	3.52	3.36	2.40	3.36	3.74	3.68	3.76	3.38	2.06

Figure 3: Mean scores for association of colours with each of the factors.

5. CONCLUSIONS

An analysis of colour for cold, cough and flu products has been carried out. The ten most prevaelnt colours used by UK brands in this sector were identified and their ability to represent concepts that have been identified by consumers as important was explored. Generally, the colours were found to represent the concepts with the orange, dark blue and bluish green colours being particularly effective. Other colours (yellow, blue and red) were less effective and resulted in more varied responses from the participants. Pink and black gave the lowest scores despite black being a very common colour used in the logos of products in this sector. Further work is underway to explore colour combinations which might explain why black is effective.

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The Influence of Colour on the Consumer Perception of a Brand, through its use in Logo Design and Packaging

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ABSTRACT

This study concerned an investigation of the extent to which consumer perceptions of brands, based on packaging and brand logos, can be influenced by colour alone, as predicted by theories of colour psychology. Consumers are surrounded by/influenced by brands on a daily basis. The research attempted to discover the extent to which colour can be used in branding as a tool by which one might influence consumer perception through effective logo design and efficient packaging.

An experiment was designed to establish the extent to which colour might influence observer perceptions of both a packaged product (a chocolate bar) and a brand (based on the logo). Analysis of the resulting data revealed that strong connections could be made between existing theories of colour harmony and psychology, and consumer perception.

1. INTRODUCTION

The concept of the "brand" has a significance that is more than just a name or a logo, it represents the personality of the company. Consumers form relationships with brands. It is therefore vital for companies to create brand identities that represent the personality of their brands appropriately. A brand logo is arguably the most important tool that a company possesses with regards to communicating brand personality, and colour is an extremely important component of this. This research was designed to investigate and establish the extent to which consumer perceptions can be influenced by colour and colour combinations, using specifically designed examples of packaging and of company logos. It involved analysing observer responses to carefully constructed questions, taking into account the theories of colour perception, colour harmony and colour psychology. Data were collected from fifteen observers, based on their perceptions of five sample sheets. Each sheet contained eight or ten carefully designed images of either product packaging or brand logos. In each case, the observers were asked a number of questions and requested to give one answer to each question, based on their initial reaction. Data were recorded and subsequently analysed in an attempt to fulfil the aims of the study.

2. METHOD

The main aim of the experiment was to establish whether or not colour/colour combinations play(s) an important role in contributing to the reactions of the consumer towards a product and a company logo. The research was aimed at establishing the responses that the specific colours of the packaging provoked in terms of price, quality, eco-friendliness and personal preference, as well as reactions to specific logo colours in terms of perceived brand personality. Additionally, with regard to brand logos, colour harmony relationships were investigated. Also sought were observers' views of the influence of brands and the importance of colour as a component of brand identity.

2.1 Brand-related statements and responses

Four key statements were used. They were designed to gain an insight into how consumers feel about brands and to what extent they are affected by brands: *“When buying a product, I am influenced by brands”; “Colour plays an important role in brand recognition”; “Colour is THE most important component of a brand’s identity”* and *“Brand colours reflect the personality of that brand”*. Data were collected by a categorical judgement method (Likert scale), whereby observers were asked to give their responses to each statement as a number from 1 (strongly disagree) to 5 (strongly agree).

2.2. Chocolate Bar Wrappers

Chocolate bar wrappers were chosen as the best form of packaging to use for this research, because they concern products with which the majority of consumers are familiar. There also tends to be fewer associations made between colour and flavour than with other products (e.g. crisps, where packet colours are commonly used to denote the flavour). There are ranges of well known brands (using different brand colours) within the chocolate bar market. One of these brands, Cadbury, dominates the market, therefore, attitudes towards a purple chocolate bar wrapper are likely to be affected because of this, and were considered in the data analysis. The shape, size and proportion of the chocolate bar wrapper images that were presented were designed to be generic, (Figure 1a). Ten different colours were chosen for the wrappers: red, orange, yellow, green, cyan, blue, purple, magenta, black and white.

The observers were asked to look at the samples provided and answer the following questions, based on their emotional response to the images: *“**which of these products** is the cheapest? /... most expensive? /...best value for money? /... the healthiest? /... least healthy? /... uses fair trade ingredients? /... will taste the best? /... would you buy?”*

Figure 1: Design of (a) chocolate bar wrappers and (b) company logos

2.3. Brand Logos

A generic company logo aimed at provoking minimal emotional response from each observer in terms of both association with existing companies and with a specific industrial sector was designed, (Figure 1b). It was decided that the fictional brand would be a website since this should help to limit preconceptions that could be associated with the commercial sector. Introducing a “.com” component enabled two different colours to be used within the text. “JSKM” was used as a seemingly random collection of letters that was unlikely to have any significance to an observer, while still representing a realistic company logo. A 1pt. thickness underline, that could provide an additional colour, was added. A coloured background was used in some cases. The eight hues that were used for the chocolate bars (black and white were excluded) were used throughout.

Sample Sheet 1 consisted of eight logos, each representing one of the eight aforementioned hues. In each case, the “JSKM” and the underline components of the logo were coloured, the “.com” component remained black, to emphasize the colour differences whilst also improving the aesthetic quality of the logos. Sample Sheet 2 was designed to establish each person’s responses to different complementary colour relationships. The eight hues were paired to give three sets of complementary colours, based on Itten’s Colour Star: red-green, blue-orange, purple-yellow (Holtzschue, 2006), and a magenta-cyan pair. Half of the logos on this sample sheet used the more dominant (darker) colour for the "JSKM" and the underline components, the other colour of the pair was used for the ".com" part. The remaining four logos on this sample sheet had the lighter colour forming a background for the text (coloured in the darker colour of the complementary pair) to study the effect of background colour.

Sample Sheet 3 consisted of six examples of triadic colour relationships, and two examples of analogous relationships between three colours in each case. A triadic relationship is a set of three colours which form a triangle between one another on the colour wheel, or in Itten's colour star (Holtzschue, 2006). These relationships were; blue-red-yellow and orange-green-purple. There were numerous colour variations possible, therefore three logos (for each triad), which were significantly different but all equally aesthetically pleasing, were used. The remaining two logos on this sample sheet illustrated examples of analogous relationships; i.e. three neighbouring colours on the colour wheel. (red-orange-yellow and purple-blue-cyan) to determine whether there was an observer preference for triadic or analagous colour relationships. Sample Sheet 4 contained eight logos exhibiting two-colour analogous relationships.

For each sample sheet, observers were asked the following questions: *"**Which company** sells the cheapest products/services? /... sells the most expensive products/services /... is the most reliable/loyal to customers? /...is the most environmentally friendly?"* The final question was: *"Of the four sample sheets, which do you feel displays the most effective set of brand logos in terms of personal preference? Choose ONE."* The purpose of this was to establish which colour harmony relationship, if any, appealed to the observers.

3. RESULTS AND DISCUSSION

The first part of the experiment showed that people are generally influenced by brands, are aware that this is the case and agreed that colour plays an integral role in the brand identity.

3.1 Packaging

Analysis of the results obtained for the chocolate bar wrappers showed that consumer perceptions of products, in terms of price, taste, healthiness, eco-friendliness and overall preference are strongly influenced by colour, (however, results for other packaged products could vary). **Red** was a popular choice with regards to the product chosen for purchase by the observers. Red was strongly perceived to represent good value for money. **Orange** appeared amongst results for almost every question, but was not strongly perceived to represent anything. **Yellow** was the only chromatic colour to be perceived as cheap, it also featured as a popular response in terms of value for money. The **green** product achieved a majority response with regards to healthiness and eco-friendliness, it was generally perceived to be the product containing fair trade ingredients. This result was expected due to green's strong associations with nature and good health. **Purple** was perceived by the majority to represent the most expensive, best tasting and overall favourite product. Its strong associations with luxury and wealth contribute to this, although it is also important to consider the influence that Cadbury might have had on the perceptions of the observers. Finally, the **cyan**, **blue** and **magenta** products rarely featured in observer responses, probably due to their lack of association with food. The **white** product was almost unanimously perceived to represent the cheapest product. **Black** was perceived to be least healthy, possibly due to connotations of danger and death, whilst it also commonly appeared in the fair trade and best tasting categories. It is possible here that observers made a connection between the black wrapper and dark chocolate.

3.2 Brand Logo Design

The results achieved for the logo also show that attitudes towards companies or brands are heavily influenced by the colour or colour combinations used in their logos. Logos that were dominant in **blue**, received very strong responses, particularly with regards to expensiveness, reliability and loyalty, market leading and overall preference. This can be linked with the strong associations found between blue and feelings of authority, reliability and trustworthiness (Ambrose 2011). **Cyan** logos received similar but fewer responses, due to this colour having similar connotations to blue but to a weaker extent. **Green** appeared amongst the results for expensiveness and reliability, and was perceived to represent the most environmentally friendly brand, due to its associations with nature. As with packaging, logos that were dominant in **yellow** were perceived by the majority to represent the cheapest companies while such connections were also made with logos containing **orange**. **Red** did not feature strongly in most cases, although red was perceived by a large number of observers to be present in the logos of market leaders. This was probably due to red's connotations of power (Ambrose 2011), along with the fact that it is commonly used in logo design, being second only to blue. There were no major trends with regards to **magenta**-dominant logos.

In terms of colour combinations, in most instances it was found that the associations of the most dominant logo colour, in terms of area occupied, had the greatest influence. The neighbouring colours within a logo did not generally impact negatively. The triadic colour combinations provoked more varied responses, perhaps due to the fact that the same colour combinations were repeated three times, therefore the logos were not too dissimilar from one another. The complementary relationship between blue and orange proved to be extremely popular in a number of instances, supporting the theory that this is the most appealing and comfortable of complementary hues.

4. CONCLUSIONS

The majority of the results achieved throughout this study can be explained to some degree by the theories of colour psychology. There were minor exceptions that could be explained by personal preference or experience. However, in general, it appears that a knowledge of colour harmony and psychology theories can be implemented into the design of packaging and brand identity images, if one wishes to influence consumer perception.

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Factor of Brand and Packaging Has Effect the Selection of Cosmetics for Male

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ABSTRACT

This research aims to show the main influences that attract the consumers who are making their decision on buying the cosmetics for men through considering on brand and packaging. The result of study has found that the cosmetics for men that mostly the sample have used to using is face cleaning. The main factors of the decision on buying the cosmetics for men are the differences of the physical condition between male and female for example facial skin, hair etc. The proper brand on the cosmetics for men is able to represent to the identity of male and it has to avoid the symbol that can be related to or to show the femininity. The label of the cosmetics for men product should be in the color of black, dark blue, brown, white, light blue, grey, silver and green, owing to the indication of masculinity, firmness and calmness. On the other hand, the color of pink, purple, gold, beige, red, orange, green and yellow, the sample recognizes that they are the symbol of obviously femininity. Branding is the most important thing to persuade the male consumers. In case there is “For Men” on the label which is the mental suitability on their mind. The sample has agreed that the package of the cosmetics for men product has not affected to their buying decision (70.8%) because of non senses in usage. On the other hand, the sample has realized that the package is important to their buying decision. In their opinion, the proper package should be indicate the masculine image and emphasize the personal care product “For Men” exclusively. Also, the package can be the indication of personality and the characteristic of consumers which support their confidence.

1. INTRODUCTION

In the past, most people doubted males who took care themselves or look good all the time that were they gay? Nowadays those attitudes have gone. Because of the results of the research randomized study of the modern male in Bangkok quantity 200 males. Found that most males were not interested who took care themselves must to be always gay.

By males 91% thought that they should be took care themselves as same as females. Males 84% accepted that they tried to make themselves look good for as much males had good personality and took care themselves. They has been recognized and be appreciated by most people including feel self-confident themselves more than former. Further, modern males felt attention and focus about the beauty. Consumption behavior resulted the market’s Metrosexual grown continuously and the total value of sales surged than 10,000 million baht. These figures point to a picture of the competitiveness and growth of the market is enormous. This is a great opportunity for entrepreneurs and SME’s in Thailand took part in this market. When males are most important to beauty each other and habits’ males usually do not care about the price or promotion but focus on the quality of the products or the brand equity. With the purchase habit of males are fast. The company related the beauty and famous cosmetics manufacturer use proactive marketing strategy in the male cosmetics believe that the business of male cosmetics market can grow again.

2. METHOD

2.1 Population and the samples

The samples were selected from population who lived in the total 50 districts in Bangkok. There are 5,712,636 people. By the researcher determine the sample size use model purposive sampling from 400 males who live in Bangkok and used to using cosmetics for men.

2.2 The data analysis

1. The collected data was analyzed by using the descriptive SPSS for Windows.
2. The perceptions brand equity analysis and package by using the descriptive Mean and Standard Deviation.
3. Correlation analysis between the perceptions brand equity with the decision in choosing the brand equity of male cosmetics by using the descriptive Multiple Regression Analysis: MRA

3. RESULTS AND DISCUSSION

Hypothesis test

The 1st hypothesis, the personal factor has affect to recognize the label of the cosmetics for men differently. The result has shown that the consumers of the cosmetics for men have status, education level, occupation and average income per month which is diverse. So, these factors of their buying decision is various significantly on 0.01. However, the consumer of the “For Men” personal care product who are in the different age, the influence of their buying decision is not quite different significantly on 0.05 as shown in Table 1.

Table 1. Shown the comparison between the personal factors and the label.

Personal factors	Statistic value	Sig.	Hypothesis test
Age	F = 2.142	0.094	Rejected
Marital status	F = 6.884	0.001**	Accepted
Education level	F = 5.280	0.005**	Accepted
Occupation	F = 6.110	0.000**	Accepted
Average income/month	F = 5.649	0.001**	Accepted

*Significant statistic level 0.05 ** Significant statistic level 0.01

Table 2. Shown the comparison between the personal factors and the package.

Personal factors	Statistic value	Sig.	Hypothesis test
Age	F = 0.134	0.940	Rejected
Marital status	F = 0.992	0.372	Rejected
Education level	F = 1.511	0.222	Rejected
Occupation	F = 2.051	0.071	Rejected
Average income/month	F = 1.847	0.138	Rejected

*Significant statistic level 0.05 ** Significant statistic level 0.01

The 2nd hypothesis, the various personal factors relate to the opinion of package. The study has found that the consumers who have the different factors such as age, marital status, education level, occupation and average income per month, are unrelated to the package of the cosmetics for men at significant statistic level 0.05 as shown in Table 2.

4. CONCLUSIONS

1. The result of research has found that the consumers of the cosmetics for men are in the high level of the opinion of the label. The main conditions satisfy the consumers extremely which researcher has suggestion as below.
    - 1.1 Awareness, the entrepreneurs should discover the new knowledge which are able to apply to create the awareness the consumers of the cosmetics for men. The product should have the label or brand which indicates that the product for men and put the word "For Men" for showing the product is especially for men. Because the product has to show or represent to the masculinity.
    - 1.2 Design and font on label, the entrepreneurs should create the design to be simple and uncomplicated which can indicate the personal care product for men. There is NO the gentle design or any curves.
    - 1.3 Benefits, the entrepreneurs should manufacture the product to be more effective and suitable to male than female. The effective cosmetics for men always has the label. Moreover, the entrepreneurs should be the company that is famous and believable with the label of the "For Men" personal care product also represent the masculinity.
2. The result of research has shown that the consumers of the cosmetics for men are in the high level of the opinion of the package. The main conditions satisfy the consumers extremely which researcher has suggestion as below.
    - 2.1 Usability, the entrepreneurs should create the package to be comfortable usability and carriage. The size of product should be fit and durable.
    - 2.2 Design and font on package, the entrepreneurs should create package to be clear, simple and uncomplicated. Also, the design represents the masculinity such as strength, solemnity and firmness with using the straight line, the cubic graphic and font. The package should be NO the line, any curves or any symbol that can relate to the femininity.

ACKNOWLEDGMENT

The research show that brand and packing of the cosmetics for men product has not affected to their buying decision (70.8%) because of non senses in usage. However the proper brand and packaging of the cosmetics for men have to represent the identity of male and it has to avoid the symbol that can be related to or to show the femininity.

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A Design of Color Space of Volumetric Display System (CSVDS)

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ABSTRACT

The color space like CIELAB that has 2 dimensions color and luminance perception is a three dimensional space. In color education, teachers can't show the volumetric color space on a plane display because a plane display can only display two-dimensional plane image. This paper propose a design of color space of volumetric display system (CSVDS) to show a volumetric color volume of a display. CSVDS we designed in this paper contains a color sensor system, a personal computer (PC), a microcontroller unit, and a LED (Light-emitting diode) volumetric display system. The LED volumetric display system contains FPGA, LED driver IC, and 21^3 LEDs that are tri-primary color LED. FPGA will allot the signal to LED driver IC separately that can driver LED for different brightness steadily by Pulse-width modulation (PWM). Finally, the colors of display color volume can be shown in the volumetric display system. CSVDS not only can show a volumetric color volume of a display, but also is proposed to applied for the color appearance model of lighting. This device can make us see the color perception of the lighting, and provide a good media display platform for the color teaching and the color space showing.

1. INTRODUCTION

All the time, in order to meet the demand of human in different domains that are like printing, textile industry, paint, display, lighting, many color systems use the words, color chips, or the number and letter to describe the colors. Product designers always used the color chips to compare and verify the product colors, but the color appearance of the color chips always vary in different reference illuminants. Moreover, the color space like CIELAB that has 2 dimensions color and luminance perception is a three-dimensional space. In color education, teachers can't show the volumetric color space on a plane display because a plane display can only display two-dimensional plane image. Therefore, this paper propose a design of color space of volumetric display system (CSVDS) to show a three-dimentions color volume which is shown in CIExyY, CIELAB color space, or other three-dimensional color space.

2. A DESIGN OF CSVDS

CSVDS we designed in this paper contains a color sensor system, a personal computer (PC), a microcontroller unit (Advanced RISC Machine, ARM), and a LED volumetric display system as Figure 1 showing. The color sensor system can feedback, amplify, and process the voltage of the tri-primary color sensor as digital voltage to obtain the color information by the appropriate calibration. Then this color sensor system of Figure 1 (A) can measure the display characters like its primary colors and maximal brightness for color volume construction. PC will calculate the color volume of the display by our color volume boundary theory of multi-primary color from the additive color mixing theory (Ou-Yang 2007, Huang 2009). Further, the corresponding LED driving signal will be inverted from the colors in color volume of the display. ARM of Figure 1 (C) will transmit and allot the signals to Field Programmable Gate Array (FPGA) of Figure 1 (B). The 21^3 LED volumetric display system as Figure 2 showing contains FPGA of Figure 1 (B), LED driver IC of Figure 1 (D), and 21^3 tri-primary color LEDs of Figure 1 (E) that are composed of 21 layers of 21*21 Led array.

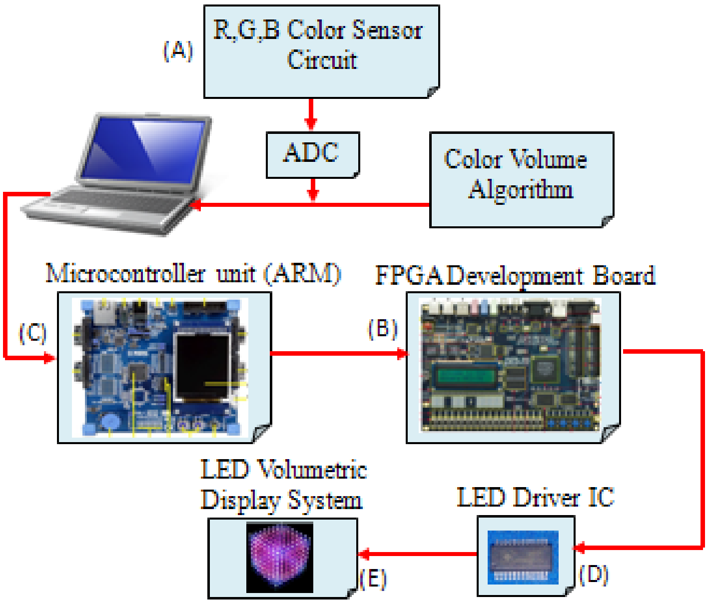


Figure 1: A signal flow-chart for color pace of volumetric display system (CSVDS).

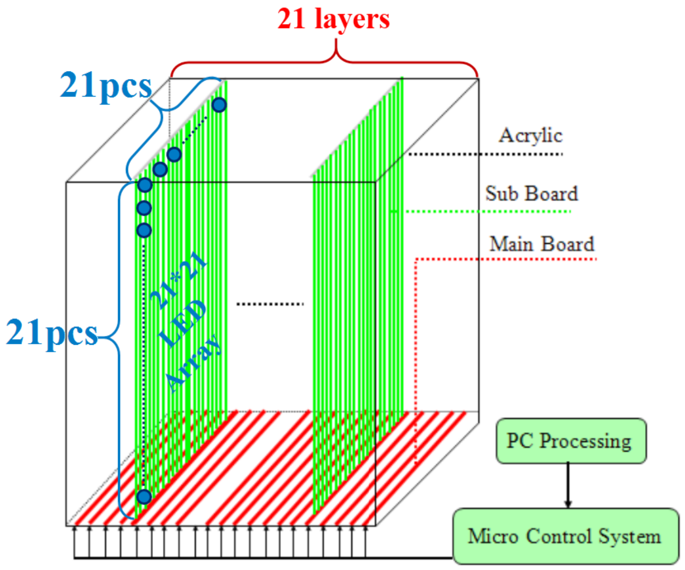


Figure 2: A signal flow-chart for color pace of volumetric display system (CSVDS).

As Figure 2 showing, there are 21 main-boards marked as red lines, where each main-board conect 21 sub-boards marked as green lines. ARM will allot the signals to each main borad separately as Figure 2 showing, and FPGA on the main-board marked as the red rectangle in Figure 3(A) will allot the signals to LED driver IC on the sub-board separately. Four LED driver IC marked as the black rectangles on sub-board in Figure 3(B) can driver LED for different brightness steadily by Pulse-width modulation (PWM). Finally, the colors of display color volume can be shown in the volumetric display system.

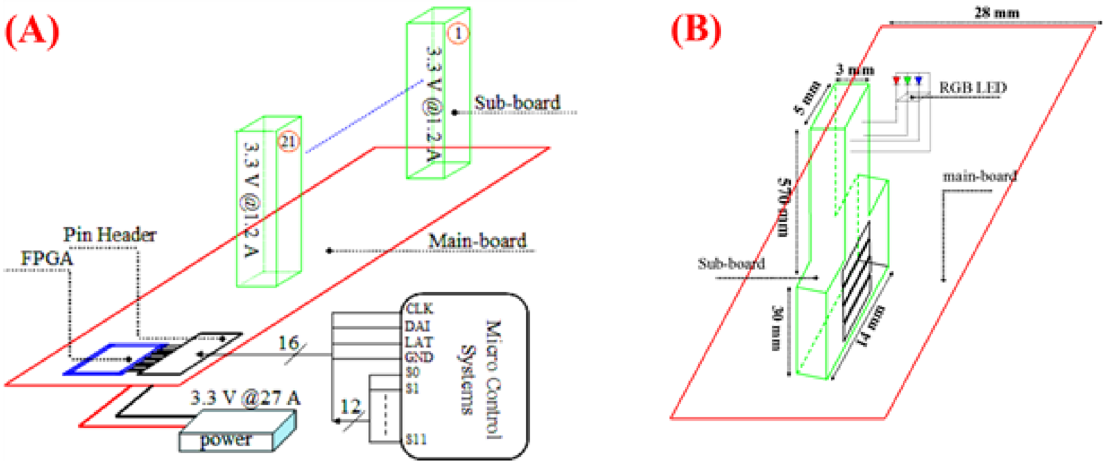


Figure 3: (A) The diagrams of main-board. (B) The diagrams of sub-board.

3. EXPERIMENTS OF ONE LAYER OF LED ARRAY

The system of one layer of LED array was implemented as Figure 4 (a) showing for demonstrating one layer main-board of CSVDS verification.

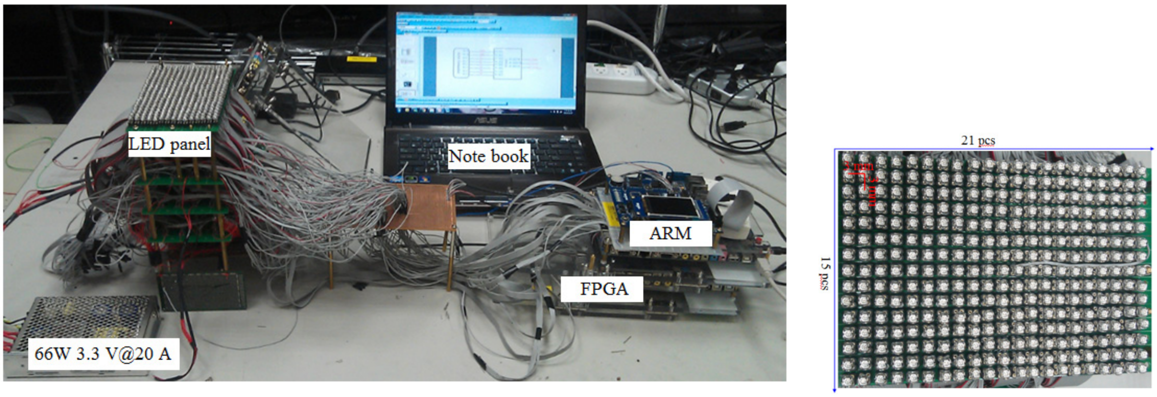
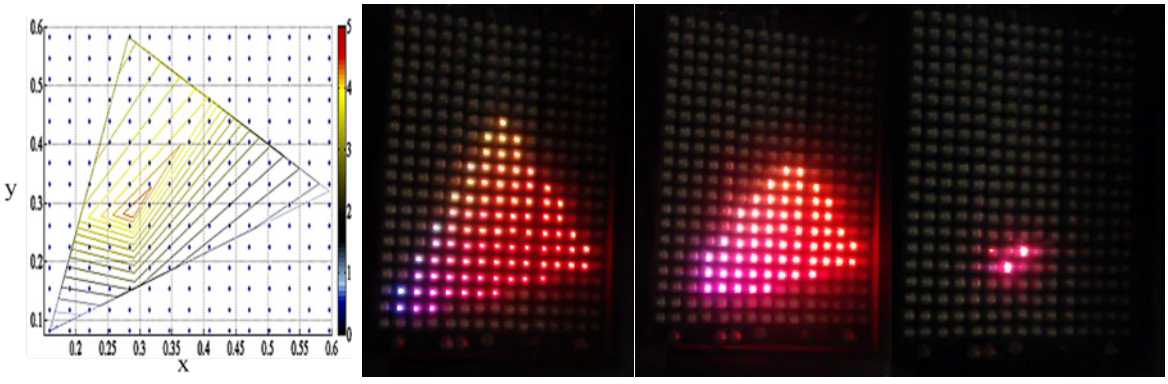


Figure 4: (a) The system of one layer of LED array. (b) The diagrams of 21×15 LED array.



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

Figure 5: (a) The gamut of various luminance of a display. (b)-(d) The gamut of low, medium, and high luminance show on one layer of 21×15 LED array.

This system contained a NB, ARM (LPC 1768), FPGA (DE2-70), power supply (RS-100-3-3, 66W, 3.3V@20A), LED array. The LED array of display has 21×15 LEDs as Figure 4 (b) showing, where LEDs are the tri-primary color LEDs (LL-U42RGBC2B-016) that driverd by the LED driver IC (DM634). The color gamut of color volume for one display will reduce when the luminance of color gamut varies from low to high as Figure 5 (a) showing (Ou-Yang 2007, Huang 2009). The three color gamut of color volume with three different luminance were shown on this system as Figure 5 (b), (c), and (d) showing. The shapes was similar to the color gamut of display, but the color was not correct because the gamut of tri-primary color LED did not match to the gamut of the display.

4. CONCLUSIONS

A design of CSVDS was proposed in this paper for showing 3D color space. One LED array was implemented for demonstrating CSVDS. The shape of color gamut is well but the color is not correct because the gamut of tri-primary color LED did not match to the gamut of the display. CSVDS with wide gamut under the approariate color calibrations not only can show a volumetric color volume of a display, but also is proposed to applied for the color appearance model of lighting. This device can make us see the color perception of the lighting color appearance, and provide a good media display platform for the color teaching and the color space showing.

ACKNOWLEDGEMENTS

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Measurement of Colour Matching Region to Infer Individual Colour Matching Functions

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ABSTRACT

Colour Matching Functions (CMFs) among people with normal colour vision are known to have individual differences. However, it is possible these individual differences in CMFs merely represent the non-discriminable range. In order to verify this hypothesis, we measured the non-discriminable colour range. The test colours presented to the subjects were expressed in RGB colour space of the primaries. 27 colours were represented inside a cube with R, G, and B Cartesian coordinates. The size of the cube was enlarged until all the responses from a subject reached an incomplete match.

An experiment was conducted for 8 different monochromatic lights. 5 subjects participated in the experiment. The obtained range were well-fit by an ellipsoid body and we could find individual differences in each ellipsoid. When reflected to u'v' space they showed similar trends with that of MacAdam ellipse. However, the size of the ellipsoid did not show big differences among subjects. This supports that individual differences in CMFs do exist and do not arise from an experimental artifact. Most of the results obtained with an adjustment method were included in the ellipsoid, but it did not locate at the center of the ellipsoid.

1. INTRODUCTION

Color Matching Functions (CMFs) have been widely used to calculate the tristimulus values. CMFs are the intensities of three primary lights required to match the equi-energy monochromatic lights. There are, however, individual differences in the CMFs even among people with normal color vision (Stiles and Burch, 1959).

Most of the experiments to obtain CMFs implemented an adjustment method in which subjects set the colour of the test stimulus into non-discriminable range of the reference stimulus. It is possible the measured individual differences in CMFs merely represented the non-discriminable range. Moreover, in the previous adjustment method the subject needed to find the right direction of the change, increment or decrement of all the primaries, which was stressful especially for a naïve subject. In order to verify this hypothesis and solve this problem, we proposed a novel method of alternative forced choice method to measure CMFs (Suzuki et al., 2012) using our apparatus (Suzuki et al., 2011). This method was less stressful for the subjects, as they did not have to “create” the right colour. We obtained the similar results for most of the colors with those obtained with an adjustment method, but some were revealed that the subjects chose other tristimulus values. In this study, we used a magnitude estimation method to get a non-discriminable range for each subject. Then, we compare the centroid of the non-discriminable range with the results previously obtained with an adjustment method. Assuming it is necessary to collect data from a large number of the subjects, the method to obtain CMFs should be less stressful.

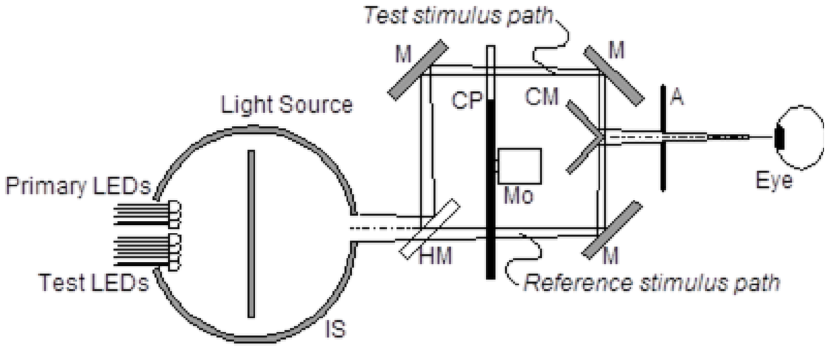

Fig.1 Experimental apparatus (IS: Integrating Sphere, M: Mirror, HM; Half Mirror, CP: Chopper, CM: Corner Mirror, Mo: Motor, A: Aperture)

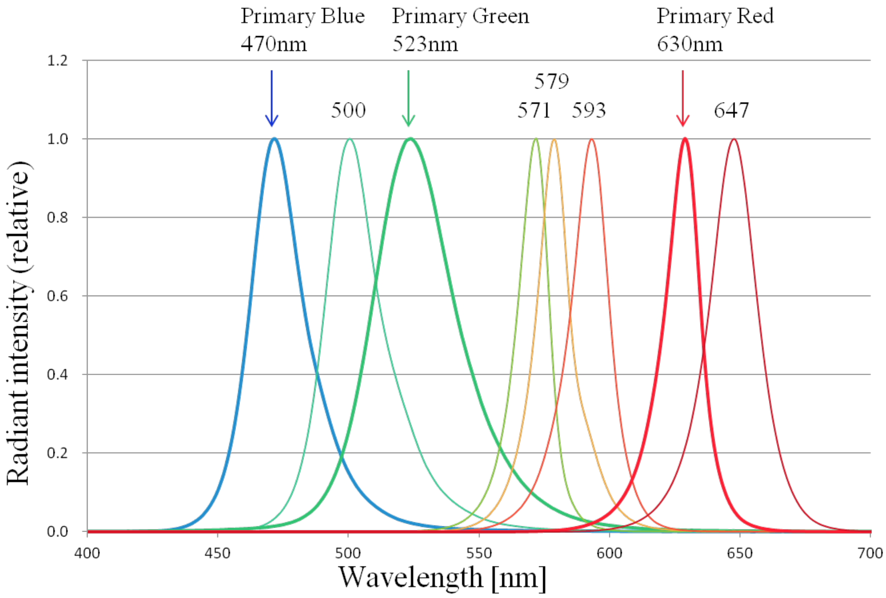

Fig.2 Spectral radiant intensity of the test stimuli used in the experiments.

2. METHOD

Experimental apparatus used in this study is shown in Fig.1. This apparatus used a single light source, in which plural LEDs inserted to a small integrating sphere (6” diameter). All the optical parts were placed on a small breadboard (450mm (17.5”) x 300mm (11.7”)).

The experiment was conducted for 8 different monochromatic lights as the reference: 470, 500, 523, 571, 579, 591, 630 and 647nm. As the test stimuli, the mixture of R, G, B primaries were presented. Their peak wavelengths were 630, 523, 470nm, respectively. The spectral peaks and distributions of the LEDs used in the experiment are shown in Fig.2. The subject responded to a presented stimulus in the following three criteria: (1) Complete match, where the entire field appeared uniform with a non-detectable border, (2) satisfactory match, where the entire field appeared uniform with a detectable border, and (3) incomplete match, where two fields are perceived as different colours.

The test colours presented to the subjects were expressed in RGB colour space of the primaries and were determined based on the mean values obtained from our previous research. 27

colours were presented to the subject. These colours were represented inside a cube with R, G, and B Cartesian coordinates, placing the mean colour at the center of the cube. A set of 27 colours was presented randomly to the subject. As is shown in Fig. 3, the size of the cube was enlarged until all the responses from a subject reached an incomplete match (condition 3).

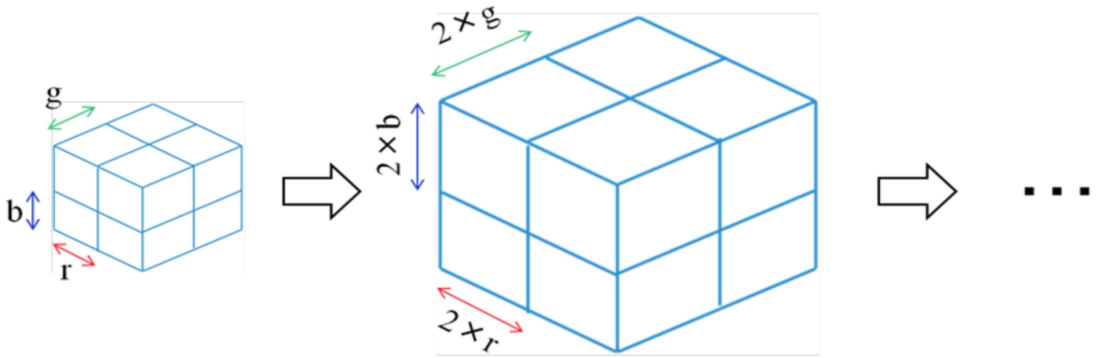

Fig.3 Enlargement of the cube whose vertex and lattice points represent test stimuli.

3. RESULTS AND DISCUSSION

Experimental results, where the colours are non-discriminable (condition 1 and 2) with the reference colour, can be expressed in three dimensional space. It turned out that these ranges were different among subjects. Some subjects responded with a several numbers of test points, while the others responded with a smaller number. The range of the colour matching from conditions 1 and 2 were well-fit by an ellipsoid body and we could find individual differences in each ellipsoid. Compared with the results obtained from the same subject with an adjustment method, most of the colours obtained from an adjustment method were within the ellipsoid. However, some of the adjusted colours were not in the center of the ellipsoid. Fig. 4 shows a fitted ellipsoid reflected to u'v' space for three test colours. Different ellipses show those obtained from different subjects. It is clearly shown that the non-discriminable range had individual differences. Compared with the mean colours obtained from 13 subjects with an adjustment method, it is clearly shown that most of the colours were in the region where the ellipses of the subjects overlap.

They showed similar trends with that of MacAdam ellipse (MacAdam, 1942). In his paper, he described that all the subjects showed a similar trends, but in our cases it was not the case. It must be because the tasks required to the subjects were not the same in these two studies.

4. CONCLUSIONS

Our results support that individual differences in CMFs do exist and do not arise from an experimental artifact. Most of the results obtained with an adjustment method were included in the ellipsoid, but it did not locate at the center of the ellipsoid. We also found that the results were almost the same between an experienced and naïve subject. Consequently, our method works as an effective way of measuring CMFs for variety of subjects.

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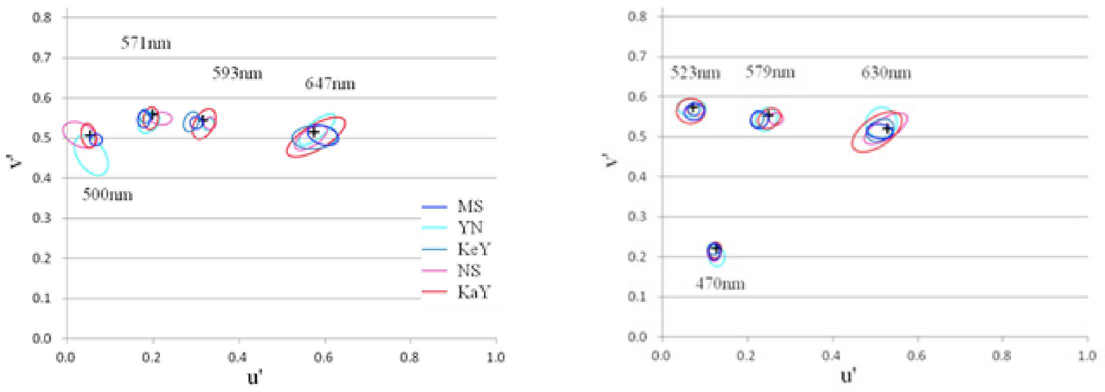

Fig.4 Fitted ellipses of each subject in u'v' colour space. Black crosses indicate the mean u'v' values obtained with an adjustment method for the 13 subjects.

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Spectral Optimizations of White Illuminants under Changes to Standard Observer

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ABSTRACT

Experimental optimizations have been carried out using synthetic spectra to assess the effect of different colour matching functions (CMFs) on the optimization of multi-band white-light spectra. The results indicate that the choice of CMFs has a significant influence on the number and nature of the optimized spectra returned by the process.

1. INTRODUCTION

It was decided to employ a modified version of a previously-published optimization tool based on the Differential Evolution (DE) algorithm (Soltic and Chalmers 2012). Further details of DE are described in Section 2. The previous version was designed to operate using the 2° CMFs since these are almost universally used for expressing the luminous output and colour properties of any light source. The modified version permits a choice between the 2° and 10° CIE colour matching functions (CMFs). It also incorporates a function generator to produce gaussian-shaped spectral functions of a selectable bandwidth, which can be freely set to any centre wavelength (400 – 700 nm) and any relative intensity. As before, computations are carried out at 5-nm intervals.

The purpose of the present DE algorithm is to derive candidate illuminant spectra with an optimal combination of LER (luminous efficacy of the radiation) and CRI (colour rendering index). The correlated colour temperature (CCT) is also computed at the end of the process.

This study has been stimulated by two recent developments: (1) Interest within CIE Division 1 in the definition of different CMFs for different adaptation states, field sizes and ages; (2) An interest among lighting researchers in the potential use of laser mixtures in the design of future white-light sources. Development (1) leads one to consider whether any spectrum that has been optimized for the 2º observer will necessarily also be optimum for different observers under different conditions. It is hypothesized not. In addition, (2) leads one to believe that such differences will be more severe for multi-band illuminants if the bandwidths are significantly less than the 25–45 nm typical of commercial LEDs (*e.g.* 10nm or less). The hypothesis is tested in the work described here which was focussed on illuminant mixtures comprising four bands, each of 5–10 nm FWHM (Full-Width at Half-Maximum).

2. DIFFERENTIAL EVOLUTION

Differential evolution (DE) is an evolutionary algorithm (Storn and Price 1997) suitable for optimization utilizing a real-value multi-modal nonlinear and non-differentiable fitness function. A population of possible solutions is evaluated using the fitness function, and only those solutions having better scores are further optimized and others are discarded from the optimization. After *N* "generations" (cycles of evaluations and optimizations) have been performed, the optimum solution is determined. A "solution" here is the spectrum of the light produced by a mixture of narrow-band spectra, and only those mixtures having better color-rendering and LER characteristics are kept for further optimization. The best solution in cycle *N* is accepted as the best white-light spectrum.

The search for an optimal solution starts with a population of *P* randomly created solution vectors, where each solution vector represents a spectrum comprising four narrow-band (gaussian-shaped) spectra, and each band has its own intensity and centre wavelength. The value of *P* is kept constant during the optimization process, and *P* must be > 4 to provide enough mutually different solution vectors for the algorithm to function properly. This experiment used $P = 80$. The solution vectors undergo evolutionary-type processes (mutation, crossover, evaluation and selection) over *N* generations, with the intention of constantly improving the fitness levels of the members of the latest population. If *N* is too small, DE has insufficient opportunity to explore an adequate number of solution vectors (*i.e.* spectra). However, if *N* is too large the optimization process is unnecessarily slowed down with little or no optimization gain. Here $N = 1{,}000$ was selected.

In this work, the original DE algorithm is used and the following pseudo-code describes its structure:

```
Require: N, P
  Create vectors {$v_{1,0},...,v_{P,0}$}
  Evaluate {$v_{1,0},...,v_{P,0}$} -> $F_{fit}(v_{i,0})$
  for all N
     Mutate $v_{i,N}$ -> $u_{i,N+1}$
     Crossover {$u_{1,N+1},...,u_{P,N+1}$} and {$v_{1,N},...,v_{P,N}$}
     -> {$w_{1,N+1},...,w_{P,N+1}$}
     Evaluate {$w_{1,N+1},...,w_{P,N+1}$}
     if $F_{fit}(w_{i,N+1}) > F_{fit}(v_{i,N})$
          $v_{i,N+1} = w_{i,N+1}$
     else
     $v_{i,N+1} = v_{i,N}$
  end for
```

The success of the DE technique depends on a proper selection of the fitness function F_{fit}, relevant to the purpose of the optimization. Here the fitness function was generalized as shown in Equation 1.

$$F_{fit} = a\times R_a + b\times R_b + c\times R_c + d\times R_{min} + e\times h \qquad (1)$$

where R_a = CIE general CRI; R_b = similar figure derived using the additional 6 test colours in the CRI method; R_c = similar figure derived using all 14 test colours in the CRI method; R_{min} = lowest of the 14 values of R_i in the CRI method; h = symbol for LER (lumens/radiant watt).

Table 1. Coefficient combinations selected for Experiments 1 to 3.

Combination	Experiment 1	Experiment 2	Experiment 3
Fitness Coefficients *a-b-c-d-e*	1-0-0-1-1	1-0-0-2-1	1-1-1-1-1

3. RESULTS AND DISCUSSION

Initial experimentation was carried out with different values of the coefficients *a, b, c, d, e* defined in Equation 1, and with different spectral bandwidths (5–25 nm), to find which combinations yielded interesting results. Based on this, the coefficient combinations shown in Table 1 were selected for further use, and the spectral bandwidth was fixed at 5nm. In each experiment, the optimization tool was given ten consecutive optimization runs with each set of CMFs in turn, and the results are summarized in Table 2.

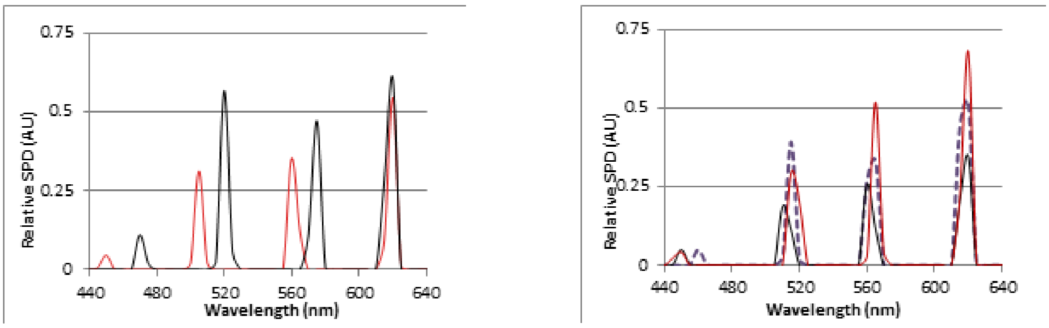
It should be noted that the optimization process starts with a ***random*** selection of candidate spectra, so that each optimization run is likely to produce a random result. In other words, the optimum result (at the end of the run) is not necessarily a global optimum.

Table 2. Results for 6 × 10 sets of optimization runs using 5nm FWHM Gaussian spectra.

	Experiment 1		Experiment 2		Experiment 3	
CMFs	**10°**	2°	**10°**	2°	**10°**	2°
Lowest *LER* (lm/W)	**429**	454	**401**	391	**400**	387
Highest *LER* (lm/W)	**448**	477	**433**	417	**420**	408
Lowest R_a	**80**	75	**86**	89	**88**	90
Highest R_a	**90**	83	**93**	93	**96**	95
Lowest R_{min}	**59**	28	**65**	77	**80**	82
Highest R_{min}	**74**	51	**88**	88	**92**	90
Lowest *CCT* (K)	**2754**	3739	**2162**	2337	**2242**	2339
Highest *CCT* (K)	**3583**	4123	**3038**	3187	**3372**	2839
% Spectra with *CCT* ≥ 2900 K	**90%**	100%	**20%**	30%	**20%**	0%

This work relates to the spectral design of white light sources intended for general lighting, and it was accordingly decided to identify those spectra yielding *CCT* values of 2900 K and above, as shown by the percentages in the last row of Table 2. In this respect, Experiment 2 appears to be of interest. The two spectra with CCT ≥ 2900 K optimized by use of the 10° CMFs are shown in Figure 1(a), and the three using the 2° CMFs in Figure 1(b).

The two spectral plots illustrate several common features for the two forms of optimization. However, the numerical results summarized in Table 2 show wide variations in the performance achieved by the different optimized spectra. There are also clear differences between the results for the optimizations based on the 10° and 2° CMFs, but it is difficult to discern any systematic difference.



(a) (b)

Figure 1: Examples of optimum spectra with CCT > 2900 K from Experiment 2 using (a) 10° and (b) 2° CMFs. (AU = arbitrary units).

4. CONCLUSIONS

The initial hypothesis is validated. The differences observed here clearly indicate the influence of the selection of the colour matching function relative to any spectral optimization. This raises an interesting philosophical debate around the question of how a 2°-optimized source will be judged by observers whose individual colour matching functions may differ from the standard 2° CMFs. It is thought that this may be of interest to CIE technical committee TC1-82 on *The Calculation of Colour Matching Functions as a Function of Age and Field Size*.

This phase of work is intended to be a forerunner to a later, more detailed, experiment in which the bandwidths of the components of a multi-band mixture will be significantly less than 5 nm.

ACKNOWLEDGEMENTS

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Extraction of Optimal Primaries Based on Maximum Possible Volume Technique in Colorimetric Space

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ABSTRACT

A novel method for selection of optimal primaries is introduced. The method is based on the selection of maximum available space in CIEXYZ color space. To verify the performance of selected spectra, the reflectance spectra of 1269 Munsell chips are spectrally reconstructed using the reflectance spectral of the extracted primaries. Results are then compared with the method that was basically designed on the maximum independencies of spectral vectors. Both spectral metrics (RMS and GFC) between the original and the reconstructed spectra are used to evaluate the performances of methods. The CIELAB color difference values between the actual and the synthesized spectra are also reported under D65, A and F11 illuminants and the 1964 standard observer. Based on results, both colorimetric and spectrophotometric criteria prove that the new method performs significantly better than the method which extracts the most independent primaries in reconstruction of 1269 color chips of Munsell patches.

1. INTRODUCTION

Comprehensive information about the visual properties of objects in various viewing conditions is provided by reflectance spectra of non fluorescent surfaces. The colorimetric data are expressed in three-dimensional spaces such as CIEXYZ color space, in contrast to the spectral data, composed of the reflectance values of sample in the visible range of electromagnetic spectrum in predefined band length. Therefore, the size of these data is more greater than that of colorimetric one and a complete surface specification become accessible through the spectral communication. Because the fact that the spectral data suffer from relatively huge sizes, some techniques have been presented to extract the main features of information to reduce the size of spectral data (Hawkyard 1993, Eslahi, Amirshahi and Agahian 2009).

Although three dimensional colorimetric data are not fairly enough to provide the adequate information about the objects in different viewing conditions, the reflectance spectra would prepare surplus/unnecessary information. Consequently, some mathematical techniques have been utilized to present the spectral data in the lower dimensional spaces with the minimum loss of information. One of the most applicable methods is the principle component analysis technique that is denoted by PCA (Cohen 1964, Fairman and Brill 2004, Garcia-Beltran *et al.* 1998, Maloney 1986, Agahian *et al.* 2008)

The extracted principal directions by PCA were known as “statistical primaries” and contain both negative and positive values (Berns 1997), in contrast with the non-negative matrix factorization technique (abbreviated by NNMF), which factorizes the data matrix into non-negative spectra and compute the more realistic features of dataset.

Recently, a novel method was presented in order to extract the main features of spectral data based on independency of the spectra. The results proved that the method generally performed better than non-linear PCA and non-negative matrix factorization techniques and the physical and realistic aspects of primaries provided the outstanding advantage among all extracted bases computed by other techniques (Farajikhah, Madanchi and Amirshahi 2012).

In this study, a novel method for selection of optimal primaries is introduced. The method is based on the selection of maximum available space in CIEXYZ color space. In fact, to select the best available primaries, all possible triads of 1269 samples of Munsell matt collection are formed and the triad which provides the pyramid with the maximum volume in the CIEXYZ color space has been selected as the best ones.

2. THEORITICAL BACKGROUND

2.1 Extraction of the most independent vectors of dataset

Assume that R is an $m \times n$ matrix where m and n represent the number of observations and the number of variables, respectively. To find the first pair of primaries with maximum independency, all binary combinations of samples were formed and the set with the minimum condition number was selected as the first pair of primaries (Hardeberg 1999). Equation (1) shows the employed idea:

$$\min\left(\frac{\omega_{\max}([R_i \quad R_j])}{\omega_{\min}([R_i \quad R_j])}\right), \quad i, j = 1, 2, \ldots n, \quad i \neq j \tag{1}$$

where $\omega_{\max}$(R) and $\omega_{\min}$(R) respectively are the maximum and minimum singular values of matrix R; R_i and R_j are the i^{th} and j^{th} columns of matrix R. Assume that $[R_i\ R_j\ ]$ are the most independent pair of primaries denoted by P. Consequently, for selecting the third primary, all remaining members of dataset were individually checked in combination with the selected pair and again the arrangement which provided the minimum value was selected and the above procedure was continued for selection of optimal primaries. By finding the k^{th} ($k < m$) primary, matrix V, consisting of the selected primaries was formed and considered as most spectrally independent primaries.

2.2 Extraction of vectors with the maximum volume available in CIEXYZ space

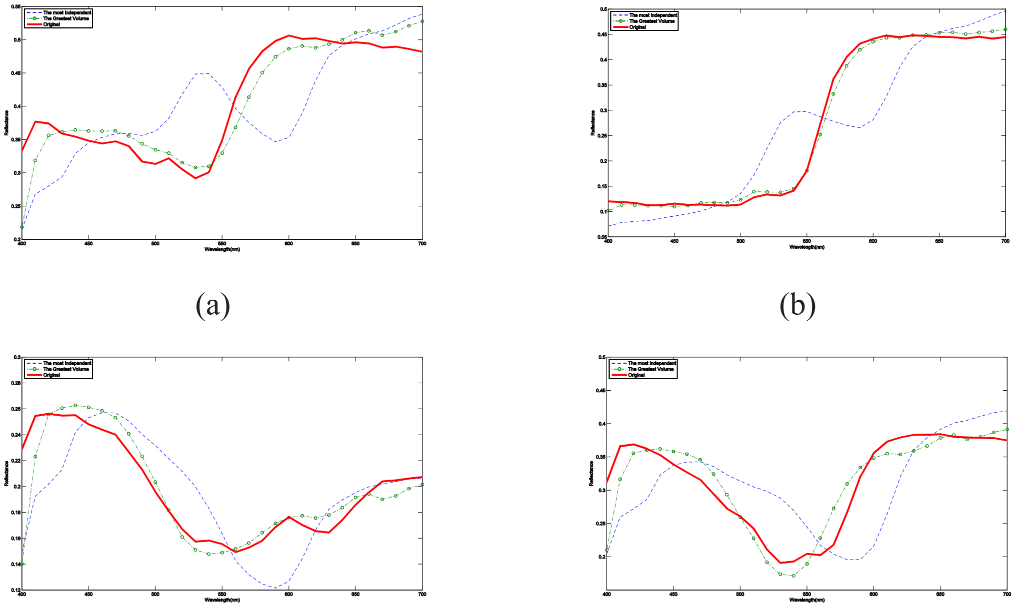
First, the tristimulus values of 1269 Munsell color samples were calculated under D65 illuminant and the 1964 standard observer. Then, all possible triads of tristimulus values of 1269 samples were formed and the volume of planned pyramids was calculated. The corresponding spectral reflectance of the samples which formed the triad with the maximum volume then selected as the colorimetrically optimal primaries.

Simply the extrated primaries were used as projection space for reducing the dimensional sizes of spectral data. In fact, the compression could be considered as $\mathrm{C}=\mathrm{V}^{\mathrm{T}}\mathrm{R}$, where C demonstrates the specification of spectra in the reduced space, V shows the matrix including the basic functions, R is the reflectance spectra of desired sample and T indicates the matrix transpose.

Similar to linear models, the reconstruction of samples could be readily possible through the $\hat{\mathrm{R}} \approx \sum_{j=1}^{k} \mathrm{C}_j \mathrm{V}_j$ where $\hat{\mathrm{R}}$ is the reconstructed data.

3. RESULTS AND DISCUSSION

To compare the above mentioned techniques, the reflectance spectra of 1269 Munsell color samples were compressed in reduced spaces and the results were evaluted by the differences between actual and the reconstructed spectra. Figures 1 shows the results of spectral reconstruction by the most independent and the maximum volume available techniques for four randomly selected samples.



(a) (b)

(c) (d)

Figure 1: (a) to (d) show the Results of spectral reconstruction for 4 randomly selected samples. (a): sample #10, (b): sample #160, (c): sample #984 and (d): sample #1120.

To quantitatively compare the results of different methods, the RMS, GFC and CIELAB color difference (ΔE_{a*b*}) values were calculated between the reconstructed and the original spectra. Table 1 shows the mean of RMS values, the frequencies of different grades of GFC and the mean of color difference values for different methods. According to Figure 1 and Table 1, the proposed method performs greatly better than the method based on the independency of vectors.

4. CONCLUSIONS

A novel method for selection of optimal primaries based on the selection of maximum available space in CIEXYZ color space was introduced. The performance of method was compared with the method that was designed on the maximum independencies of spectral vectors. The performances of methods were examined by the spectral reduction and reconstruction of Munsell spectra. Both spectral and colorimetric metrics demonstrated that the proposed method performs greatly better than the method that was designed on the selection of primaries by with maximum spectral independency.

Table 1. $\Delta E_{a^*b^*}$, RMS and GFC values for the employed compression methods.

Method	$\Delta E_{a^*b^*}$			RMS	GFC		
	D65	A	F11		Acceptable	Good	Excellent
The most independent vectors	9.8414	7.3166	9.8610	0.0393	363	11	4
The maximum possible volume	2.7452	2.3420	3.2966	0.0268	684	103	7

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Categorical Colour Rendering Index based on the CIECAM02

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ABSTRACT

The current CIE color rendering index is based on the color differences between the objects under different illuminants. In 1999, we proposed a method to evaluate the colour rendering performance of illuminant based on the colour name categorization instead of the colour diffrence. We call it the categorical colour rendering index (CCRI). Since the 1999-CCRI was based on the CIECAM97s, we update the CCRI based on the CIECAM02 in this study. We have evaluated the colour rendering of various types of light sources including white LEDs with the CCRI based on CIECAM02.

1. INTRODUCTION

If an identical object is illuminated with different light sources, the colour may sometimes appear different one another. For example, an object that appears brown under a tungsten lamp may appear purple under a white fluorescent lamp. Such a case, rendering of the colour may be judged to be unsatisfactory, because even the same object is differently categorized in colour name. Since the colour name can be considered to one of the attributes of colour appearance and the colour name itself is independent of the viewing condition, the use of colour names is very useful method to communicate colour information under various illuminating conditions. Currently, we use the CIE colour rendering index for evaluating the quality of light sources. The CIE-CRI, however, is based on the colour fidelity. In 1999, we proposed a method to evaluate the colour rendering performance of illuminant based on the colour name categorization instead of the colour fidelity. Since the CIE Color Apperance Model, CIECAM97s has been replaced by the CIECAM02 (CIE, 2004), we update the CCRI based on the CIECAM02 in this study.

2. METHOD

2.1 Categorical Colour Naming Experiment

In order to specify the regions of basic colour names under various adaptation conditions, categorical colour naming experiments were carried out using a variety of colour chips under many kinds of light sources (Yaguchi et al. 1999).

The set of JIS (Japanese Industrial Standard) colour chips specified with the Munsell Colour System is used for the experiment. We used 292 colour chips consist of samples found at even value *V*, even chroma *C*, and hue *H* labeled 5 and 10. The size of each colour chip was 5.5 x 7 cm, and it was put on an N5 gray background. The stimuli were viewed at an angle of about 45° at a distance of 50 cm.

Nine light sources used for the present study were a fluorescent lamp (D65) as a simulator of CIE standard illuminant D65, a cool white fluorescent (W), a three-band type fluorescent warm white (EX-L), three-band type fluorescent neutral (EX-N), a halogen (IL), a high pressure sodium (NH), a metal halide (MHL), a high pressure mercury (H), and a fluorescent high pressure mercury lamp (HF). The range of the correlated colour temperature was from 1880K to 6700K. The illuminance was 1000 lux for all illuminants.

Subjects were asked to sort samples into eleven basic colour categories specified by Berlin and Kay (1969). These colours are red, green, yellow, blue, orange, pink, purple, brown, white, gray and black. Sorting of colour samples under each illuminant was repeated three times for each subject in different experimental sessions.

Colour samples sorted into the same colour category consistently for all three trials under each illuminant are selected for each subject. Colour samples selected from four subjects were not much different from subject to subject. In order to examine consensus colours, we extracted colour samples named with a same colour by at least three out of four subjects.

2.2 Colour Name Regions in the CIECAM02 Space

In order to allocate the basic colour name regions in a viewing-condition independent colour space, we applied the CIECAM02 to our data. The lightness J, the chroma C and the hue angle h of the CIECAM02 output were calculated for all colour samples which were consistently sorted in a same colour name under each illuminant. Fig. 1 shows the basic colour name regions in the hue circle of the CIECAM02 space at four different lightness levels. Each colour name region was determined with a union region for all light sources. Although some regions of the colour name such as black and gray seem to be overlapped with each other, they are separated in lightness. It is found that the eleven basic colour name regions are clearly separated in the CIECAM02 space with each other. This means that the CIECAM02 provide a good prediction of colour names under various light sources.

2.3 Categorical Colour Rendering Index

Based on the experimetnal results shown in Fig. 1, colour name regions of eight chromatic basic colours from Berlin and Kay's eleven basic colour names were defined in the CIECAM02 (J, C, h) space. Assuming the CIE D65 illuminant as a reference illuminant, the comparison was made between the colour category area under the CIE D65 illuminant and those of the test light sources. At first, four colour-chips which lie on the boundary of the fan shape area in the polar coordinate for each of eleven basic categories under the CIE D65 illuminant are selected as reference colour samples. Let this region of each colour name S_i. The subscription i corresponds to each colour name. Then the lightness J, the chroma C, and the hue h for these four colour samples under the test light sources are calculated to obtain the region S_t under the test light sources. The overlap area between S_i and S_t, ($S_i \cap S_t$) are determined. The categorical colour rendering index is defined as *CCRI-CAM02* = $100(S_i \cap S_t) / S_t$. A general categorical colour rendering index may be obtained by taking an average of S_i for all colour names except for achromatic colour names.

3. RESULTS AND DISCUSSION

We calculated *CCRI-CAM02* for a variety of light sources available on the market in Japan including white LED lamps, then analyzed the correlation between *CCRI-CAM02* and the CIE general colour rendering index R_a for these light sources of which R_a are higher than 50. Fig. 2 shows the correlation between *CCRI-CAM02* and R_a for all light sources. Calculation results show high correlation coefficients; $r = 0.805$ for all 151 light sources, and $r = 0.871$, 0.878, 0.891 and 0.939 for 10 incandescent type lamps, 64 white LED lamps, 63 fluorescent lamps and 14 HID lamps, respectively. If you see correlation for light sources with R_a above 80 shown as inside of a dotted square of Fig. 2, correlation coefficients decreases to $r = 0.165$. With restrict to light sources with higher colour rendering indexes, the correlation between *CCRI-CAM02* and R_a seems to be very little.

Correlations between the CCRI-CAM02 and the currently proposed colour rendering indices of different concepts, such as nCRI-CAM02, CQS, and GAI will be also discussed at the presentation.

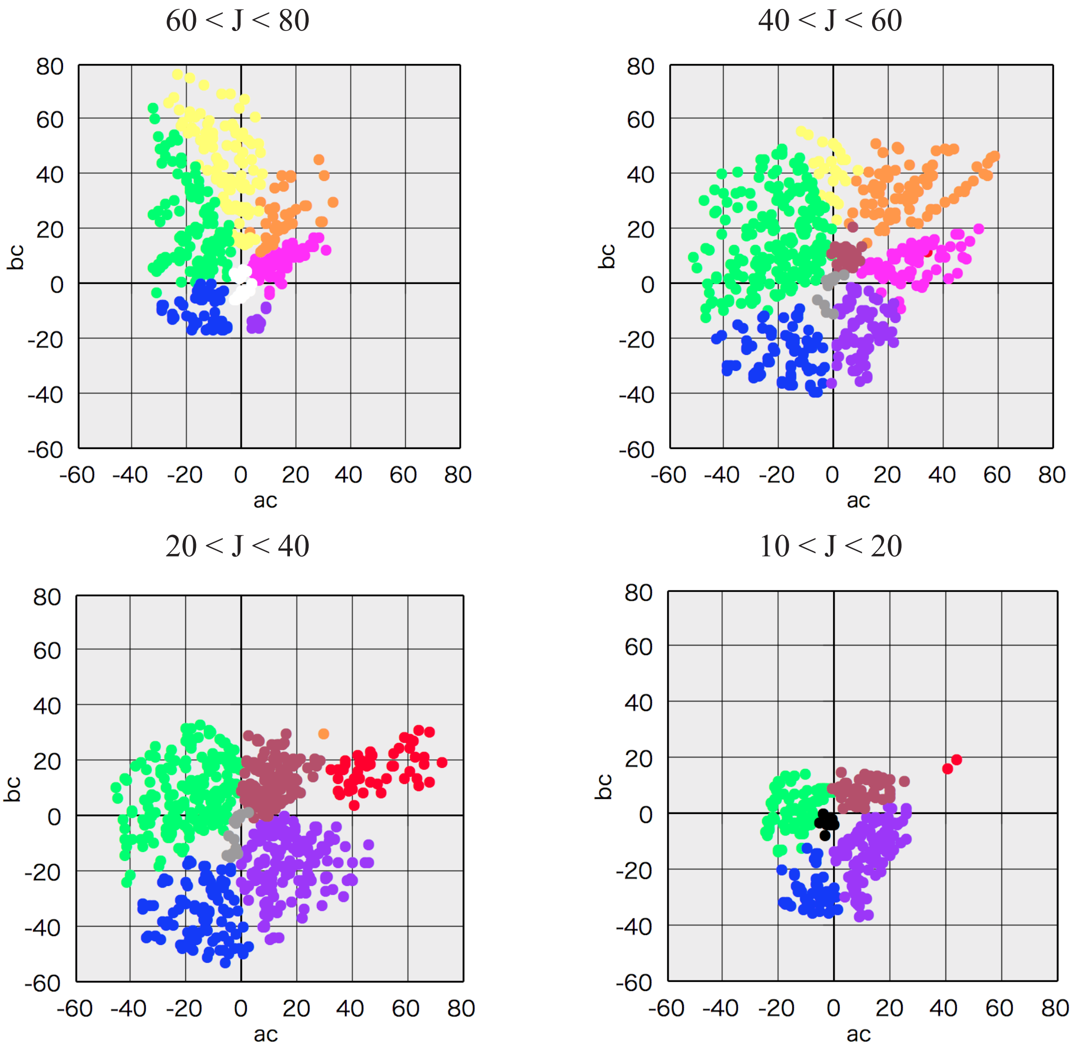

Figure 1: Colour name regions in CIECAM02 space.

4. CONCLUSIONS

We have updated the categorical colour rendering index (CCRI) based on the CIECAM02. Results of evaluation using 151 light sources including incandescent type lamps, white LED lamps, fluorescent lamps and HID lamps show high correlation between the CCRI-CAM02 and the current CIE R_a. With restrict to light sources of which R_a s are higer than 80, they show very high CCRI-CAM02 above 90, but the correlation with R_a seems to become very poor.

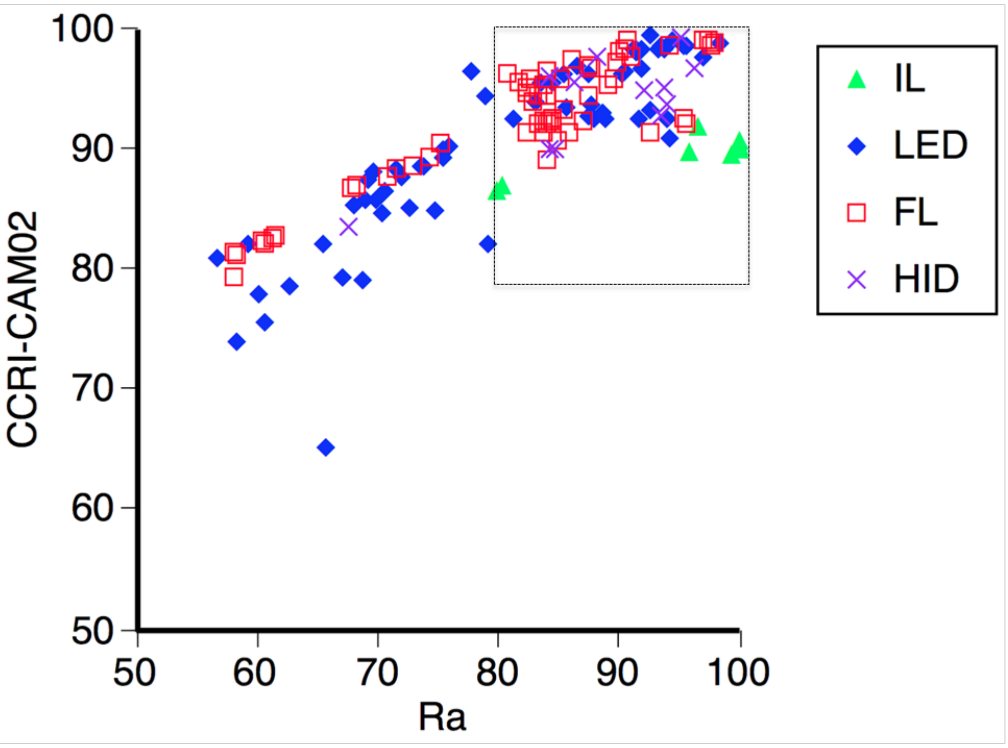

Figure 2: Correlation between CCRI-CAM02 and Ra.

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Actual Retroreflectance Measurement of White Diffuse Reflectance Standards

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ABSTRACT

Actual retroreflection at normal incidence of four white diffuse reflectance standards (Spectralon, matte white Russian opal glass, matte white ceramic and pressed barium sulphate) is presented in this work. The results obtained, reveal a BRDF increase between 10% and 30%, compatible with the coherent backscattering of light (CBS) model. Fitting functions are given for the studied standards in order to allow extrapolation around that direction to be done and to minimize the error.

1. INTRODUCTION

The hemispheric reflectance of white diffuse reflectance standards is carried out at 0º:d or 8º:d, using the latter to include the specular component. To take these values as completely equivalent in any measurement system, as commonly assumed, the standards should be perfectly Lambertian, which is not the case in practice. Therefore, there is a systematic error associated to these standards that will depend on the geometrical arrangement of the measurement and on the material the standard is made of. In order to estimate this systematic error, the BRDF (Bidirectional Reflectance Distribution Function) of these standards, including the retroreflection direction and its surrounding directions, has to be measured. However, many of the developed gonio-spectrophotometers don't have this capability and BRDF values in this region are extrapolated. This solution lacks accuracy because around this direction an increase in reflectance is produced, which cannot be extrapolated. This increase is known with several names in literature, including the opposition effect or surge and the Minnaert effect (Corey, Kissner and Saulnier 1995).

2. METHOD

A gonio-spectrophotometer (Rabal et al. 2012) has been used to measure the actual BRDF at normal incidence ($\theta_i = 0º$) and around the retroreflection direction of four diffuse reflectance standards: Spectralon (Sintered polytetrafluoroethylene or PTFE), matte white Russian opal glass, matte white ceramic standard from CSS series, and pressed barium sulphate ($BaSO_4$). The observation polar angle (θ_s) was scanned from 0º to 8º every 0.2º (see Figure 1) subtending a $1.5 \cdot 10^{-3}$ sr solid angle with a 0.1º field of view. The azimuthal angles were kept constant.

3. RESULTS AND DISCUSSION

To compare the results, the spectral average of the BRDF was calculated and normalised to the value at $\theta_s = 8º$, $\Delta f_r(\theta_s) = [f_r(\theta_s) - f_r(8º)]/f_r(8º)$, where the opposition effect should be negligible (Corey, Kissner and Saulnier 1995). Moreover, data were deconvolved to minimize the measurement aperture effect [Richardsson (1972)].

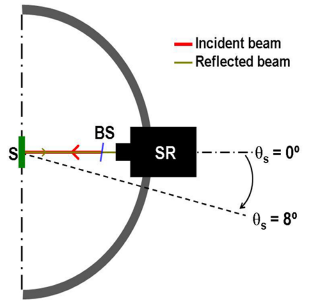

Figure 1: Measurement sketch. BS: Beamsplitter; SR: Spectroradiometer; S: Sample.

Figures 2 to 5 show the results obtained. The first graph in every figure (left side) presents $\Delta f_r(\theta_s)$ versus observation angle, θ_s. Error bars show the standard deviation of three measurements. Data between 2.3° and 5.5° are not shown because of the noise produced by the partial oclusion of the beamsplitter's mount. The second one (right side) shows $\Delta f_r(\theta_s)$ after aperture deconvolution, which is relevant only for angles < 1.4° and an exponential function (dashed line) defined as $\Delta f_r(\theta_s) = ae^{-b\theta_s}$ and fitted to the data, where a and b are the parameters to be fitted. The value a is indicative of the distribution's peak, while the value b is inversely proportional to the full width at half maximun (see Table 1). Data at $\theta_s = 0°$ were excluded from the fittings, because this direcction, where lies supposedly the peak of the distribution, may be very much affected by errors due to the non-zero field on view (0.1°).

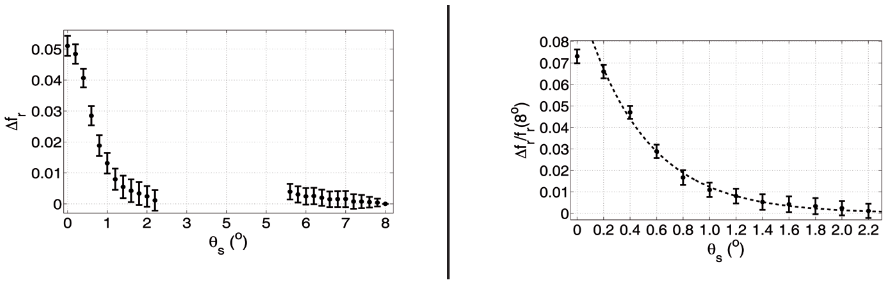

Figure 2: Spectralon. Left side: Variation of the relative spectrally-averaged BRDF around the retroreflection direction. Right side: Deconvolved experimental data and exponential fitting.

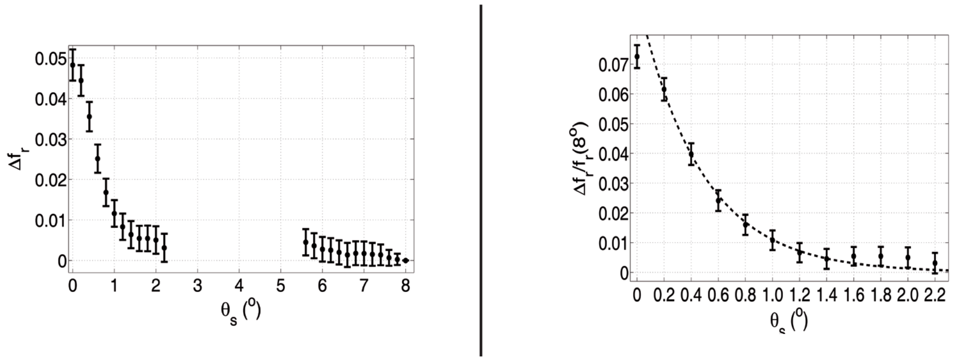

Figure 3: Matte white Russian opal glass. Left side: Variation of the relative spectrally-averaged BRDF around the retroreflection direction. Right side: Deconvolved experimental data and exponential fitting.

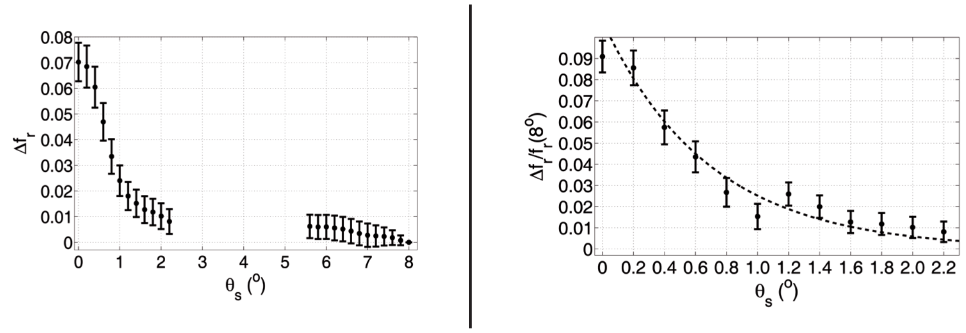

Figure 4: Matte white ceramic standard. Left side: Variation of the relative spectrally-averaged BRDF around the retroreflection direction. Right side: Deconvolved experimental data and exponential fitting.

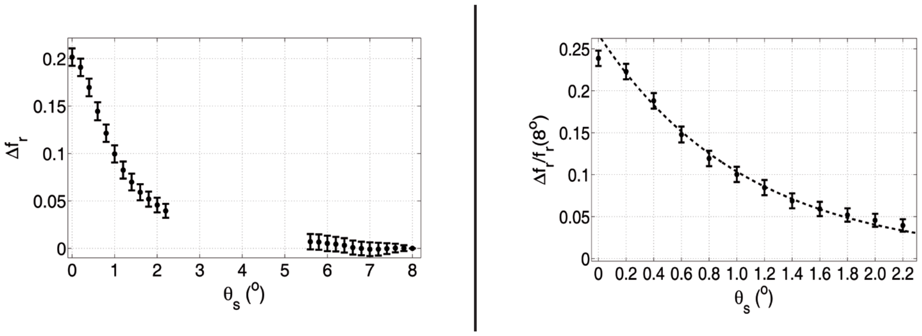

Figure 5: $BaSO_4$. Left side: Variation of the relative spectrally-averaged BRDF around the retroreflection direction. Right side: Deconvolved experimental data and exponential fitting.

Table 1. Exponential function fitting parameters,their standard uncertainty, the FWHM and Δρ for the reflectance standards.

Material	a	u(a)	b	u(b)	FWHM (°)	$\Delta\rho$ (%)
Spectralon	0.1028	0.0035	121.1	4.8	~ 0.65	$4.4\cdot10^{-3}\cdot f_r(8°)$
Russian opal glass	0.0931	0.0052	112.2	7.7	~ 0.65	$4.6\cdot10^{-3}\cdot f_r(8°)$
Ceramic standard	0.108	0.010	83.3	9.7	~ 0.95	$9.8\cdot10^{-3}\cdot f_r(8°)$
$BaSO_4$	0.2671	0.0057	54.2	1.6	~ 1.5	$5.7\cdot10^{-2}\cdot f_r(8°)$

An approximately triangular distribution around $\theta_s = 0°$ is observed for all studied materials. As predicted by the CBS theory, Spectralon, matte white Russian opal glass and matte white ceramic standard distributions have widths at half-peak lower than 1°, but $BaSO_4$ has got a width of 1.5°. The maximun surge observed is for $BaSO_4$, with a 22 % increase, whereas Spectralon, matte white Russian opal glass and matte white ceramic standard have a similar surge between 4.8 % and 7.0 %.

The last column of Table 1 shows the difference between the hemispherical reflectance including the retroreflectance peak and that calculated assuming a lambertian behaviour ($\Delta\rho$). This error is significant in the case of barium sulfate and less relevant for the other standards.

Although not shown, a very slight dependence on wavelength was observed in the visible range for the retroreflectance peak, whose amplitude varied by less than 2% across the complete spectral interval.

4. CONCLUSIONS

The increase of the BRDF around the retroreflection direction has been measured for four white diffuse reflectance standards: Spectralon, matte white Russian opal glass, matte white ceramic standard and pressed barium sulphate ($BaSO_4$) powder.

It has been shown that these materials commonly used as diffuse reflectance standards differ from perfect diffuser in the vicinity of the direction of incidence at normal incidence. Differentiation depends on the standard, so it will be necessary to study this source of uncertainty and its impact on the different geometric configurations used in measurements.

The results show up the importance of making measurements in the direction of incidence and of having instruments capable of them.

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An Effective Formula for Munsell Lightness Function

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ABSTRACT

In this paper a simple and effective formula for Munsell lightness function is proposed. The proposed function *f* is designed to be continuous and smooth within the whole domain $Y \geq 0$. The function includes only simple arithmetic operation, so that the inverse function is also simple. As an application of the formula, observing condition of Munsell color chart is inferred quantitatively.

1. INTRODUCTION

The correspondence between Munsell value V and the luminance factor Y is denoted by Munsell lightness function. A representation of Munsell lightness function by a simple mathematical formula is useful not only for the mutual transformation between V and Y, but also for a basic relation between the perceptual color and the stimulus value. Several formulae approximating Munsell lightness function, such as CIE lightness function L^* (1976) and SVF lightness function $v_1(Y)$ (Seim and Valberg 1986), are proposed. However, these formulae have some difficulty in practical use because of either accuracy or complexity.

If Munsell value V and the luminance factor Y follow the stimulus-response relation of Naka-Rushton type (Naka and Rushton 1966)

$$V = \beta\, Y^{\gamma} / (\alpha + Y^{\gamma}),$$

then $1/V$ is expressed by a linear expression of $1/Y^{\gamma}$. Figure 1 shows relations of $1/Y$ or $1/\sqrt{Y}$ to $1/V$ for many Munsell data (Y, V)'s. The abscissa represents $1/V$. The graph shows that for small V ($1/V > 0.33$), $1/Y$ is almost linear to $1/V$, while for large V ($1/V < 0.33$), $1/\sqrt{Y}$ is linear to $1/V$. Therefore the lightness function $V = f(Y)$ is considered to be a composition of two parts according to the value Y. One part is expressed by a first order fraction of Y for small Y, and another is expressed by a first order fraction of square root of Y for large Y.

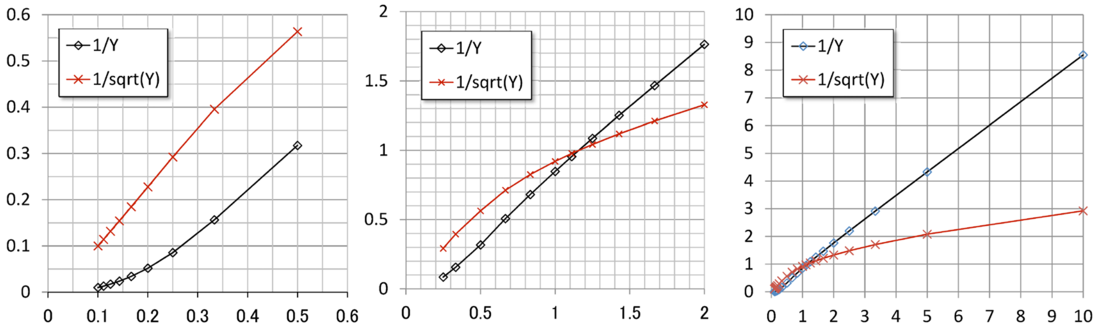

Figure 1: Relations of 1/Y or 1/√Y to 1/V (abscissa).

2. CONSTRUCTION OF THE FORMULA

For a suitable Y^* in [0, 100], Munsell lightness function *f* is supposed to be represented by

$$(1)\quad f(Y) = b\,Y / (a + Y) \qquad (Y < Y^*),$$
$$= B\,\sqrt{Y} / (A + \sqrt{Y}) \qquad (Y \geq Y^*).$$

Note that the inverse of f has also a simple form which is easy to handle analytically.

The function f is designed to be continuous and smooth within the whole domain $Y \geq 0$. Thus the following three conditions are imposed:

a) $f(100) = 10$.
b) f is continuous at $Y = Y^*$.
c) $\mathrm{d}f/\mathrm{d}Y$ exists and continuous at $Y = Y^*$.

From these conditions, each parameter B, a, and b in the expression (1) is explicitly expressed as a simple expression of A and Y^*:

$$(2)\quad B = A + 10,$$
$$(3)\quad a = AY^* / (\,A + 2\sqrt{Y^*}\,),$$
$$(4)\quad b = (\,A + 10\,)\cdot 2\sqrt{Y^*} / (\,A + 2\sqrt{Y^*}\,).$$

Then the problem is to find the optimal pair of A and Y^*, so that the equation $V = f(Y)$ best approximates the prescribed table of Munsell data (Y, V)'s. As it is difficult to obtain A and Y^* simultaneously, first obtain A with fixed Y^* and then, by varying Y^*, search adequate Y^* to minimize the error. The method to obtain A with fixed Y^* is explained as follows:
The graph of $V = f(Y)$ in the (Y, V) plane can be transformed to a linear equation of A

$$(5)\quad A\cdot f_1(Y, V) - f_2(Y, V) = 0,$$

where,

$$(6)\quad f_1(Y, V) = V - \sqrt{Y} \qquad (Y \geq Y^*),$$
$$= (Y^* + Y)V - 2\sqrt{Y^*}\cdot Y \qquad (Y < Y^*),$$
$$(7)\quad f_2(Y, V) = (10 - V)\sqrt{Y} \qquad (Y \geq Y^*),$$
$$= (10 - V)\cdot 2\sqrt{Y^*}\cdot Y \qquad (Y < Y^*).$$

In order to obtain A the least square method is applied to the expression (5) to minimize the square error for the given Munsell data:

$$(8)\quad \Sigma\,[A\cdot f_1(Y, V) - f_2(Y, V)]^2 \rightarrow \text{min, with respect to } A.$$

The solution is given by $A = \Sigma f_1(Y, V) f_2(Y, V) / \Sigma\,[f_1(Y, V)]^2$.
The summation Σ was taken for a set of all data (Y, V) given in Table 1. The following parameters are obtained:

$$(9)\quad Y^* = 6.264,\quad A = 37.11,\quad B = 47.11,\quad a = 5.51,\quad b = 5.59.$$

The absolute values of error in V were calculated for one thousand values of V from 0 to 10 with step 0.01. Maximum error was found to be 0.028 at $Y = 0.354$.

Table 1. Munsell data for fitting.

V	*Y*
0	0
0.1	0.117
0.2	0.231
0.3	0.343
0.5	0.567
0.7	0.799
1	1.18
1.2	1.468
1.5	1.971
1.7	2.362
2	3.048
2.2	3.579
2.5	4.498
2.7	5.199
3	6.391
3.5	8.778
4	11.7
4.5	15.19
5	19.27
5.5	23.97
6	29.3
6.5	35.29
7	41.98
7.5	49.41
8	57.62
8.5	66.68
9	76.69
9.5	87.75
10	100

As approximated and rounded values of the above parameters,

$$(10)\quad Y^* = 6.25,\quad A = 37,\quad B = 47,\quad a = 5.5,\quad b = 5.6$$

can be adopted. In this case the maximum error was found to be 0.029 at $Y = 0.366$.

The errors of the case (9) or (10) are less than and about one third of those in CIE or SVF lightness functions. Thus the lightness function with the parameters (10) must be quite effective and has enough ability of practical uses.

As a consequence of the above discussion, the formula

$$(11)\quad V = 5.6\,Y / (5.5 + Y) \qquad (0 \leq Y < 6.25),$$
$$= 47\,\sqrt{Y} / (37 + \sqrt{Y}) \qquad (6.25 \leq Y).$$

is recommended for Munsell lightness function. The behavior of error in the function (11) is compared with those of CIE and SVF lightness functions (see Figure 2).

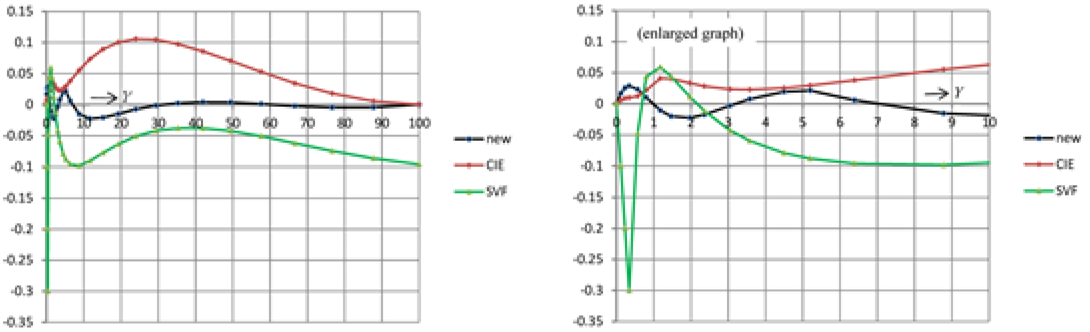

Figure 2: Error of lightness functions (11), CIE, and SVF.

The inverse function from V to Y of the function (11) is defined below for convenience.

$$(12)\quad Y = 5.5V / (5.6 - V) \qquad (0 \leq V < 2.97),$$
$$= [37V / (47 - V)]^2 \qquad (2.97 \leq V).$$

Maximum error of this inverse function is found to be 0.160 at $V = 4.38$. It is interesting that this error is less than the maximum error in the inverse function of the function with the parameters (9) (the maximum error is 0.171 at $V = 4.41$).

3. ON OBSERVING CONDITON OF MUNSELL COLOR CHART

In this section, the condition of the observation of Munsell color chart will be discussed as an application of our new formula. The lightness V of a color chip with luminance factor Y placed on the background with luminance factor Y_B is approximately given by

$$(13)\quad V = (Y_B + 100)\,Y / [10(Y_B + Y)]$$

(Judd 1940).

If this holds and also the lightness V is given by the formula (11), the following expression must hold:

$$(14)\quad Y_B = (550 + 44Y) / (50.5 - Y) \qquad (0 \leq Y < 6.25),$$
$$= 370\sqrt{Y} / (47 + \sqrt{Y}) \qquad (6.25 \leq Y).$$

This tells that the luminace factor of the background must vary correlatively depending on the luminance factor of the color chip in the observing condition of Munsell color chart. The lightness of the background, defined by $V_B = f(Y_B)$, and the lightness of the color chip are plotted together in Figure 3.

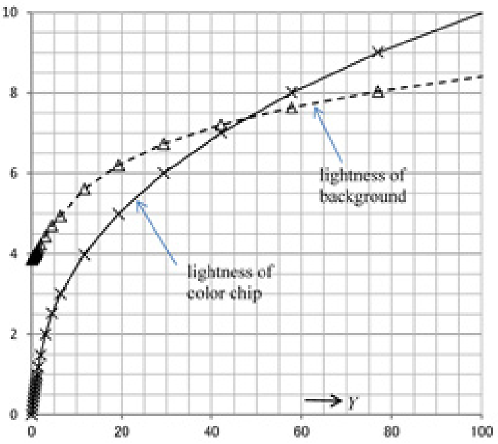

Figure 3: Relation of the lightness between a color chip and its background in the observing condition of Munsell color chart.

4. CONCLUSION

An effective and useful formula for Munsell lightness function is developed and proposed. The formula includes only simple arithmetic operations such as addition, subtraction, multiplication, division, and square root, so that the inverse function is also simple. Thus the formula is easy to handle analytically, e.g., by means of differentiation or integration, which leads us to theoretical investigation. As an application of the formula, observing condition of Munsell color chart is inferred quantitatively. The mathematical analysis of the structure of Munsell color order system using the lightness function is one of the important future problems.

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Estimating CRIs using a Calibrated Digital Camera

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ABSTRACT

A method which uses widespread ColorChecker Color Rendering Chart to estimate CIE Color Rendering Index (CRI) is proposed. The camera has to be calibrated initially under illuminant D65 and A. After linearization, color correction, CCT estimation, chromatic adaption, CRI calculation and CRI fitting, the general CRI can be estimated roughly without knowing the spectral information of the light source.

1. INTRODUCTION

Camera-based color analyzers were developed in recent years to measure luminance, brightness, CIE UGR (Unified Glare Rating), tristimulus values of a scene for optimizing lighting design (Li *et al.*, 2012). It's better to report CRI (Color Rendering Index) of the scene with the analyzers. Color accuracy of a mixed lighting environment can be estimated effective by means of the 2D CRI analysis. To calculate CRIs, a spectroradiometer is normally used to measure the spectral power distribution of a light source. However, the spectral data cannot be acquired by a RGB camera directly. One the other hand, CIE TC1-33 recommended ColorChecker chart as a replacement of obsolete CIE 1974 Color Test Samples for CRI measurement. The aim of this study is thus to provide a method to accurately estimate CRIs using calibrated RGB camera with the widespread ColorChecker Color Rendering Chart.

2. METHOD

A camera-based method is proposed here to estimate CIE general CRI values using 24-patches ColorChecker chart under any white light source. It involves colorimetric camera calibration, color temperature estimation, chromatic adaptation, color difference calculation, and CRI fitting. Figure 1 illustrates the workflow of the proposed method. It will be detailed next.

2.1 Colorimetric Camera Calibration

A RGB tri-band digital camera is used for estimating CRIs. It must be calibrated with known standard light sources. ColorChecker is taken by the camera under illuminant D65 (filtered halogen) and illuminant A (tungsten) respectively. Based on the method described in ISO 17321 (2012), the gray scale on the ColorChecker (CC) is used to linearize the raw RGB signals and all 24 colors are used to generate two 3×3 color correction matrices (for D65 and A individually) for linear RGB-to-XYZ color transform. According to the CIE CRI, daylight and black body radiation (Planckian functions) are used as reference illuminants for test source with high- and low-correlated color temperature respectively. We calibrate the camera using D65 and A sources for the two conditions and convert the first 18 colors on the CC to CIE 1960 UVW space as the reference colors. The reason of using obsolete UVW space is to comply with the conventional CIE CRI calculation.

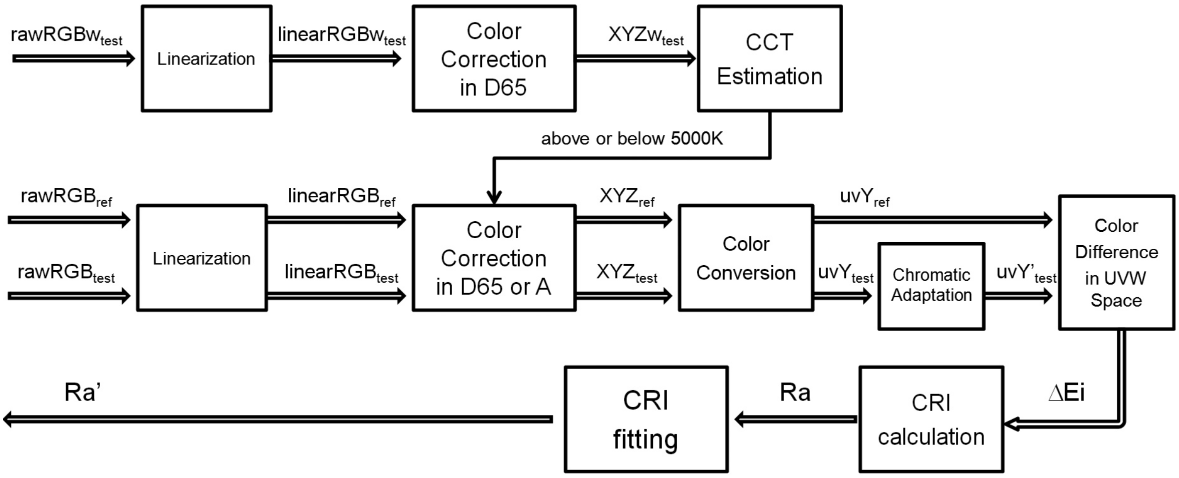


Figure 1: Flowchart illustrating the process of camera-based CRI estimation.

2.2 CCT Estimation

To estimate the CRI for an unknown light soure, we need to take the CC image under the light source. The setting of white balacing must be identical to the calibration stage. The first row of Figure 1 shows the steps of CCT estimation. It uses only the averaged raw RGB signal of the CC white patch (denoted as rawRGBw$_{test}$) as input. After linearization, the white RGB signal converts to XYZ using the D65 color correction matrix. Using its (u,v) chromaticity values, the correlated color temperature can be estimated easily.

2.3 CRI Estimation

Averaged raw RGB signals of the first 18 colors of CC chart under test illumination are extracted and denoted as rawRGB$_{test}$ in Figure 1. After the linearization, one of the color correction matrix (i.e., CCM) is chosen by the result of CCT estimation to convert linearRGB$_{test}$ to XYZ$_{test}$. If the CCT is below 5,000K, the reference source is illuminant A and the CCM for illuminant A is used. Otherwise, the reference source is D65, the CCM for illuminant D65 is used. Based on CIE method (CIE, 1995), Von Kries-type chromatic adaption is applied to the test colors in uvY space. Afterward, the color differences between the test and the reference color pairs are calculated in the UVW space. It results in 18 color differences which denoted as DE$_i$ in the Figure 1. The initial CRI value (Ra) is equal to (100 – 4.6 $\overline{\Delta E_i}$). A second-order polynomial fitting is used to fit their real CRI values in our database.

3. RESULTS AND DISCUSSION

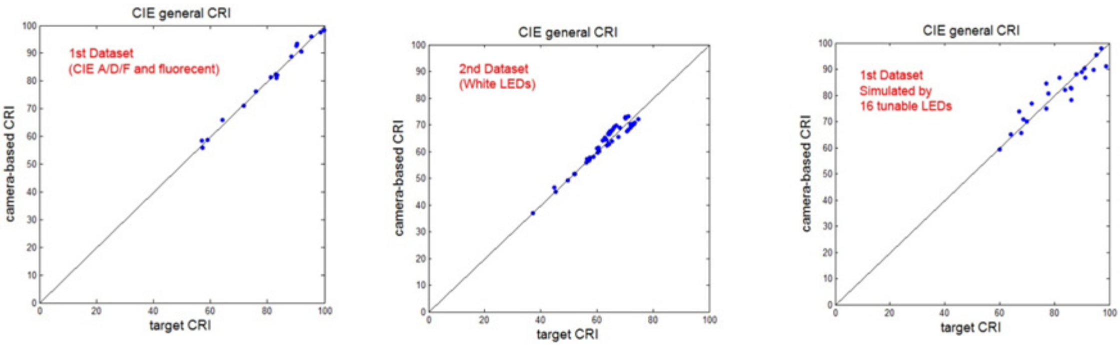
3.1 Virtual Cameras

The spectral sensitivities of 12 real digital cameras estimated by SVD method (Zhao et. al., 2009) were used to simulate virtural cameras for testing the accuracy of the CRI estimation. There are two data sets: (1) CIE A, D50, D65, F series, and 10 real fluorescent samples, (2) 70 white LED spectra provided by Lextar Ltd. The test using 380nm to 730nm spectral data with 5nm interval. The results is show in Table 1. As can be seen, calculating the CC color differences in UVW space is much better then LAB space in fitting the real CRI values. For the first data set, the correlation coefficient of the fitting is 0.994 for the best camera and the mean and maximum CRI errors were 1.24 and 3.08 respectively (referring to Figure 2(a)).

The second data set shows similar results (referring to Figure 2(b)). However, the worst camera might provide maximum errors which is three times higher than that of the best one. We found that the maximum errors have high correlation (r = 0.71) to the maixmum errors (DE_{UVW}) of camera color correction under D65. It means that if the cameras cannot convert to XYZ accurately, then the CRI estimation will be inaccurate. If a camera uses CIE1931 color matching functions as its spectral responses, best performance can be achieved in UVW space (referring to the Idea camera in Figure 1).

Table 1. CRI accuracy of 12 cameras in the virtual camera test.

data set		1st (CIE A/D/F and fluorescent)			2nd (White LEDs)		
space	camera	r	mean ΔRa	max ΔRa	r	mean ΔRa	max ΔRa
UVW	Idea	0.999	0.56	1.23	0.996	0.71	2.66
	Best	0.994	1.24	3.08	0.970	1.78	3.04
	Median	0.988	1.81	5.06	0.978	1.44	3.26
	Worst	0.856	6.33	11.10	0.935	2.32	9.02
LAB	Idea	0.998	0.43	1.02	0.968	1.82	7.99
	Best	0.940	3.91	10.18	0.611	6.17	20.71
	Median	0.899	4.94	13.58	0.627	6.33	20.54
	Worst	0.767	7.50	14.30	0.243	7.11	27.15



(a) (b) (c)

Figure 2: CRI estimation of (a) 1st dataset (virtual Canon 400D), (b) 2nd dataset (virtual Canon 400D) and (c) 1st dataset simulated by a 16-band LED source (real Canon 5D II).

3.2 A Real Camera

A Canon 5D Mark II digital camera was used to capture 12-bit raw images for testing the proposed method using real light sources. X-rite SpectraLight III D65(filtered halogen) and A (tungsten) were used to calibrate the camera. A 16 bands Telelumen tuneable LED source was used to simulate the spectra of the first data set. The mean and maximum errors of color correction were 2.54 and 5.50 DE respectively. The correlation coefficient of CRI estimation was 0.906 and the mean and maximum errors of the CRI estimation were 4.18 and 7.97 ΔRa respectively. It seems that the accuracy of the color correction affects the performance of the CRI estimation. The accuracy of camera's color correction can be further improved by high-order polynomial regression (Hong et. al., 2001). Figure 2 show the error distributions of the best virtual camera (Canon 400D) and the real camera (Canon 5D Mark II). If the agreement is perfect, all data points must be located at the 45 degree line.

4. CONCLUSIONS

A camera-based CRI estimation method is proposed and tested. 12 virtual cameras were tested using two datasets and the best camera provides 0.98 correlation to the real CRIs where the mean and maximum errors are 1.5 and 3.0 ΔRa respectively. The performance is acceptable for those cameras whose colors can be calibrated accurately. Estimate the CIE CRI in UVW space is much better than LAB space as the CIE CRI is calculated in UVW space. Once the color differences of the patches can be accurately measured, it's possible to transfer the color of the image to any given light source while the spectral reflectances of the scene are similar to that of the ColorChecker.

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Colorimetric Calibration of a Display Device under a Room Illumination

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ABSTRACT

The colorimetric calibration of a display device is an important technology to reproduce a color image accurately on it. Although the influence of the internal flare, which comes from internal scattering or the output from other channels at the same pixel location, on the colorimetric calibration has been studied and the reproduced color was measured in a completely darkened room, however little report have been appeared for the influence of the external flare, which comes from the reflection of the room illumination at the monitor surface, on the accuracy of the reproduced color under the room illuminations. In this paper the direct experimental evidences which show that the colorimetric characterization of a monitor by taking into account the external flare is very effective to reproduce an accurate color image under a room illumination.

1. INTRODUCTION

The color appearance and the impression of an artistic painting differ markedly with the illuminations, i.e., they depend on their spectral power distributions and illuminance levels. To reproduce a color image accurately on a display device by the use of color appearance models (Nayatani 1995), the colorimetric calibration of the device is very important. The colorimetric calibration of the device means estimating the frame data that will reproduce a color stimulus with the intended tristimulus values accurately. Various studies have been carried out on the colorimetric calibration (Katoh 2001). Although the influence of the internal flare, which comes from internal scattering or the output from other channels at the same pixel location, on the colorimetric calibration has been studied and the reproduced color was measured in a completely darkened room (Katoh 2001, Day 2004), however little report have been appeared for the influence of the external flare, which comes from the reflection of a room illumination at a monitor surface, on the accuracy of the reproduced color under the room illumination. Since a color image reproduced on a display device usually observed in the room illumination conditions, it is important to confirm the influence of the reflected room illumination at the display device on the colorimetric calibration accuracies. In this paper the direct experimental evidences which show that the colorimetric characterization of a monitor by taking into account the external flare is very effective to reproduce an accurate color image under a room illumination.

2. METHOD

To achieve an accurate calibration we employed a CRT color monitor (EIZO, T761), since the monitor shows a power law tone response correction. The chromaticity diagram of the basic stimulus of the color monitor was adjusted to coincide with that of the room illumination (fluorescence lamp). Each luminance of the RGB primary stimulus was normalized to the maximum luminance of the basic stimulus, respectively and they are denoted by R, G and B. Estimation of the frame data to reproduce a color stimulus with the tristimulus values of XYZ was carried out as described below. To evaluate the calibration accuracy the color difference ΔE^*_{ab} in the CIELAB space, the tristimulus values XYZ were normalized with the maximum luminance of the basic stimulus. In the following, the tristimulus values XYZ denote the normalized values.

The tristimulus values of a color stimulus to be reproduced by RGB primaries were measured by the spectroradiometer (Minolta CS-1000) and they are expressed by

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} X_R & X_G & X_B \\ Y_R & Y_G & Y_B \\ Z_R & Z_G & Z_B \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix} + \begin{pmatrix} X_{min} \\ Y_{min} \\ Z_{min} \end{pmatrix}, \qquad (1)$$

where X_{min}, Y_{min} and Z_{min} represent the tristimulus values at zero-frame data. Figure 1 shows a typical example of the tristimulus values X, Y, Z as a function of R. The same characteristics can also be obtained for primaries of G and B. From the slopes of the lines, the values of $X_i, Y_i, Z_i, i = R, G, B$ were estimated. Since the tristimulus values X, Y, Z in (1) indicate the color stimulus reproduced by the three primaries R, G, B, so the reflected room illumination at the display device must be added to equation (1),

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} X_R & X_G & X_B \\ Y_R & Y_G & Y_B \\ Z_R & Z_G & Z_B \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix} + m \begin{pmatrix} X_n \\ Y_n \\ Z_n \end{pmatrix} + \begin{pmatrix} X_{min} \\ Y_{min} \\ Z_{min} \end{pmatrix} \qquad (2)$$

where Xn, Yn and Zn are the tristimulus values of the perfect reflecting diffuser under room illumination and m represents the reflectance of the illumination at the monitor surface. The values of R,G,B in (2) can be obtained by

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} X_R & X_G & X_B \\ Y_R & Y_G & Y_B \\ Z_R & Z_G & Z_B \end{pmatrix}^{-1} \begin{pmatrix} X - mX_n - X_{min} \\ Y - mY_n - Y_{min} \\ Z - mZ_n - Z_{min} \end{pmatrix} \qquad (3)$$

The R, G, B primaries as a function of the frame data, D_i, i=R,G,B, is given in Figure 2. Various models have been proposed to formulate these curves such as the gain-gamma-offset (GGO) and gain-offset-gamma-offset (GOGO) models. We tried to estimate the frame data using two models. The GGO model formulates the curves by

$$\begin{aligned} R &= \alpha_R D_R^{\gamma_R} + \beta_R \\ G &= \alpha_G D_G^{\gamma_G} + \beta_G \\ B &= \alpha_B D_B^{\gamma_B} + \beta_B \end{aligned} \; . \qquad (4)$$

The values of the α_i, β_i, γ_i, i=R,G,B are derived from the curve fitting. The frame data are also expressed by next equations.

$$D_R = \left(\frac{R - \beta_R}{\alpha_R} \right)^{\frac{1}{\gamma_R}}, D_G = \left(\frac{G - \beta_G}{\alpha_G} \right)^{\frac{1}{\gamma_G}}, D_B = \left(\frac{B - \beta_B}{\alpha_B} \right)^{\frac{1}{\gamma_B}} \qquad (5)$$

By substituting three primaries R,G,B obtained by (3) into (5), we are able to estimate the frame data to reproduce a color stimulus with tristimulus values of X,Y,Z. The GOGO model formulate the curves as:

$$R = (\alpha_R D_R + \beta_R)^{\gamma_R} + \delta_R$$
$$G = (\alpha_G D_G + \beta_G)^{\gamma_G} + \delta_G$$
$$B = (\alpha_B D_B + \beta_B)^{\gamma_B} + \delta_B \qquad (6)$$

The same method as described above was also used to estimate the frame data by using the GOGO model.

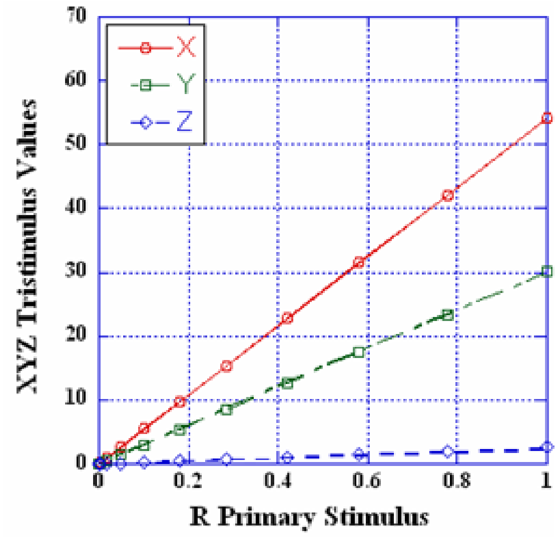

Figure 1: Tristimulus values of XYZ as a function of R primary stimulus.

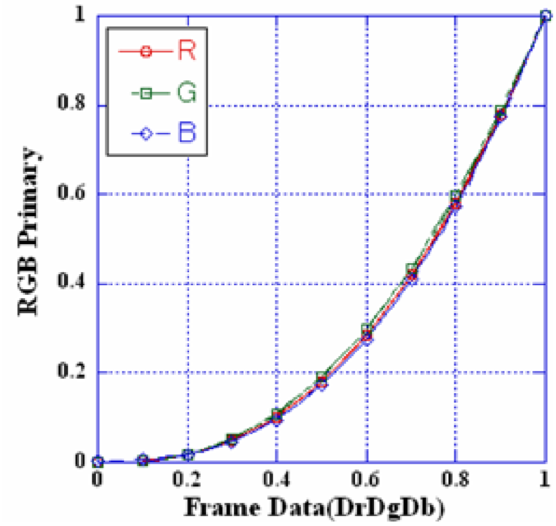

Figure 2: RGB primary stimuli as a function of frame data.

3. RESULTS AND DISCUSSION

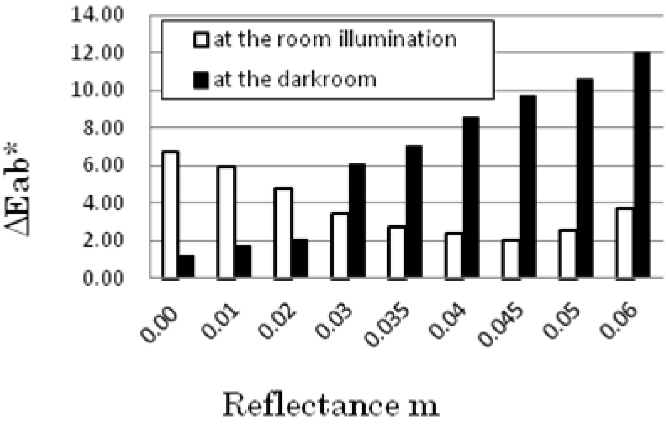

Figure 3: Color difference ΔE^*_{ab} of the reproduced colors as a function of reflectance m.

We repoduce the GretagMacbeth ColorChecker on the CRT display device and the averaged color difference ΔE^*_{ab} over 24 colors was used to evaluate the calibration accuracy. Figure 3 shows the experimental results obtained by the GGO model and shows the color difference as a function of the reflectance m, in which white and black bars show the color difference mesured under the room illumination and dark condition, respectively. The experimental reuslts show that minimum values of colorimetric error was acheved at m=0.045 under the room illumination. The accuracy of the colorimetric characterization by the GOGO moel was also evaluated. Although this GOGO model gives more accurate results at completely darkend room conditions but the accuracies by this model was inferior to that of the GGO model under the room illuminatin conditions.

4. CONCLUSIONS

Colorimetric calibration of a CRT display device under a room illumination condition was carried out by using the GGO and GOGO models as the characteristics between the R,G,B primaries and the frame data. The most accurate calibration was achived at the 4.5% reflectance of the illuminatin at the surface of the device. This means that the colorimetric characterization of a monitor by taking into account the external flare is very effective to reproduce an accurate color image in the room viewing condition. The GGO mode gives superior results to the GOGO model under room illuminatin conditions.

ACKNOWLEDGEMENTS

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The Assessment of Uncertainty in Spectrometry

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ABSTRACT

Ideally, manufacturer specifications provide performance characteristics and specifications that can be used to evaluate the suitability of colorimeter and spectrometer measuring and test equipment for a given application. However, understanding specifications and using them to compare; a) equipment from different manufacturers, b) the quality of products and adherence of colour measuring equipment and c) products to specifications can be a perplexing task. This primarily results from inconsistent definitions, terminology, units, and methods used to develop and report equipment performance specifications. This paper discusses how to; a) determine if manufacturer equipment specifications are adequate for the intended purpose, and b) interpret & assess colorimeter & spectrometer performance & reliability. A new approach that quantifies uncertainty in the field of colorimetry is presented. Derivations of the component values of uncertainty are presented. Recommended practices are presented and illustrative examples are given for obtaining appropriate data and then combining that data as components values of uncertainty into a specification. These component values, which are Chi distributions, are combined in such a manner so that the result is the combined expanded uncertainty. This value represents the 95% confidence interval. An international standards organization adopted this approach. This standard enables colorimeter and spectrometer users to be in compliance with the uncertainty requirements of international standards; such as, ISO/IEC 17025.

1. INTRODUCTION

Approximately two years ago, in 2009, ASTM International[1] undertook to study this problem and to define a procedure that would assist the color measuring community in obtaining international accreditation. This paper describes the results of that study and the procedure finally standardized for the assessment of the uncertainty of spectrophotometric and colorimetric measurements; such as reflectance and transmittance measurements.

Instruments, as the term is used in this paper, mean spectrometers, spectrophotometers, abridged spectrometers, colorimeters, spectro-colorimeters, and other color measuring instruments. This includes whatever data processors are used to collect, process and compute the colorimetric values, color difference values and total color difference metrics.

Manufacturer specifications should provide detailed information about colorimeter and spectrometer performance characteristics. Some of the manufacturers may only provide a single specification for overall accuracy. None of the classical manufacturers provide ample information detailing individual performance specifications; such as uncertainty. In some instances, specifications can be complex, including numerous time and range dependent characteristics and values. And, since specification documents are also a means for manu-

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[1] ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania, USA, www.astm.org, (610) 832-9500

facturers to market their products, they often contain additional information about features, operating condition limits, or other qualifiers that are not relevant to this paper.

There are various published approaches to the estimation of uncertainty and/or variability in testing. ISO/IEC 17025[2] does not specify any particular approach; rather laboratories are encouraged to use statistically valid approaches. The concept presented here is to provide a reasonable estimate of the appropriate uncertainty data according to known parameters within the industry. For instance, both the intermediate precision and reproducibility (from interlaboratory comparisons) described in ISO 57255[3] (see clause 5.4.6.3, note 3 of ISO/IEC 17025) may be used in estimating measurement uncertainty. However, these may omit some uncertainty sources that should also be identified.

Manufacturers publish colorimeter and spectrometer specifications in a variety of places. For instance, on their web pages, in product data sheets, technical notes, control drawings, and operating manuals. In some instances, manufacturers will only provide information about colorimeter and spectrometer specifications and data upon formal request by phone, fax or email. What is worse is that some manufacturers do not provide meaningful or interpretable data! In general, however, published specifications are relatively easy to find via an internet search or by phone. In specifications for spectrometry, it is helpful for one to know the relevant industry-specific terminology and jargon).

2. DEFINITIONS

There are several definitions and concepts that may be new to the reader. Uncertainty is defined as a property of measurement in a laboratory, not at a national standardization laboratory. Since uncertainty has been developed expressly for spectrometry and colorimetry and have different meanings, they are presented here.

a. Uncertainty-n, a parameter associated with a measurement result or test result that reasonably characterizes the dispersion of results attributable to the particular quantity being measured of the particular characteristic being tested.

b. Instrument uncertainty conditions-n, of a measurement, conditions wherein the measurements are made repetitively and carefully over a short timescale, without replacement of the specimen being measured in the specimen port of the instrument.

c. Operator uncertainty conditions-*n*, *of a measurement*, conditions wherein the measurements are made repetitively and carefully over a short timescale, with replacement of the specimen being measured by the operator completely withdrawing the specimen from the specimen port and replacing the specimen back in the specimen port prior to the ensuing measurement so that the specimen aperture samples the same location on the specimen, and the specimen has the same orientation as previous, to the best of the operator‘s ability to accomplish.

d. Uniformity uncertainty conditions-n, of a measurement, conditions wherein the measurements are made repetitively and carefully over a short timescale, with replacement of the specimen being measured to an entirely new location on the face

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[2] ISO/IEC 17025:2005, *General requirements for the competence of testing and calibration laboratories*

[3] ISO 5725-5:1998*, Accuracy (trueness and precision) of measurement methods and results - Part 5: Alternative methods for the determination of the precision of a standard measurement method* by ISO TC 69/SC 6/WG

of the specimen with the intent of sampling the entire surface of the specimen, or as much of the surface as is practical, by the end of the repetitive sampling run.

e. Instrument uncertainty-n, the results of an uncertainty analysis of a measurement system made under instrument uncertainty conditions.

f. Operator uncertainty-n, the results of an uncertainty analysis of a measurement system made under operator uncertainty conditions.

g. Uniformity uncertainty-n, the results of an uncertainty analysis of a measurement system made under uniformity uncertainty conditions.

h. Expanded uncertainty-n, uncertainty reported as a multiple of the standard uncertainty.

i. Measurement system-n, the entirety of variable factors that could affect the precision, accuracy, or uncertainty of a measurement result. These include the instrument, the operator, the environmental conditions, the quality of the transfer standard, the specimen aperture size, as well as other factors.

3. METHOD

ASTM derived a method of measuring uncertainty of measurement as follows: Assume that the components of uncertainty consist of the instrument, the operator, and the uniformity of the sample surface. Make 30 measurements of the sample under consideration under instrument uncertainty conditions, 30 measurements under operator uncertainty conditions, and finally 30 measurements under conditions that will discover the lack of uniformity of the surface of the sample. Each of these three conditions is defined in the standard as to exact procedure to follow to separate these contributions from each other.

$$\text{Number of differences} = n * (n - 1) / 2 \qquad (1)$$

There are differences among these 30 measurements. There are 435 differences when each measurement has been differenced with each other measurement. When the differences are sorted in ascending order, the 413th value of these differences is the 95% confidence interval.

The differences may be appropriately subtracted from each other by treating the components as if they were a square-root of the sum of the squares. Thus, one may determine magnitudes of the sources of uncertainty for the purpose of assessing where effort may need to be placed to reduce or minimize uncertainty.

Caution must be exercised in separating these components from each other as the 95% confidence intervals do not subtract from each other under quadrature unless the distributions of the differences are nearly that of the Chi distribution, which many times they are not.

4. RESULTS AND DISCUSSION

Typical results would be as is contained and presented in the following tables. The first group of data is the experimentally determined 95% confidence values, but each of these is determined under conditions wherein the previously determined component is also present. That is, having determined the instrumental component, that component is also present when the operator uncertainty is determined. Similarly, the instrument and the operator components are present when the uniformity component is determined. These must be separated from each other as has been done in the second group of data, Table 2.

Table 1: Instrument, operator and uniformity uncertainty for a white paper specimen.

Experimental values	
Instrument Uniformity	0.0513
Operator Uniformity	0.0529
Sample Uniformity	0.4091

Table 2: Separated values of uncertainty for a white paper specimen.

Calculated Uncertainty Values	
Instrument Uncertainty	0.0513
Operator Uncertainty	0.0129
Sample Uncertainty	0.4069 ΔE^*_{ab} 10°- D65

Uncertainty can be used to decide whether there is a difference between results from different laboratories, or if the results from the same laboratory at different occasions (time trends etc.) are different from one another. Uncertainty is also necessary when comparing results to allowable values, e.g. tolerance limits or allowable (legal) specifications. To make a correct decision one needs the uncertainty value which is the range of total color difference, ΔE. In this case, ΔE means $\Delta E_{ab}*$, ΔE_{cmc}, ΔE_{94}, ΔE_{2000}. The ΔE used in the specification or reporting must be clearly specified by subscript notation.

5. CONCLUSIONS

The laboratory desiring to obtain uncertainty values should identify all the significant components of uncertainty for each test. A component with an uncertainty of less than one –fifth (1/5) of the total measurement uncertainty will usually have little impact on the total measurement uncertainty. However, if there are several or more of such components, their combined contribution to the total measurement uncertainty may become significant and should not be ignored. Laboratories should make every endeavor to identify error sources. Even where reliance is to be made on overall precision data or where note 2 of clause 5.4.6.2 of ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories* is evoked. These data will provide information to confirm that all reasonable and significant components have been identified and accounted for.

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ASTM E 2244, Calculation of Color Tolerances and Differences from Measured Color Coordinates

ISO/IEC 17025:2005, General requirements for the competence of testing and calibration laboratories

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Preparation Human and Machine Metamer Sets and Their Reciprocal Responses

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ABSTRACT

The modern color recording devices are increasingly used for color measurement and reproduction purposes. Nevertheless, some practical problems occur due to the different responses of human and machine to identical colors. While such an issue can simply cause different responses for a given sample when detected by human and machine, the problem is more pressing for metameric pairs. The present paper deals with the problem of metameric pairs in human and machine vision systems. In this research, different sets of human and device metameric pairs were prepared by using different combinations of colorants on identical textile substrates. The responses of each system, i.e. human versus device, for the metameric pairs of the other system were colorimetrically evaluated. Based on the results, the human metameric pairs are recognized by the device with large color differences and likewise, the device-metameric pairs showed significant color differences when assessed by human observer under a given set of illumination. This finding highlights the basic differences of human and machine visions and reconfirms the imperfection of such instruments in color control of metameric samples.

1. INTRODUCTION

In the past few decades, imaging capture devices have gained attention because of their daily applications. Machine visual system designers attempt to stimulate the human color perception. However, existing machine visual systems are very different from human visual system (Sharma and Trussell 1997). The major problem in machine vision is that in some cases what people see is different from what machine does. Although pair of spectrally different samples could match in color for the observer under a certain illumination, they are inspected with different colors by a machine even under the same illumination and likewise. In fact, a metameric pair for one system would be likely non-matched samples for the other.

Metameric pairs are color stimuli with different spectral power distributions but with equal tristimulus values under defined illumination condition. According to CIE definition, the equality of tristimulus values under a certain light source can be expressed by Equation 1.

$$\sum E_\lambda S_\lambda R_{1,\lambda} = \sum E_\lambda S_\lambda R_{2,\lambda} \qquad (1)$$

where $R_{1,\lambda}$ and $R_{2,\lambda}$ are reflectance spectra of the metameric pairs, S_λ shows color matching functions or detector sensitivity functions and E_λ demonstrates the illuminant spectrum. While according to Equation 1 it should be possible to achieve the same colorimetric results for human and machine system, but in practice it is not simply possible because the human and machine vision arrangement have different sensitivity functions (Marszalec *et al.* 1997).

Metamerism is a phenomenon which has both positive and negative aspects in color applications (Sharma and Trussell 1997) that needs to be taken into consideration. Most color imaging devices provide the metameric pair of subject to display the reproduced color and most industrial matched color products are metameric pairs (Shen and Xin 2004). Therefore, metamerism is of cardinal importance in human daily life. Since the metamerism occurs due to compression of spectral data into three dimensions by the eye or a camera, obviously the changing of the sensor system i.e. from eye to scanner, changes the spaces and yields different colors (Drew and Funt 1992). In fact, a pair which is metameric for a human could not be detected as identical color by scanner and *vice versa*. The problem originates from non-satisfaction of the Luther-Ives condition by the most of the colorimetric devices where the spectral sensitivities of the photo-detectors are not a linear combination of the eye cone responses (Ives 1900).

The present paper deals with the problem of metameric pairs in human and machine vision systems. In this work, different sets of human and device metameric pairs were prepared by using different combinations of colorants on identical substrates. The human-metameric pairs matched in color with small residual color difference under D65 illuminant and the 10-dgree 1964 standard observer. The device-metameric pairs were selected as those having close RGB values measured by the two common types of scanner that were used in this study. Then, the responses of each system to the metameric pairs of the other system were colorimetrically evaluated.

2. MATERIALS AND METHODS

2.1 Sample Preparation

To prepare the human metameric pairs, two sets of dyestuffs were used for preparation of standard and the matched samples over the identical cotton fabrics. The pairs were matched under D65 illuminnat and the 10-degree 1964 standard observer.

Two commercially available scanners, i.e. Epson Perfection 3170 PHOTO and HP Scanjet 3970 were used to measure the RGB values of samples. Similar to human metameric pairs, different sets of dyestuffs were also employed for preparation of device-metameric samples. The selected pairs were those that benefited from close RGB values by one of the scanner.

2.2 Devices

As mentioned in the previous section, Epson Perfection 3170 PHOTO and HP Scanjet 3970A were employed as machine type color measurement devices. A bench type spectrophotometer named ColorEye 7000A was used to measure the reflectance spectra of samples within 400 to 700 nm at 10 nm intervals. EyeOne pro spectroradiometer was also used to measure the spectral radiances of scanners' light sources.

The scanners were characterized by using of gray chips of Kodak Q_60 Color Input Target in gray balance method the lateral linear regression technique. Finally, the responses of each observing system were converted to other system and compared with each other.

3. RESULTS AND DISCUSSION

The CIELAB color difference values between the metameric pairs were calculated under three different illuminants. The RGB color differences of samples were also computed as a Ecuelidian distance in RGB space for both scanners. Based on calculation, samples that satified the $\Delta E_{ab}(D_{65}) \leq 1$ in CIELAB space and $\Delta E_{RGB} \leq 4$ in scanner space were supposed to be metameric pairs. In other words, the values of $\Delta E_{ab}(D_{65}) \leq 1$ and $\Delta E_{RGB} \leq 4$ were respectively considered as criteria for human and device color matching. Table 1 represents the color differences of 4 human metameric pairs under illuminants D_{65}, A, and F11 and the values of color differences of each pair by the scanners. As the results of Table 1 show, while the pairs show small color differences under D_{65}, they have noticeable differences when they are measured by scanners. In fact, such acceptable pairs are absolutely unacceptable if the scanners were used for color evaluation.

Table 1. The color difference values for the human metameric pairs under different illuminants and color measurement systems.

Human metameric pair	Color	$\Delta E_{ab}(D_{65})$	$\Delta E_{ab}(A)$	$\Delta E_{ab}(F_{11})$	ΔE_{RGB} for the Epson scanner	ΔE_{RGB} for the HP scanner
1	Brown	0.66	2.16	4.93	9.52	14.33
2	Brown	0.82	3.59	3.65	10.76	7.60
3	Gray	0.39	1.51	1.50	17.32	9.91
4	Gray	0.69	2.25	2.02	18.86	15.18

Tables 2 and 3 similarly show the results of color differences for the machine metameric pairs, i.e. HP Scanjet 3970A and Epson Perfection 3170 PHOTO by human system. As these tables display, the machine metamer pairs show significant color differences when they are observed by human.

Table 2. The color difference values for metameric pairs under the HP Scanjet and the color differences for human observer under D65 illuminant.

Machine metameric pair	ΔE_{RGB}	$\Delta E_{ab}(D_{65})$
1	1.8	9.89
2	3.20	9.43
3	3.97	10.29

Table 3. The color difference values for metameric pairs under the Epson Perfection and the color differences for human observer under D65 illuminant.

Machine metameric pair	ΔE_{RGB}	$\Delta E_{ab}(D_{65})$
1	3.60	11.6
2	3.76	9.89
3	3.85	9.69

4. CONCLUSIONS

In this paper, different sets of human and machine metameric samples were prepared and their reciprocal responses were evaluated. It was found that the accepted pairs in human visual system could have significant color differences when they are measured by machines and similarly, the pairs that are detected as acceptable match by machines, show completely perceptible color differences when they are judged by human observers.

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Rendering the CIE 1931 Chromaticity Diagram

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ABSTRACT

Widely used in scientific and educational applications, this iconic colour chart consists of a two-dimensional projection of colour coordinates specified by CIE tristimulus values. It is frequently to be found in text books and on posters promoting colour-measuring instruments and related products. Despite its ubiquity, little attention seems to have been paid to correctness of reproduction. On the contrary, most versions simply strive to create a "pleasing" representation which both precludes the diagram being employed for colour identification tasks and also gives a misleading impression of colour relationships.

In this paper, an approach is described through which an improved rendering of the chromaticity diagram may be created in print or other media. The goal is to create a colorimetrically accurate reproduction (given the colour gamut constraints of the medium) whilst preserving hue and chroma smoothness and continuity. In addition, the chart needs to include both white point and also the technically correct depiction of colours close to the spectrum locus.

1. INTRODUCTION

In 1931, the CIE published their system of colorimetry (CIE 1986) which enabled a colour stimulus to be defined by just three numbers, *XYZ*, for a given set of viewing conditions. The system is still in widespread use today for industrial and scientific colour-matching tasks. It had long been recognised that three dimensions were cumbersome, and so a two-dimensional projection was created which ignored the brightness (*Y*) dimension thereby enabling colours to be plotted on an *xy* chromaticity diagram (Wright 2007). On this diagram, additive mixing can be predicted via straight lines connecting the points representing the lights' chromaticities. Chromaticity coordinates are used in numerous applications such as international standards for signal lighting. The diagram is also helpful for examining the dominant wavelength and excitation purity of stimuli.

While many attempts have been made to reproduce the CIE chromaticity diagram, this is typically done of the basis of aesthetic appeal rather than accuracy. As a result, users are presented with a distorted view of CIE colour space which precludes its use for visual matching of a specimen's chromaticity. To produce a "better" diagram, the two most significant obstacles are colour fidelity and colour gamut. Approaches such was the industry-standard ICC system for colour management (Green 2010) can help address the former, however dealing with gamut is rather less straightforward.

2. COLOUR GAMUT

The CIE system of colorimetry was designed to encompass the entire range of visible colour, whereas any practical printing or display system is only capable of reproducing a subset. Furthermore, colour gamut is a device-dependent property, meaning that it varies according to the specific technology and its components.

2.1 Medium Gamut

The range of colours that are reproducible on an imaging medium (e.g. printer and paper) can be described in terms of a gamut boundary through colour measurement. Only colours within this boundary are reproducible. An example of this for the printer used in this study is shown in Figure 1. Similarly, image-acquisition devices (cameras and scanners) have their own colour gamuts which limit how bright or colourful stimuli may be. In addition, images themselves contain a certain range of colours. Gamut mismatch is typically addressed by colour management. With the ICC system, for example, users need to select one of four separate rendering intents according to their application (Green 2010).

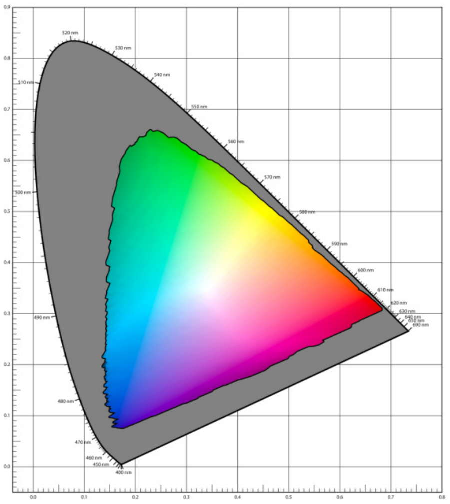


Figure 1: colour gamut of the printer used in this study.

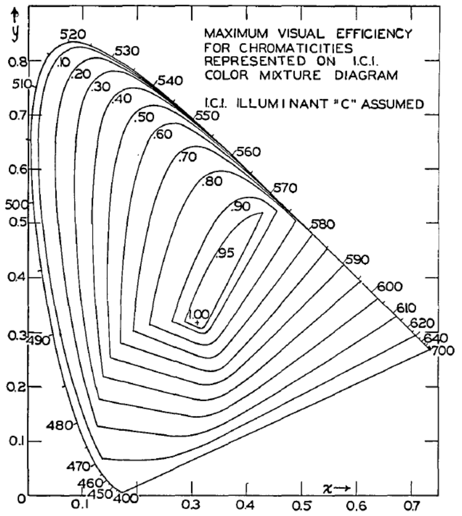


Figure 2: chromatic limits of real colours (MacAdam 1935).

2.2 CIE Gamut

The CIE chromaticity diagram is somewhat misleading in that the chromatic domain does not extend to the spectrum locus at every luminance. Calculations by MacAdam (1935) have shown that lighter colours have a much more restricted range of chromaticities. Only when the luminance factor is zero do colours reach the extremities. This means that a chromaticity diagram becomes darker as distance from the white point increases.

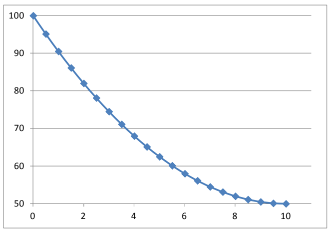
2.3 Gamut Mapping

There have been numerous algorithms proposed for mapping colours from one medium's gamut to another – for a survey of some of these, see Morovič (2008). These are generally aimed at producing pleasing images and are thus unsuitable to the task of faithfully reproducing the CIE diagram.

3. PROPOSED SOLUTION

Although it is evidently not possible to render colours beyond the target device's gamut, the out-of-gamut regions should at least be expected to preserve the correct hue if not the chroma. In order to include the white point without further reducing available colour gamut, it is necessary to reduce lightness as chroma is increased. A function was therefore defined which accomplished this as follows:

$$
\begin{aligned}
&L' = L_{max} + \alpha \bullet C^2 + \beta \bullet C && \text{if } C < C_{max} \\
&L' = L_0 && \text{otherwise} \\
&\text{where } \alpha = (L_{max} - L_0) / C_{max}{}^2 \\
&\text{and } \quad \beta = \text{-}2 \bullet \alpha \bullet C_{max}
\end{aligned}
$$



In the above, L' represents the new CIELAB lightness value to be rendered based on the hue-dependent maximum CIELAB chroma, C_{max} at a CIELAB lightness of L_0. L_{max} is the lightness of the white point (i.e. when $a^* = b^* = 0$). In this case, constant values for L_0, α and β of 50, 0.5 and -10 respectively were chosen in order to make lightness flatten out once the gamut threshold at $L^* = L_0$ and $C^* = C_{max}$ has been crossed. Beyond this boundary, lightness could either be preserved or alternatively – at the risk of changing hue – diminished to better reflect the MacAdam limits.

3.1 Gamut Smoothing

A further complication arises at the interface between in- and out-of-gamut regions. Gamut boundaries differ significantly between devices not only in volume but also shape. The irregularities and practical uncertainties of this boundary can lead to unacceptable discontinuities and so a smoothness constraint needs to be applied. This was accomplished using a combination of averaging of the maximum chroma values at each hue together with a slight relative reduction. The specific parameters used were determined empirically in order to produce visually acceptable results.

3.2 Creating the Diagram

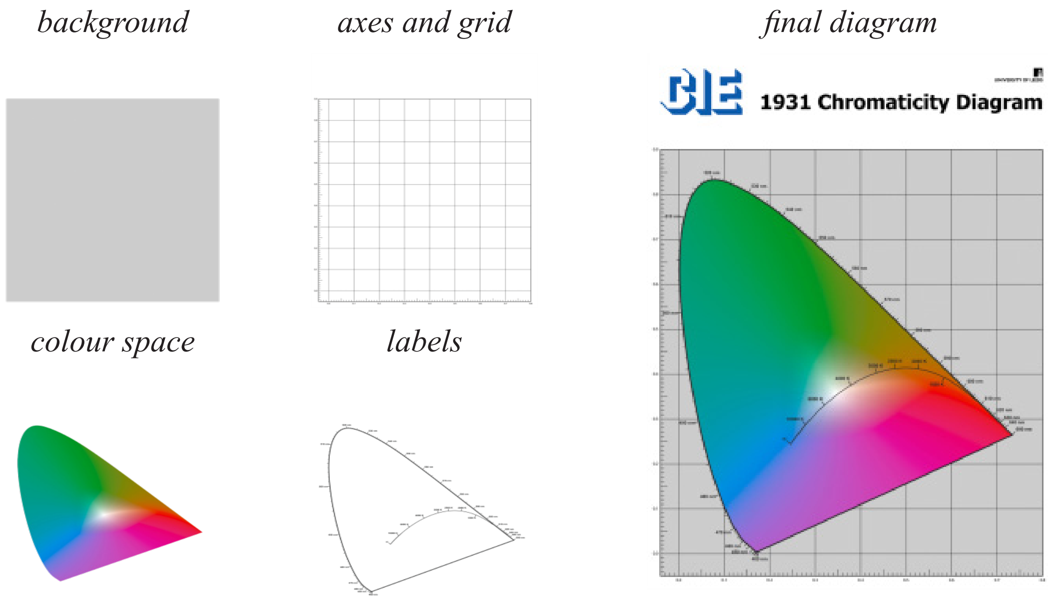
For this study, an HP Designjet Z3200 pigmented inkjet printer was used since it offered a relatively wide colour gamut and also included built-in spectrophotometer that could be used to both calibrate (ensuring repeatability) and characterise (profile) the device. The printer is capable of printing on a wide variety of substrates, however a semi-gloss instant-dry paper was chosen since this was found to deliver superior colour gamut compared to matt paper and also had good lightfastness and stabilisation properties.

The basis for computation was an ICC profile for the printer. Given this, gamut checking calculations were performed to determine the gamut boundary before creating a composite image of the final chart. This image was stored as a 16-bit CIELAB TIFF file to ensure colorimetric fidelity. Other elements of the diagram such as the spectrum locus, axes, grid lines, labels and black body curve were created as vector images using the Postscript language and these were subsequently rasterised as layers within the final TIFF image. These components are illustrated in Figure 3. (It should be pointed out that the colours shown are only approximate: they are meant to be rendered onto a specific printer and so are device dependent.)

4. CONCLUSIONS

Clearly any attempt to render the CIE chromaticity diagram has to involve a compromise due to real-world gamut limitations, however this work has succeeded in creating a much more faithful representation of the chart. The same technique could be applied to the reduction of other – more perceptually uniform – chromaticity diagrams such as the CIE 1976 UCS or $L^*a^*b^*$ which are more approprate for tasks such as comparing colour gamuts.

The entire method has been implemented using a 12-channel wide-format printer which, in conjunction with an enhanced colour-management algorithm, is capable of reproducing individual colours to an accuracy of around 1 ΔE. The resultant charts are now being considered for adoption by the CIE as their official version of the chromaticity diagram.


background

axes and grid

final diagram

colour space

labels

Figure 3: constructing the CIE 1931 chromaticity diagram.

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Bringing Traditional Thai Colours to Life using an Original Developed Software System

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ABSTRACT

In 2008, the Department of Imaging and Printing Technology initiated a project, within the Faculty of Science in Chulalongkorn University, called Traditional Thai Colour Naming Project. Toward the end of 2010 we imagined a method for identifying and analyzing the traditional Thai colours based on Siripant's work. In January 2011 we assumed full responsibility for this project with only two years left to finalize a four year project. While describing the methodology in a first article, we already realized that it is impossible to finish the project using that method. The problems are outlined in the first article we wrote. In the second stage of our research we improved the methodology and created a software to be used as a tool. We mentioned it in a second article but, due to different review speed and editing time, the second article was published first. The present paper is a short description of the software system itself, of its usage in traditional colour identification and of the context of its creation. This paper is written after submitting the complete study on traditional Thai colours and the Traditional Thai Colour Name Dictionary to Color Research and Application.

1. INTRODUCTION

Traditional Thai Colour Naming Project was part of the first five-year academic development plan of Chulalongkorn University (2008-2012). The allocated budget for this plan is known as Chulalongkorn Centenary Fund. The project was initiated in 2008 and started in 2009. Everyone in the department of Imaging and Printing Technology was invited to participate. Activities in the first two years have been of preparative nature, such as: ordering Munsell sheets from abroad, recovering some of the work done by Siripant (Siripant, 1988) until 1988 (mostly destroyed by floods), investigating Thai colour names in four regions of Thailand.

After assuming full responsibility of this project in 2011, we wrote an article about the applied methodology for identifying and analyzing traditional Thai colours, outlining the problems that we were facing, mainly the high colour inhomogeneity on samples painted by artists (Katemake and Preda 2013). Our first method could handle only a limited degree of inhomogenity, as described in that article. The article mentions some possible solutions that we were prepared to test. Shortly after submitting the first article, we thought about the possibility of using a scanner glass as wide measurement port to obtain good average CIELAB values, in D65/2o viewing conditions, for the inhomogeneous samples. Knowing about research related to obtaining colorimetric data from scanners, we believed to be quite easy finding software products that turn scanners into colorimeters. We tried hard to find one but could not. Therefore, we decided to create our own system. The software is mentioned in a second article (Preda et al. 2011) that was published faster than the first one we wrote (Katemake and Preda 2013). The published results of our intensive work might create some confusion if not followed in their strict chronological order.

2. ORIGINAL SOFTWARE USED IN COLOUR INVESTIGATION

The software was developed as a tool in research, not as a research object. It was initially created to provide solutions in our Traditional Thai Colour Naming Projects, not as an aim.

2.1 Short self answered questionnaire about the software system

1. What is the name of the software and how was the name chosen? We named the software Trichromatic Colour Analyser, abbreviated TCA. The name was chosen to reflect its basic function: Trichromatic Colour Analysis.

2. What is the purpose of this software and what is its main advantage? TCA turns a scanner into a colorimeter in order to use the scanner glass as measurement port. It measures colour samples on flexible sized areas, unlike dedicated colorimeters that are limited by their fixed aperture of the measurement port. The main advantage of this software system resides in the long list of colorimetric calculations that exploit its unique feature of measuring flexible sized areas between 0.07 to 100 sqmm.

3. Why do you call TCA sometimes “software” and other times “software system”? TCA was initially a software application that was destined to offer a reasonable solution to the inhomogeneity problems of artists’ paintings in our Traditional Thai Colour Naming Project. Encouraged by the fact that no scientific software was released in Chulalomgkorn University until 2011, according to the Universities’ IP office, we decided to create a fully functional software system that controls the scanner, overrides its factory settings, performs a large variety of colorimetric calculations etc., through easy-to-use drop-down menus and graphical interfaces. However, we still refer to it many times just as “software”.

4. Using a scanner for colorimetrically-accurate colour capture is the object of colour management and has been achieved somewhat through the use of ICC profile. Is TCA another colour-management software? Absolutely not. The main objective of a colour management software is to obtain good matches across colour devices connected to computer, colorimetric accuracy being sacrificed in favour of offering pleasing images on these devices rather than colour-accurate ones. TCA’s primary goal is to obtain colour accurate information from scanner. It defines a colourspace (TCA colourspace), based on user’s needs and system’s limits, in which any colour samples can be analyzed with the accuracy of a colorimeter. This approach is fundamentally different compared with colour management software. Therefore, TCA cannot be assimilated to this type of software.

2.2 Using TCA in traditional colour identification and analysis

We exemplify the use of TCA for identifying ‘Khiao Tong On’ colour name from samples painted by 6 artists (Fig 1). The scanner used is an Epson GT-20000. All CIELAB values are calculated in D65/2^{o} viewing condition.

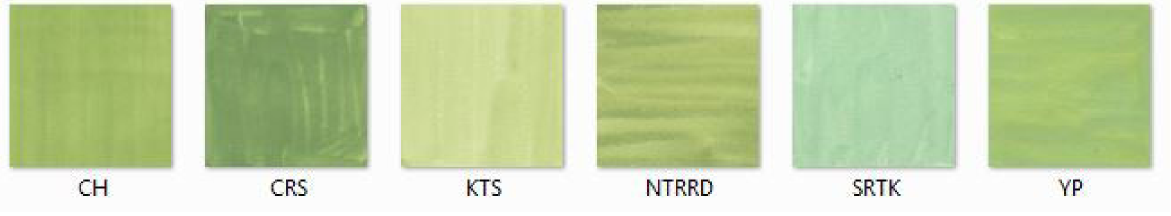

Figure 1: Khiao Tong On color name painted by 6 artists.

Each sample shown in Fig.1 is marked with the abbreviated name of the artist who painted it. Samples are scanned and introduced in TCA's colour catalog for creating the database, which can be of 2 kinds: with equally sized samples or random sized scanned samples. Size cannot exceed 100 x 100 mm. There are 2 ways of scanning: one with TCA's Location Calibrator and a software module developed for it, another one through a different software module that controls the scanner's TWAIN interface. The Location Calibrator places the sample at a determined distance from the scanner-glass-edges and forces user to scan always in the same position, keeping consistency of measurements and eliminating part of the influence that image noise could have on TCA's colour correction algorithms. Samples are placed on scanner glass with a pair of gloves to avoid the interference of fingerprints. TCA can be operated through voice commands and has built in voice user guides, so that gloves do not have to be removed when handling multiple scans at once, as in our case. Next step is to load each file in TCA's Colour Engine. This software module performs processes such as colour corrections and CIELAB calculations for each colour position (0.07 sq. mm) on the physical sample, identification of the most frequent colour and of the average colour on the sample, and generates files with processed data for each scanned file. Colour Engine is a preparative module that does the most time consuming and repetitive calculations needed in all future colorimetric-related computations that TCA performs for analyzing and for matching the scanned sample trichromatically. After using the Colour Engine, files can be analyzed with various tools, some of them developed at suggestion of participants in presentation workshops since February 2012. For the exemplified case we use only tools for calculating colour differences among most frequent colour and average colour on each sample, for calculating colour differences across the 6 samples and for performing colour matching with the digitized Munsell and NCS dictionaries. Due to space limitations, we just show results with a few comments.

3. RESULTS AND DISCUSSION

Table 1 contains the calculated average CIELAB values for each sample in the columns marked with "X" and the most frequent colour's CIELAB values identified on each sample, in the column marked "MF". The last row of Table 1 shows the colour difference between average and most frequent colour for each sample, expressed in ΔE_{00} units.

Table 1. Average and most frequent colours on artists' samples (TCA CIELAB D65/2^{o}).

	CH		NTRRD		CRS		KTS		SRTK		YP	
	X	MF	X	MF	X	MF	X	MF	X	MF	X	MF
L*	73.41	72.83	75.09	75.61	64.29	63.60	85.44	85.74	83.04	83.13	76.26	74.65
a*	-20.35	-20.29	-16.70	-16.58	-20.06	-20.02	-14.34	-14.19	-19.39	-19.50	-21.83	-21.61
b*	38.21	38.12	35.33	35.75	27.69	27.42	31.48	31.08	16.85	16.95	35.35	32.27
ΔE_{00}	0.44		0.44		0.59		0.26		0.09		1.75	

The high inhomogeneity of some samples can be seen with naked eye in Fig 1. Using TCA's module for determining colour distributions on the samples we obtain results of over 90% individual colours within a tolerance of $\Delta E_{ab} = 4$ towards the calculated average colour only for CH (97.72%), KTS (95.58%) and SRTK (97.84%). Although the inhomogeneity is high for the other 3 samples, the colour differences between the most frequent colour identified on each entire sample and its calculated average colour are small (Table 1). This shows unequivocally that the identified CIELAB values represent coordinates of the colours that artists had in mind when painting the samples. Having now unique colour coordinates for each sample, we must decide which sample should be chosen to represent the colour name “Khiao Tong On”. The obtained CIELAB values are compared across the 6 samples using TCA’s Compare Sample Pair module. Colour differences are calculated with both 1976 and 2000 formulas. The number of calculated colour differences are a combination of 6 taken 2 at a time (15 calculations). Table 2 shows ΔE_{00} calculated for the 15 combinations of pairs established from the 6 samples.

Table 2. Colour differences between artists’ sample pairs.

Pairs	CRS-CH	CRS-NTRRD	CRS-KTS	CRS-SRTK	CRS-YP	KTS-CH	KTS-NTRRD	KTS-SRTK	KTS-YP	SRTK-CH	SRTK-NTRRD	SRTK-YP	YP-CH	YP-NTRRD	NTRRD-CH
ΔE_{00}	8.51	9.57	16.09	14.97	9.76	9.08	7.35	9.19	7.44	12.16	11.28	9.87	2.7	3.02	2.28

As can be seen in Table 2, the smallest colour differences are between YP and CH, YP and NTRRD, NTRRD and CH, last 3 values. We group YP, CH and NTRRD together and calculate the average CIELAB values among them: L^*=74.92, a^*=-19.63 and b^*=36.30. The group contains 2 highly inhomogenous samples: YP and NTRRD. These CIELAB values are associated to a virtual sample that we note “AV”. TCA can match this virtual sample through its Trichromatic Colour Matching module using the digitized colour dictionaries implemented in the system, Munsell and NCS being only two of them. Alternatively it can choose a “representative sample” for this colour name, based on the smallest colour difference of each selected artists’ sample towards “AV”. Closest to “AV” is CH at 1.32 ΔE_{00} units, for which TCA finds the NCS match S2040-G50Y at a colour difference of 1.45 ΔE_{00} units. The match can be visually confirmed by observers under D65 light source.

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NCS – Natural Colour System property of and used on license from NCS Colour AB, Stockholm 2012. References to NCS in this publication are used with permission from the NCS Colour AB.

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Colour as Heritage: Chromatic Dynamics in the Requalification Process of Historic Centers of Fortaleza and Almada

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ABSTRACT

In the search for elements that can contribute to the *renewal* of urban spaces, colour is becoming a key component, especially in the intervention at historic centers. We developed a chromatic record from the observation and analysis of requalification projects in the cities of Almada and Fortaleza, in order to see how colour is being used in the intervention of urban spaces. The analysis showed that colour is recognized in the speeches of policymakers as an important element in this process of *patrimonialization* or *ennoblement* of cities, although the lack of a Plan of Colour can compromise the idea of urban *renewal*.

Keywords: Renewal. Patrimonialization. Urban Spaces. Plan of Colour

1. INTRODUCTION

Innovation in the identification marks of cities includes urban policy experiences grounded in the idea of patrimonialization. These practices denote a strategy for differentiating cities within the scope of competing for investors or new residents and visitors. The speeches of policymakers are demonstrating that cities can be renewed through the promotion of tourism and also through strategies that combine leisure and culture. In this context, elements that have an aesthetic or symbolic component, either material or immaterial, are the most susceptible to a restructuring that adjusts tradition to modernity.

The conversion of architectural structures into heritage, in addition to deriving from a legal action, ie, an act with wich the state declares a material or immaterial asset as heritage, also derives from the narratives of policy makers, planners and architects when implementing projects for requalification. It is common to disseminate speeches using the term *heritage* to enunciate the transformation of vernacular spaces into ennobled areas, now having other uses and appropriations. In this sense, regardless of cultural, historical, architectural and geographical characteristics of the cities, this phenomenon shows relatively similar aspects.

Among the elements that can contribute to the renewal of urban spaces, colour is becoming a fundamental component and is being used to enhance the patrimonial value of these spaces. However, the chromatic dynamics must go beyond aesthetic conveniences and a Plan of colour can strengthen the sense of belonging of the inhabitants and visitors with the requalified spaces, thus strengthening the identity of places. Speeches often use the idea of an original colour, related to the history of the place. However, we realize that colour is being used in a standardized way, which empties these urban spaces of their social and ideological content (Boeri, 2010).

The intervention model that uses colour as an important symbolic element in the enhancement of urban heritage has some exemplary cases, as the project “Barcelona posa’t guapa”, carried out in 1980 in the capital of Catalonia, and the project to revitalize the stone Pillory in the historic city of Salvador de Bahia in Brazil, developed in the early 1990s.[1] Regardless of the political importance and social uses, this idea is being spread in different cities, with much or little discretion with regard to the social value of colour. In Portugal, programs like “A Séptima Colina” (The seventh hill), “Lisboa a Cores” (Lisbon in colours), “Gaia bonita” (Beautiful Gaia), “Coimbra tem mais encanto” (Coimbra has more charm) or “Porto com Pinta” (Cool Porto), respond with greater or lesser fidelity to the challenge placed by these models circulating globally (Peixoto; Providência e Aguiar, 2011). In Brazil, besides the city of Salvador, a pioneer in this kind of intervention, the model has been replicated in different capitals through the project Colours of the City.[2]

The analysis we propose in our investigation considers, as empirical referents, the experiences of use of colour in the process of requalification in the Brazilian city of Fortaleza, and in the Portuguese city of Almada. Although having very different historical peculiarities, the choice of these two cities is justified by both having spaces classified in official speeches as degraded, though invested with patrimonial value through the allocation of a touristic potential related with recreation.

2. METHOD

The contextualization and use of colour and light respecting the feelings and ideas of city users, especially its inhabitants, is essential for the identification, readability and quality of the city. In other words, we perceive light and colour in a specific space and time, as ephemeral values that generate uniqueness, specificity, and its use is very important in the quest to transform the metropolis into a dynamic landscape that is continually renewed (Lenclos e Lenclos, 1995; França, 2003).

In this context, we use the ethnographic method and elected as subject of study the street of Tremembés, in the quarter of Praia de Iracema, in Fortaleza, and the street of Cândido dos Reis, in the parish of Cacilhas in Almada. The choice of these so distant streets, was based on the following criteria: they have historical value to the respective cities, both are inserted in requalification projects and in different discourses are identified as city heritage. Our analysis does not focus on a comparison; rather than confronting different realities, our goal was to make a general chromatic record, in order to understand how colour is being used in these processes of urban *renewal*.

Assuming that there are different levels of perception or observation scales of landscape, and considering the specificity of urban elements that make up the street, we consider three observation scales for the two streets being analyzed: global, punctual and detail. In the global perception we considered the environment from the idea of a street limited in a quarter. In the punctual perception, the street, urban benchmark and main scope of the analysis, was defined according to factors such as: environmental impact, referential elements, patrimonial values, spatial characteristics, functional organization of spaces, materiality of

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[1] In the case of Salvador this process has received much criticism for the way it was conducted, especially with the removal of traditional inhabitants.

[2] The first edition of project *Cores da Cidade* (Colours of the city) began in 1992 and was inspired by the European model driven by Akzo Nobel in the cities of Barcelona, Turin and Rome. This project proposed to rescue a colour palette of each city, through the restoration of buildings in historic areas. The project was a partnership of the municipalities with Ypiranga Paints and Roberto Marinho Foundation.

constructed objects, shape, texture, colour, reading and perception of colour, of natural and artificial light, and other pre-existences. The perception of detail enabled us to know factors intrinsic to local cultures.

It was an eminently field work, based on the concept of *geography of colour* defended and developed by Lenclos e Lenclos (1995). In order to obtain the necessary information for the whole research, graphic data of the place was taken, as well as photographic material and annotation of the areas of the facades.

3. RESULTS AND DISCUSSION

As a still partial conclusion of our analysis, we noticed the intervention at *Rua Cândido dos Reis*[3] is not being implemented following a planning strategy, which would involve a communication between the potential of colour and light.

Figure 1: Rua Cândido dos Reis, Serial Perspectives (Photos: Roselane Bezerra).

We found several compositions and tonal variations of base colours with the predominance of green and yellow, whose effect becomes important in the creation and recreation of the urban scale, for it generates important harmonies and contrasts that comprise the visual rhythm of space. Meanwhile, the good relation, or harmony, between the colour of the buildings' facades and the window frames is broken by the sign pannels of shops located in those buildings. We also perceive situations where there is a good integration between the colours of the facades, sign pannels and frames, but the colour tones do not have a good visual rhythm in the chromatic sense.

Figure 2: Rua Tremembés, Serial Perspectives (Photos: Roselane Bezerra).

As for the *Rua Tremembés*[4], we perceive much ambiguity about the use of colour. On one side there is some careful maintenance of a building, considered cultural heritage of the city, and in this case colour and light are in proper harmony. Meanwhile this building itself

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[3] In the street Cândido dos Reis a survey of existing buildings was carried out, which served to characterize them in terms of floor, design, façade signage and other appropriations of space. The annotation of colours was subsequently transformed into a colour palette and coded using the system NCS (Natural Colour System).

[4] For the street of Tremembés, we chose to analyze the use of colour in some buildings that are considered city heritage. This street was requalified by the municipality in the early 1990s, but from the 2000s the street went through a period of social and spatial degradation, due to lack of maintenance of buildings. Currently the requalification of some buildings is being implemented.

becomes an island in the middle, and there is a certain disregard for a Plan of colour for its surroundings. Another case worth mentioning is a venue that stands out for the use of garish colours as a way of distinguishing spaces; in this case even the electricity poles are painted with strong chromatic colours, marking the boundaries of the place.

4. CONCLUSIONS

In both streets analyzed, we identified a lack of advance planning regarding the use of colour and light. This fact is especially noticed when strong, chromatic colours are used as a way to atract the eye to the building. It is common that technicians responsible for these requalification processes claim that the use of colour is based on the idea of respect to a supposedly original colour or, in some cases, they delegate the responsibility to the taste of the properties's owners. Although recognized as an important element in the *patrimonialization* or ennoblement of cities, applying colour requires a deeper reflection whose justification is based on history and pre-existences, but also on the ability to articulate the spatial, temporal and cultural relations of the urban space.

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The Use of Color in Theater and Film

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ABSTRACT

In this paper, I propose a brief overview on the use of color in theatre and film and point to some references that I consider as seminal on this topic. How is color used in theatre and Film? How is it different and why? What is used on stage and on screen in terms of colors (props, costumes, make ups, sets, lights)? Are there any aesthetic rules and conventions, and how can they be questioned? I relate these rules and conventions to other color theories. In particular, what is the impact of certain colors in terms of meaning and in terms of emotions? I discuss the following questions: how do color choices participate in the aesthetic choices of a stage or screen director? Are these choices conscious or unconscious? How do color impact on the viewer? Is it cultural or universal? I share some of my experience as a stage and screen director in terms of using colors. Finally, I explain how I articulate my own artistic practice with theory, and how my status as an artist-researcher allows me to do so.

1. INTRODUCTION

Colors convey emotions. And they usually convey emotions in a very subtle way, but also in a very uncontrolled manner. Colors are undoubtedly an important aesthetic component in any artistic creation. This component can be consciously used or not, depending on the artist and on the process. But it is always there. Let's have a look at the way colors are used in theatre and film.

In theatre, the audience can see a show because it is lit. A great amount of thinking is usually put into designing the lighting. And it is very common in theatre to put color filters on lights in order to create particular moods. The first aim of lighting is to make things on stage visible. But the second aim, as important as the first, is to create an appropriate mood for each moment of the story. A lot of books have been written about how to light a show (Palmer, 1993) (Setlow & Essig, 2012) (Gillette, 2013) (Reid, 2001) (Shelley, 2009). The work of designing the light for a show is usually done jointly by the director and the light designer. But light is not the only choice connected to colors in the elaboration of a show. Every choice relative to the set, props, costumes also has an impact on the general color perception. And in the end, it is the combination of the two (the elements on stage and the lighting) that provides the audience with an emotional experience, partly impacted by the color perception.

In film, the work on colors is quite different. The lighting is usually much simpler in terms of colors (Alekan, 1998) (Storaro, 2011) (Frost, 2009) (Brown, 2007) (Brown, 2011). Again, the overall color perception is impacted by the choice of sets, props, costumes. But when a director or a cinematographer wants to add a color tone to an image, they put filters on the camera rather than on the lighting itself (there are of course exceptions). And the director also has the option to correct colors with a colorist at the end of the post-production chain. So a lot of choices related to colors are made at the very end of the process, even though it is usually much easier if these considerations about colors have been discussed and planned before the shooting.

To summarize, both theatre and film directors use sets, costumes, and props to impact the colors of their work. But in theatre, the lighting is the important phase, being the one that reveals what is seen. Whereas, in film, the perceived colors are the results of a combination of filters put on the camera and fine-tuning made by the colorist at the end of the post-prod chain.

In part 2, I describe in more details what are the vehicles of color on stage and in film. In part 3, I investigate on the aesthetic rules and choices that can guide the use of color, whether these choices are conscious or not. In part 4, I draw examples from my own experience as a stage and screen director. And finally, part 5 concludes this introductory survey on the use of color in theatre and film.

2. COLOR VEHICLES

Every element that is part of the design of a stage or a set (furniture, costumes, props, make-up, carpets, wallpaper, wall paints, etc.) impacts the overall color perception. A director can choose for instance to have every element in pastel tones or in bright colors, and that will obviously create a very different feeling. Every element has an impact on the overall composition. A lot of inspiration can be drawn in this matter from the paintings of the great masters. Which paintings do a director like the most? How are they composed? What is the palette of their colors? Is it harmonious or not? What mood does it create? Paintings are obviously a great source of inspiration for stage and screen directors. Not just for colors, but also for composition, and for lighting.

Color and light go closely together. Colors are the components of light. So anything that generates light or reflects it or let it go through has an impact on what is seen and on the colors of the scene. Take a moment to look in front of you and notice every color you can see. Which ones catch your eyes first? What is the relationship between color and light? Can you list every element that is defined, among other things, by its color (a book, a wall, a framed picture, a lamp, a floor, a carpet, etc.)? Now, how would you describe your overall feeling in front of this scene? What has the biggest impact on the definition of this feeling? This is the kind of questions stage and film directors ask themselves when preparing a show or a film. As the director, you are the person in charge of the overall aesthetics, and therefore in charge of each decision that contributes to the aesthetics. Are there any rules that guide all the decisions stage or screen directors have to make?

3. AESTHETICS CONSIDERATIONS

The way directors approach colors is very different from one director to another. There are some color theories that can be used as guidelines (Hyman, 2006) (Bleicher, 2011) (Mollica, 2012). Some directors follow them, or at least make their choices being aware of them, and some directors have their own personal approach to color, which may or may not be different from what these color theories propose. The way directors choose colors is based, in my opinion, on several things, and the influence of these things can vary greatly along their careers: what they know about colors, their culture, their experience in using colors, the questions they ask themselves about colors, the possibility of them having a dialog about colors with their lighting designer or their cinematographer, the show or the film they are directing and its needs in terms of color, etc. So there may exist some aesthetic rules about the use of colors, and they may be used by some directors as guidelines, and broken by other directors, or even followed unconsciously by some directors. And some people might argue that the knowledge of these rules can only improve the artistic abilities of a director. But as with any aesthetic rules and guidelines, this is when directors can transcend them that they truly become artists.

Another interesting question is the way certain colors impact meaning and emotions, and these considerations are also very important in the way directors work with colors. Colors are components of light, and therefore, each color has a different energy. So each color has a different feeling, acts differently upon us, and there are various ways to draw a typology of colors, and these ways have been different across the ages (Finlay, 2003) (Ball, 2003). There are very few books that manage to do a great synthesis on this subject, but two of them are particularly amazing as they draw from history, from various cultures, but also from spiritual traditions (Berton, 2002) (Simpson, 1999).

Finally, there is the question of culture and its impact on the interpretation of colors in terms of meaning and emotions (Gage, 1999). If color is intrinsically linked to a culture, then will an audience in Japan or in Cameroons react the same way to a show or a film? Probably not. And the challenge then becomes to find ways to make a show or a film as universal as possible, in terms of its storytelling and emotional meaning, in spite of the fact that some of its aesthetic components will remain quite identifiable in terms of its origin, and may seem a bit strange or odd to some cultures. But this is in my opinion one of the great advantages of cultural differences: they provide learning experiences about other cultures, and therefore about our own.

4. EXAMPLES

Here are some brief illustrations to the various points I discussed so far, chosen from my experience as a stage and screen director. The first example is my stage direction of the play *The Lesson*, written by Eugène Ionesco, which I directed in 2010. I started by reading the play over and over again, letting images come into my mind, and usually these images came with lighting and colors. At some point in the process, I also played around with the color cards of William Berton (Berton, 2002). I thought of certain aspects that I wanted to emphasize in the play and I let my mind free-associate colors with these aspects. I worked on this show with Olivier Horn, who is an amazing light designer. He captured the essence of what I wanted, and translated it into lighting in a very subtle way. I also started thinking about the set, props, and costumes very early in the process. I thought very early about a small round table covered with a bright red cloth in center stage. And then I wanted the professor to have a dark outfit and the student a bright one. They ended up dark brown and light yellow. I work very intuitively on colors, and the final decisions are always the end result of a fruitful collaboration with the light designer, the costume designer, and the make up artist (I did most of the set and props design on this show).

The second example is the making of the short film *King Cake (La Galette des Rois)*, written by Vinciane Mokry, which I directed in 2012. Very early in the process, I wanted a golden yellow and a royal blue to be the two guiding colors in my creative process. I made choices of props and costumes as well as lighting based on these two dominant colors. And these two colors also served as guidelines for the colorist. At the end, the result is very subtle, and is the consequence of a permanent dialog with the cinematographer, the production designer, and the colorist. But the original intention is there and has an impact on the general tone and mood of the film.

Being an artist-researcher, that is, sharing my time between my art practice and my research, I can articulate the two together. My practice informs my research, and is the basis for it. And my research opens new perspectives to me as an artist and directs some of my artistic choices. For instance, this investigation on the use of color in theatre and film is based on my practice, but at the same time allows me to go one step further in my thinking, and therefore will have an influence on how I do things next time. There is a permanent interaction and dialog between practice and research.

5. CONCLUSIONS

Colors are perceived in film and theatre as the result of several components: set, props, costumes, make up, lighting, and each of these components has an impact on the overall color perception. Colors have a direct impact on the emotions of the viewer and are usually chosen for that purpose. There are some aesthetic rules that can be used as guidelines and some cultural differences that can be taken into consideration. But in the end, much of the creative process happens in the subconscious mind and is the result of several factors: what directors know about colors, their culture, their experience in using colors, the questions they ask themselves about colors, the possibility of them having a dialog about colors with their lighting designer or their cinematographer, the show or the film they are directing and its needs in terms of color.

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Indian Bride in White: A Visual Investigation of Colour Perceptions in Bridal Wear

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ABSTRACT

The study investigates bride's conduct of attire to analyse and synthesise the effective socio cultural shifts that have been the driving the evident changes in colour perceptions of bridal fashion in India. In a culture led society -India, colours and their connotations play a very important role in deciding and designating the nature of an event, occasion; they also are signifiers of identity, religion and bring a certain sense of belonging or cohorts (Russel, 1923; Kumar, 1999; Mukherjee, 2001; Diane & Cassidy, 2009). The study is aimed to map acceptance of white as a colour in Indian bridal wear through the diffusion process using frameworks defined by Rogers and Robertson (Brannon, 2007) and adoption process defined Sproles Model (Forsythe, Butler and Kim, 1991). The connotation of white colour in India is generally in the context of mourning and grief as opposed to the Western understanding of white as pure and a good omen. Visual abstraction and trend spotting methods were employed to identify the evident paradigm shifts or radical trends. Reportage scan and wedding photographs were used as a mode of inquiry for the study (Lynch & Strauss, 2009). The identified changes in preferences illustrate the values and perception of the present society.

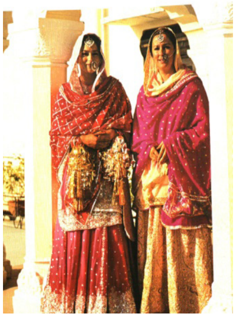
1. INTRODUCTION

Symbolism of colour affects bridal wear globally (Foster & Johnson, 2003). Similarly in an Indian wedding, colour has its symbolic and emotional meaning; a connotation attached to it. As diverse are India's culture, equally diverse are its numerous wedding traditions; each community has its own norms dictating even the colour of the bride's attire.

The tradition lead segment of bridal wear, has lately witnessed a radical shift. It has been observed that the traditional palette of colours has moved beyond the traditional to include unconventional colours such as white. Such trends are indicative of a constantly evolving society; reflecting the motivation that drives the brides to alter their traditional dress, their understanding of world view, changing goals, preferences and values of a society against the previous assumption of customs being static in a traditional setting (Foster & Johnson, 2003).

Traditionally a Hindu Bride cannot wear a white bridal lehanga or sari to her wedding because of religious values and superstitious beliefs. White in general is a symbol of morning grief and death in India. A widow is the only one titled to wear white or off white in the Hindu religion. While in the western sensibilities white symbolises pure and a fresh start, it is also a connotation for virginity, love, faith and holiness. On the other hand in certain Indian cultures such as in Parsi and Kerela, white is considered auspicious for the bride and brings good luck to her. The connotations of white as a colour changes according to religion and regional practices in India.

However, these older styles have no relation to the current context of traditions and fashions. Brides often alter their traditional attire and make changes according to the present day context which result in a seemingly traditional dress but with the motivations and aspirations reflecting through the changes made. Sometimes the bride is left with no choice and has to follow what the family has to offer (Kaiser, 2003, P-58).



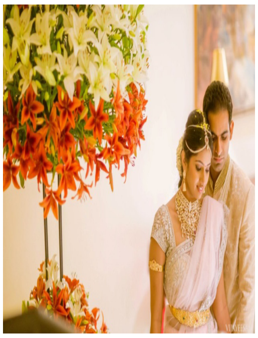


Figure 1 (left): Maharani of Nalagarh, Punjab dressed in her traditional bridal attire along with her daughter on her wedding (Royal Costumes and Textiles of India, Kumar, 1999).

Figure 2 (right): Bride Shravanya Reddy along with her Groom on her wedding day in January 2013 (Vijay Eesam Wedding Photography).

Traditional and royal are taken to be synonyms and harbingers of culture, as they were essentially passed down through generations (Martand Singh, 1999). Fashion today is ruled by media. Kumar's (1999) concerns are evident through the advancements in communications and increase in the average travel has caused the geographical boundaries to dissolve which has resulted in "cross- pollination" of regional styles and practices resulting in the emergent new design vocabularies. Working brides have fast access to fashion information from across the world and due to globalisation. The colour white for an Indian bride is no less than an innovation in Bridal wear keeping in mind the Indian market and religious beliefs. Figure 1 illustrates the traditional bridal attire and colours, in comparison figure 2 is an example of a modern day bride of 2013 wearing pure white bridal wear attire. This study aims to map this transition of percpetions and changing traditions.

2. METHOD

Brannon (2005) suggests that observation becomes important method to collect primary data, as opposed to other studies which take observation through media and book scans as to be secondary. Brannon cites Greco (1994), who asserts that "three's a trend" rule works promisingly while identifying fashion trend and change. This led to the identification change agents and drawing of the diffusion curve prescribed by Rogers (1983). The innovation 'white bridal wear' was hence identified and scrutinised against the characteristics provided by the Rogers -1983 (Brannon, 2005). The consumer adoption process prescribed by Sproles (1981) was used to further understand the change agents. Figure 3 illustrates the methodology followed during the study.

2.1 Identification of Innovation: Sample Preparation

To investigate the fashion and cultural changes at the mass level, magazines, such as Asiana, Wedding Affair, Vogue, Vivah, Verve, Designer Mode and Vanitha were observed for bridal trends and other real time weddings (IRS, HANSA Research, 2010). Television shows: Big Fat Indian Weddings and Band Baja Bride on NDTV Good Times were observed for bridal trend related information by bridal couture designers. Newspapers: Times of India and Hindustan times were kept track for any real weddings that made it to the news. Personal observations and insights of friends and family supported the analysis of the larger picture of the on-going transitions (Brannon, 2005, pp-114). Personal interviews of brides were conducted based on snowball sampling to further diagnose the actual reach of the innovation.

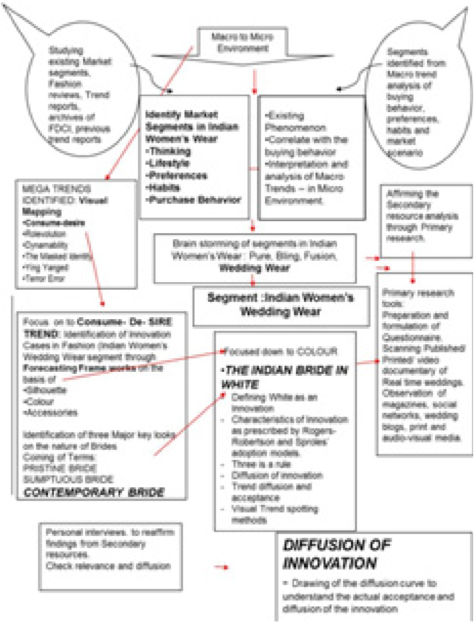
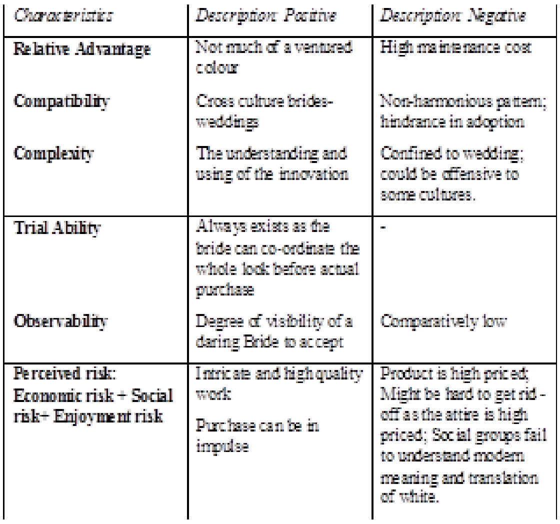


Figure 3: Methodology adopted in study.

Table 1: Characteristics of Innovation.



Characteristics	*Description: Positive*	*Description: Negative*
Relative Advantage	Not much of a ventured colour	High maintenance cost
Compatibility	Cross culture brides-weddings	Non-harmonious pattern; hindrance in adoption
Complexity	The understanding and using of the innovation	Confined to wedding; could be offensive to some cultures.
Trial Ability	Always exists as the bride can co-ordinate the whole look before actual purchase	-
Observability	Degree of visibility of a daring Bride to accept	Comparatively low
Perceived risk: **Economic risk + Social risk+ Enjoyment risk**	Intricate and high quality work Purchase can be in impulse	Product is high priced; Might be hard to get rid - off as the attire is high priced; Social groups fail to understand modern meaning and translation of white.

2.2 Characteristics of the Innovation

White bridal wear was scrutinised against characteristics identified by Rogers (Brannon, 2005):

3. RESULTS AND DISCUSSION

The colour white is no less than an innovation in the Indian bridal wear segment. The trend was first spotted in 1999 and has trickled across the fashion segments with the highest diffusion levels in the year 2007 and 2010, while in 2009 white was not the obvious choice by the brides. In the present day context of year 2013 the innovation has reached high end and couture retailers catering to niche bridal wear. Figure 4 maps the diffusion of white colour in bridal wear, Figure 5 illustrates the diffusion curve.

Figure 4: Mapping of number of occurrences.

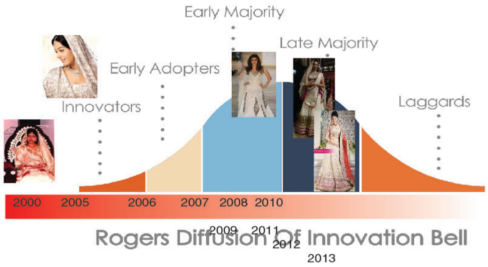


Figure 5: Diffusion curve.

4. CONCLUSIONS

It is the need of the hour to document the numerous ongoing transitions before they perish, as these transitions give us meaning and shape a society's identity. Today, India requires such changes and cultural shifts across genres while maintaining the Indian identity and not blindly aping external influences, to be able to attain the status of a fashion capital and to be able to deliver Indian couture in its true essence (Kumar1999; Nagarath 2003). This radical trend would further help designers and researchers to design well and cater to this niche market in an organised manner.

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We thank all the brides for their support. We are grateful to Vijay Eesam and Amar Ramesh for sharing their work. I also thank designer Sabhyasachi Mukherjee for his design directions and to my mentor Prof. Shalini Sud for her constant guidance. Thanks to Prof. Varsha Gupta, M. Suhail, Kavita Yadav, Prof. Nilanjana B., Dr. Vien Cheung, Prof. Tom Cassidy and Dr. Tracy Cassidy for their valuable insights. At last I would like to thank my parents and my brother who brought in lot insights, traditional knowledge and helped me quantify my research through their wide experiences.

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Study on Color Variation of Randoseru

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ABSTRACT

A questionnaire survey on randoserus with color chart had been conducted with Japanese parents who has child(ren) go to the municipal kindergarten to reveal the modern intentions or manner of their selection and their color. The color chart includes three kinds of color circle consisted of twelve hue in different tone to investigate the color suitability for randoseru. The result shows the statistical significance in gender of children, namely boys or girls who uses the randoseru. Many respondents selected black, blue, or green for boys, and red for girls. The refused colors, on the other hand, are red or purplish red for boys, and blue or green for girls. Although the diversification of the color of children's fashion advanced, there still is stereotype as black randoseru for boys and red one for girls.

1. INTRODUCTION

A randoseru is a firm-sided backpack made of stitched firm leather or leather-like synthetic material, most commonly used in Japan by elementary schoolchildren (Figure 1). The term randoseru is a borrowed word from the Dutch "ransel" meaning "backpack", a clue to its origins nearly 200 years ago as used in the Netherlands (Vardaman 1995).

Traditionally, the randoseru is black in color for boys, red for girls. While in more conservative schools the color (and often the brand and design) is mandated and enforced, the backpack is available in a variety of colors, partly as a compromise for parents to retain some tradition within modernized schools which no longer require the use of traditional uniforms or of the randoseru (Comzine 2004, Wikipedia 2013).

Figure 1: Japanese elementary school children with randoseru. (Seiban, 2012).

In this study, a questionnaire survey on randoserus with color chart had been conducted to reveal the modern intentions or manner of their selection and their color.

2. METHOD

A paper-based questionnaire survey on randoseru with color chart had been conducted. The color chart includes three kinds of color circle consisted of twelve hue in different tone to investigate the color suitability for randoseru.

2.1 Color Circles

Three types of color circles, prepared to answer about boys and girls respectively, were used for the paper-based questionnaire. Each of them was consisted of 12 chromatic colors (additive primaries, subtractive primaries, and their intermediate color) and one achromatic color in different tone (vivid, light, dark), as shown in Figure 2. The colors were selected in equal distance of *RGB* value on a personal computer and were printed on the paper by using the color laser printer (Epson, LP-M5600A).Their Munsell's *HVC* values measured on the paper by the spectrophotometer (Konica Minolta, CM-2600d) are shown in Table 1. The reproducibility of them in slandered deviations was 0.52H 0.11/0.23.

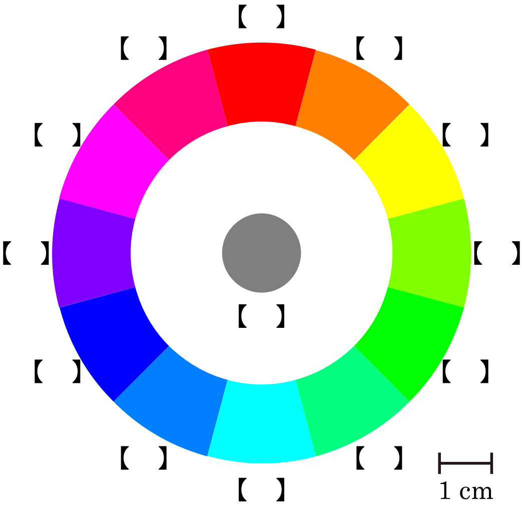

Figure 2: Example of Color circle used for questionnaire.

2.2 Questionnaire Survey

The respondents of the survey were eighty one Japanese parents who has child(ren) go to Mikunigaoka kindergarten of Sakai city in Osaka, Japan. They judged the suitability of the colors for randoseru and gave rankings in parentheses according to the five grade evaluation system using marks (◎ ; excellent, ○; good, △ ; average, _; fair, ×; poor). In the results analysis, the ranks were converted into value from 5 to 1 for calculate the suitability.

Table 1. Color used for questionnaire in Munsell's HVC notation.

		v (vivid)		dk (dark)		lt (light)
R (red)	🟥	7.9R 5.5/9.8	🟥	2.0YR 4.5/2.5	🟥	3.4RP 6.8/6.0
YR (yellow red)	🟧	7.6YR 6.7/8.8	🟫	2.0Y 4.8/3.2	🟧	2.2Y 8.2/3.7
Y (yellow)	🟨	9.0Y 8.7/10.0	🟫	3.5GY 6.0/7.0	🟨	0.2GY 8.9/5.7
GY (green yellow)	🟩	8.3GY 6.7/8.4	🟩	0.6G 5.2/7.0	🟩	8.8GY 7.4/6.0
G (Green)	🟩	1.3G 6.0/9.0	🟩	2.3G 5.0/6.4	🟩	2.0G 6.8/6.5
bG (bluish green)	🟩	6.8G 6.2/7.3	🟩	4.6G 5.1/8.9	🟩	2.5BG 7.0/5.3
BG (blue green)	🟦	3.7B 6.7/7.5	🟦	1.7B 5.4/8.1	🟦	4.6B 7.4/6.0
B (blue)	🟦	8.6B 5.8/8.4	🟦	9.5B 4.2/8.7	🟦	9.1B 6.9/6.7
PB (purple blue)	🟦	1.6PB 4.7/8.1	🟦	1.6PB 3.7/8.0	🟦	2.0PB 5.9/6.6
P (purple)	🟪	6.5PB 5.0/6.7	🟪	4.8PB 4.0/7.3	🟪	8.0PB 5.7/5.7
RP (red purple)	🟪	8.9P 5.8/7.4	🟪	5.7P 4.3/7.1	🟪	6.3P 6.2/5.7
pR (purplish red)	🟥	7.8RP 5.9/9.7	🟥	4.0RP 4.1/5.2	🟥	4.1RP 6.9/7.0
		Gy (gray)		Bk (black)		W (white)
N (neutral color)	▨	7.9B 7.7/1.0	⬛	5.2G 2.6/0.6	⬜	0.1PB 9.2/1.2

3. RESULTS AND DISCUSSION

Figure 3 shows the results of the survey by dodecagons for hues simultaneously indicating tones, and lines for neutral colors. The upper color circles in Figure 3 show the suitability obtained for boys and girls respectively, and lower ones show the gender difference.

The result shows the statistical significance in gender of children, namely boys or girls who uses the randoseru. About the vivid and light colors, many respondents selected black, blue, or green for boys, and red for girls. The refused colors, on the other hand, are red or purplish red (pink) for boys, and blue or green for girls. In the dark colors, the suitability of colors around red (brown) was increased for boys, and was decreased for girls on the contrary. The hue of Blue Green (cyan) was specific, there was no gender difference in each tone and generally showed a regular value. There are some previous works on gender difference in color preference of the college students (Omori 2009, Komoto 2011), and the aged (Shirai 2013). However, our investigation has different results from these works, and this suggests the existence of a special stereotype in randoseru.

There is the opinion that this stereotype is not necessarily to be completely denied, and may help with psychological growth of children (Sasahara 2008). Although the diversification of the color of children's fashion advanced, there still is stereotype as black randoseru for boys and red one for girls. In addition, the color of the randoseru which the parents actually purchased or plan to purchase, by our survey (*n* of boys = 33, *n* of girls = 30), were black for most boys (73%), and brown (33%), red (23%), or pink (13%) for girls. And the reasons to choose the colors for boys were the demand of him, tolerant, and the dirt is hard to be outstanding. That for girls were pretty, hard to be stained, and hard to get tired. In other words, the range of the color choice for girls was wide, and girls were not seized with the stereotype such as "red color = girls' color" in comparison with boys.

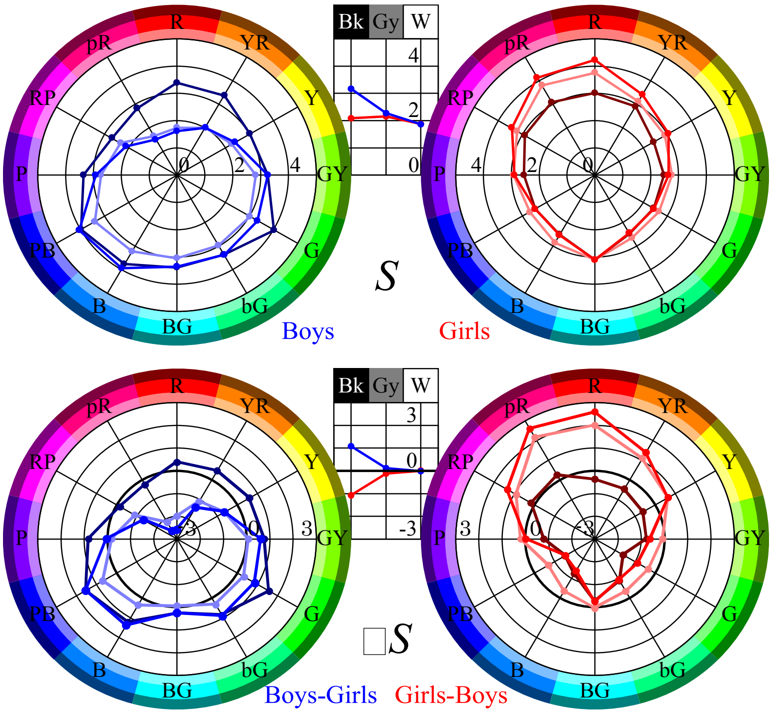

Figure 3: Results of color suitability (S) for randoseru and their gender difference (DS).

4. CONCLUSIONS

The result shows the statistical significance in gender of children, namely boys or girls who uses the randoseru. Many respondents selected black, blue, or green for boys, and red for girls. The refused colors, on the other hand, are red or purplish red for boys, and blue or green for girls. Although the diversification of the color of children's fashion advanced, there still is stereotype as black randoseru for boys and red one for girls.

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Surface Structure and Color of *Chogin*- and *Mameitagin*-coins Used in the Edo Period

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ABSTRACT

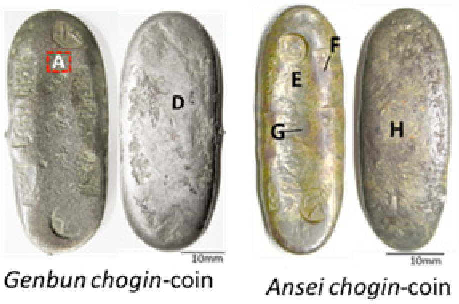
Chogin and *Mameitagin* are coins manufactured from an Ag–Cu alloy that was used in the *Edo* period. These coins are believed to have been manufactured by a treatment referred to as *Iroage*, which enables the formation of an Ag-rich layer on the surface of a coin. Two types of *Chogin* and *Mameitagin* coins manufactured in the *Genbun* and *Ansei* eras were studied by spectrophotoscopy. Because the surface colors of the *Chogin* coins are varied, we evaluated the colors of each coin by gonio-photometric spectral imaging. The spectra of the *Chogin* coins were typical of that of a coin subjected to the *Iroage* treatment, without the characteristic copper absorption edge at 600 nm. Microstructural and compositional analyses are important in evaluating the colors of coins. Therefore, the coins were studied by scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS), and X-ray diffraction (XRD) analysis. The results indicated that the surface structures of the obverse and reverse sides of the *Chogin* coins were different. These results suggest that the *Chogin* and *Mameitagin* coins were subjected to the *Iroage* treatment and that the observed color change was caused by their surface structure and preservation environment.

1. INTRODUCTION

Chogin and *Mameitagin* are coins manufactured from an Ag–Cu alloy that was used in the *Edo* period. These coins were produced by using the same concentration of ground Ag metal. The Ag concentration in coins decreased with time, with the exception of that in the *Kyoho* era. To maintain the value of silver, coins have been manufactured by a treatment known as *Iroage*, which is a traditional Japanese metal-working technique. With this technique, a Ag-rich layer can be formed on the surface of a coin, and thus, the color of the surface changes from copper to silver. However, sufficient details regarding *Iroage* are not available. In our previous study, we studied 12 different types of *Mameitagin* coins. (Taguchi and Kirino 2012) The colors of the coins varied from black and yellow to silver. Using spectrophotometry, we classified the shapes of the reflectance spectra of the coins into one of the two types: (1) reflectance spectra showing low reflectance values irrespective of the wavelength and (2) those showing a decrease in reflectance intensity with a decrease in wavelength. In either case, no characteristic copper absorption edge was observed at 600 nm in the reflectance spectra despite the Ag concentration or the surface color. The microstructure analyzed via transmission electron microscopy revealed that the *Ansei Mameitagin* coin contains two surface layers: a 0.6-μm-thick Ag-rich layer over the ground metal and a 0.8-μm-thick oxide layer composed of Cu_2O. *Keshi* (plating) is another traditional Japanese metal-working technique. These techniques can change the color of the ground metal to silver. EDS analysis showed that Hg was not detected in the *Ansei Mameitagin* coin, which indicates that the *Iroage* was performed on the *Ansei Mameitagin* coin instead of *Keshi* to produce a Ag-rich layer. The oxide layer is presumably formed by deterioration due to aging. Understanding the corrosion processes due to aging and surface treatments is important because they affect the original color of the metal objects. However, very few studies have focused on the *Iroage*- and corrosion-induced color change in Ag–Cu alloy coins. To evaluate the colors of the coins, it is essential to examine the microstructures of the coins. This study aims to examine the surface layer of *Mameitagin* and *Chogin* coins manufactured during the Edo period in order to clarify the *Iroage*- and deterioration-induced color change in these coins.

Table 1: Description of coins.

	Weight (g)	Year	Nominal silver content according to the *Edo* shogunate(%)
Genbun Chogin	166.2	1736	46
Genbun Mamegin	1.1		
Ansei Chogin	156.2	1859	13
Ansei Mamegin	1.5		



Genbun chogin-coin *Ansei chogin*-coin

Figure 1: Images of the coins (property of one of the authors, F. Kirino).

2. METHODS

In this study, four coins manufactured during the *Genbun* and *Ansei* eras were investigated. The *Chogin* coins are shown in Figure 1, and descriptions of the coins are provided in Table 1. The areas denoted in Figure 1 as (A)-(H) were analyzed. The weights of the *Mameitagin* coins used in this study are low – a property commonly referred to as *Tsuyugin*. The reflectance spectra of the coins were measured by spectrophotometry. Specifically, the surface colors of the *Chogin* coins were evaluated using a gonio-photometric spectral imaging system (Osumi, 2011) composed of a liquid crystalline tunable filter (LCTF) and a monochrome CCD camera. The illumination angles were 15°, 45°, and 75°. The surface structures of the coins were observed by scanning electron microscopy (SEM), the crystal structures were evaluated by X-ray diffraction (XRD), and the compositions of the coins were investigated by energy-dispersive X-ray spectroscopy (EDS).

3. RESULTS AND DISCUSSION

The metal structures of the *Chogin* and *Mameitagin* coins were observed by SEM. The coins exhibited a eutectic structure, which is characteristic of Ag-Cu alloys; however, the grain size of Cu varied substantially. The average grain size of Cu was approximately 9.6 µm in the *Ansei Chogin* sample and approximately 1.1 µm in the *Ansei Mameitagin* sample, as determined by image processing using SEM. The same results were obtained for the *Genbun Chogin* and *Genbun Mameitagin* samples. The difference in the grain size between the *Chogin* and *Mameitagin* samples is attributed to the difference in the cooling rates of the alloys. The reflectance values of all coins used in this study decreased in intensity with decreasing wavelength, as discussed in the Introduction. Therefore, it is possible that *Iroage* was also performed on these coins.

Although the surface color of the *Mameitagin* coins is black and uniform, the color of the *Chogin* coins differs between the front and back sides of the coins. The reverse sides of the *Chogin* coins exhibit a smooth surface, while the obverse sides exhibit a rough surface with numerous stamps. The surface color of the *Genbun Chogin* coin is black, but white particles were observed on the obverse face. The surface color of the *Ansei Chogin* coin is yellow; however, brown and black rust was observed only on the obverse face. The shapes of the curves in the spectrophotometric spectra of the *Chogin* coins examined by gonio-photometric imaging were classified into five types. Representative examples are shown in Figure 2. Table 2 shows the classification of the shapes of each area. Shapes (1) and (2) are similar to the shapes produced by *Mameitagin* coins that were examined in a previous study. (Taguchi and Kirino, 2012) Shape (1') is similar to shape (1), with an additional peak observed at 430-440 nm. Shape (2') is similar to shape (2), with an additional peak at 430-440 nm. The absorption edges corresponding to shape (3) appears at 510-520 nm and 640-650 nm. These edges appear only in the spectra of area (G), where brown rust was observed. Shapes (1) and (2) suggest that the *Iroage* treatment had been performed on the *Chogin* coins. With respect to area (E), which is the obverse side of the *Ansei Chogin* coin, and area (F), which is the brown rust area, the shapes of reflectance spectra do not change with the incidence angle of light. With the exception of area (G) – the black rust area of the *Ansei Chogin* coin – the shapes of the reflectance spectra change as (1) → (1') or (2) → (2') as the angle increases. However, the shape of the reflectance spectrum of area (G) changes as (1) → (2) → (2'). These changes are caused by the change in the surface structure of the *Chogin* coins resulting from the *Iroage* treatment or possibly by corrosion.

Figure 2: Reflectance spectra of coins.

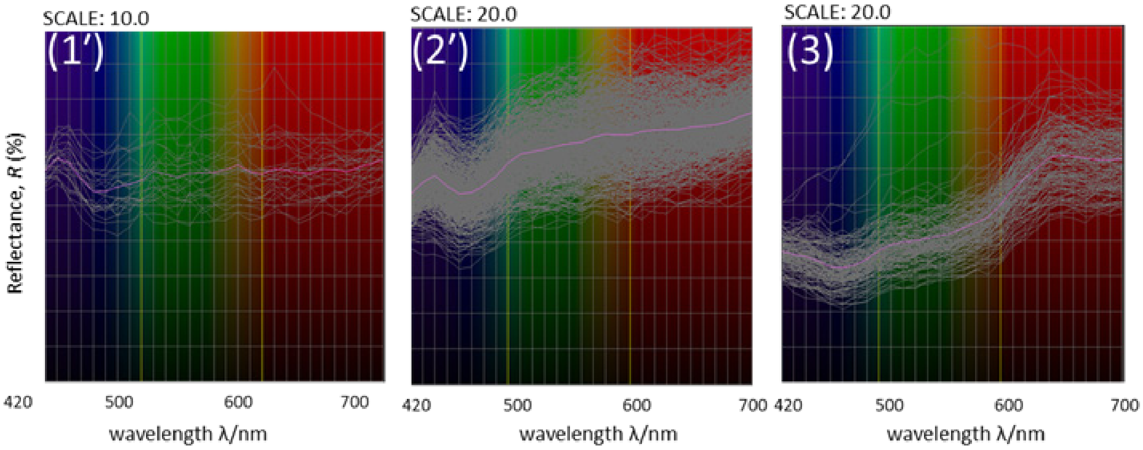


Table 2: Classification of reflectance spectra.

Genbun Chogin-coin												
area	(A) Obverse			(B) White particle			(C) Blackish area			(D) Reverse		
degree	15	45	75	15	45	75	15	45	75	15	45	75
shape	2	2	2'	1	1'	1'	2	2	2'	2	2'	2'

Ansei Chogin-coin												
area	(E) Yellowish area			(F) Brown rust			(G) Black rust			(H) Reverse		
degree	15	45	75	15	45	75	15	45	75	15	45	75
shape	2	2	2	3	3	3	1	2	2'	2	2	2'

We performed EDS and XRD analyses on areas (A)-(H) indicated in Figure 1. The Ag concentration in the white particle (area (C)) on the *Genbun Chogin* coin is 38.4 mass%, while that in the blackish area (area (B)) is 8.9 mass%. The fact that the Ag concentration in area (B) is greater than that in area (C) suggests the segregation of Ag. The XRD pattern of the *Genbun Chogin* coin indicated the presence of corrosion products; compositional analysis by EDS indicated the presence of Cu_2O, Cu_2S, and AgCl. The white particles were identified as AgCl via XRD analysis. In areas (F) and (G) of the *Ansei Chogin* coin, the metallic structure is difficult to observe. The Cu concentration in the *Ansei Chogin* coin was 98 mass%, which is a high value. Cu_2O was detected in the *Ansei Chogin* coin by XRD. Therefore, with respect to the *Ansei Chogin* coin, a thick Cu_2O layer may have been formed owing to aging on the Ag-rich layer formed by the *Iroage* treatment. Because a Cu_2O layer completely covered the Ag-rich layer, the reflection spectrum of area (F) exhibited shape (3). However, the difference in color between areas (F)-(H) of the *Ansei Chogin* coin was not explained by EDS or XRD, the top surface of the coin needs to be extensively examined.

As per the abovementioned results, the surface structures of the obverse and reverse sides of *Chogin* coins were different. The mold called *Yudoko* used in the casting and the stamps on the obverse sides of the *Chogin* coins affects the surface structures of the coins. In particular, the stamps on the obverse side of the *Chogin* coins may induce residual stress, which would lead to further corrosion. Thus, the surface structure formed during casting influences the degradation process due to aging and results in different colors of the *Chogin* coins.

4. CONCLUSIONS

The color and surface structure of *Mameitagin* and *Chogin* coins used in the *Edo* period were investigated, and the following results were obtained.

1) The *Chogin* and *Mameitagin* coins were subjected to the *Iroage* treatment.
2) The color change in *Chogin* coins was caused by the surface structure and the preservation environment.

ACKNOWLEDGEMENT

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New Geographies of Colour: The Emotional Politics of Urban Colour Interventions

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ABSTRACT

Since Jean Phillipe Lenclos' (1989) *The Geography of Color*, the place of the 'geographic' in colour studies has become almost synonymous with Lenclos' mappings of the chromatic characters of places and the identities that arise. However, few geographers themselves have contributed to the study of colour, particularly in urban settings, where colouring practices such as Dulux's *Let's Colour* project are often used as an interventionist strategy to (re) instate emotions in grey city spaces. Rapidly growing fields in geography have animated sustained critical interest in urban art, the site, practice and emotions; affirming the place and value of colouring practices within key geographic concerns.

This paper is a vignette of ongoing doctoral research on the spatial practice, lived experience and emotional politics of urban colour interventions. Rejecting the often discursive and representational tendencies of scholarship on colour and emotions, my PhD research seeks to investigate the fluid, embodied and relational nature of both colour and human emotions. Complimenting a poster presentation, this paper introduces the research framework, intents and approach taken in my geographical investigation of the emotional politics of urban colour interventions.

1. INTRODUCTION: COLOUR AS AN INTERVENTION

The city looked dead[1]. - Edi Rama (2003).

Shortly after entering politics, Edi Rama, the artist-turned-mayor of Tirana, Albania, curated an ambitious aesthetic project. In 2000, Rama unleashed a huge city-scale colouring intervention, brightly painting many of the grim and grey facades of the communist architecture that made up modern Tirana. "After 1997," Rama said, "Albanians came to look on their country as a sort of transfer station between life and death. My real project is to try and resuscitate hope, so that people will start looking on their country as… a place they might want to live" (Rama in Woodword, 2006).

The colourful manipulation of space as a method of 'resuscitation' can be seen elsewhere. Now almost a century ago, Bruno Taut's *Call for Colourful Buildings* manifesto (1919) sought to challenge the building of 'joyless' houses. More recently in Brazil, the *Favela Painting* project by Haas and Hahn (2006) transformed the chromatic landscape of the Santa Marta favela settlement in Rio as part of an agenda to improve and restore a sense of community.

Little is known about the relationships between colour, politics, emotions and space in urban interventions. Interventionist spaces seek to "prise open spaces and opportunities for collective and critical engagement and participation, to provoke active involvement in and questioning of urban conditions" (Pinder, 2008: 733). Practices intent on *bringing places to*

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[1] Quoted in documentary *Dammi I Colori* (dir. Anri Sala, 2003)

life reveal a significant emotional agenda; the colouration of Tirana as resuscitating *hope*, Haas and Hahn's Favela Painting as instating community *pride* and the Let's Colour project as *bringing life*, all circulate feelings, affects and emotions.

This research seeks to identify emotional experiences in an empirical study of 3 historical and one active London-based colouring interventions. In order to investigate the complex emotional politics of colour, the research will employ a triad of ethnographic and action-based methodologies that attends to 3 interconnected modes of inquiry; by attending to the circulation of *claims* made about what colour does, or enables, both to people and places; the socio-spatial *practices* of urban colouring strategies; and the *lived, emotional* experiences produced. The overall research aims are to situate claims, values and emotions in these practices, and to explore how these coloured spaces are socially, spatially and emotionally experienced.

2. CONCEPTUAL FRAMEWORK: GEOGRAPHICAL PERSPECTIVES

The intimate and ephemeral quality of colour has stimulated sustained interest in the emotions. But the question remains: what makes an *emotional geography* different? According to Davidson et al. emotions "need to be understood as events that take place in, and reverberate through, the real world and real beings…the existence of living, breathing creatures is a pre-requisite for emotions to exist at all" (2007: 2). As such, work on emotional geographies elicits the ways different emotions emerge from, and (re)produce, specific socio-spatial orders and the lived geographies of place (Davidson et al. 2007).

Geographical studies attuned to emotions and feeling open the field to research beyond the visual, the textual and the linguistic domains often characterised by contemporary environmental colour studies. The power of colour is its ability to shape what bodies can do. It is these emotional experiences that take place through the body as, ultimately, "the most immediate and intimately felt geography" (Davidson et al., 2004: 523).

3. APPROACH

3.1 Evaluating claims

The proposed research is situated between two tensions that have emerged around the use of aesthetics to improve urban conditions. In the case of art and urban regeneration, Hall and Robertson argue that multiple claims are made about the contribution of artwork to the lived environment, without sound empirical evidence (2001; see also Zebracki, 2010). Similarly, there is no conceptual apparatus or paradigm to evaluate these claims. There is also no tradition of employing social science methodologies in the investigation and evaluation of these practices (Hall, 2002) or how these claims are (re)produced and sustained. The second tension emerges from an evidence based design group. A provocative research project by the Coalition for Health Environments Research (CHER) in 2004 claims that "the popular press and the design community have promoted the oversimplification of the psychological responses to color. Many authors of guidelines tend to make sweeping statements that support myths or personal beliefs" (Tofle, et al. 2004: 69). My proposed research will situate claims made about colour in practice, rather than in healthcare settings, exploring emotions and claims against a pragmatic, embodied research design.

3.2 Colour and emotions: a detailed ethnographic investigation

Secondly, the research will investigate the embodied experiences of practitioners, both expert and non-expert, in the empirical sites of the colouring practices through a sustained period of 9 months. The focus of this research is placed in the physical coloured spaces themselves and within the bodily and emotional responses of the painters. A practice-based, participatory research design will be implemented in order to engage with ideas of embodiment as an intrinsic factor in the experience of colour.

3.3. Colour and practice

Attending to (e)motions and (en)actions (Thien, 2005), this research will investigate the spatial practices, active participation and engagements with colouring as a *practice.* These bodily senses do not just experience space, but also help to structure how the space is experienced (Muirhead, 2012). The research emphasises not only 'being-in-colour', but also the engagements, encounters, connections and feelings not only through the participants, but also through the active, reflexive orientation of myself as a researcher.

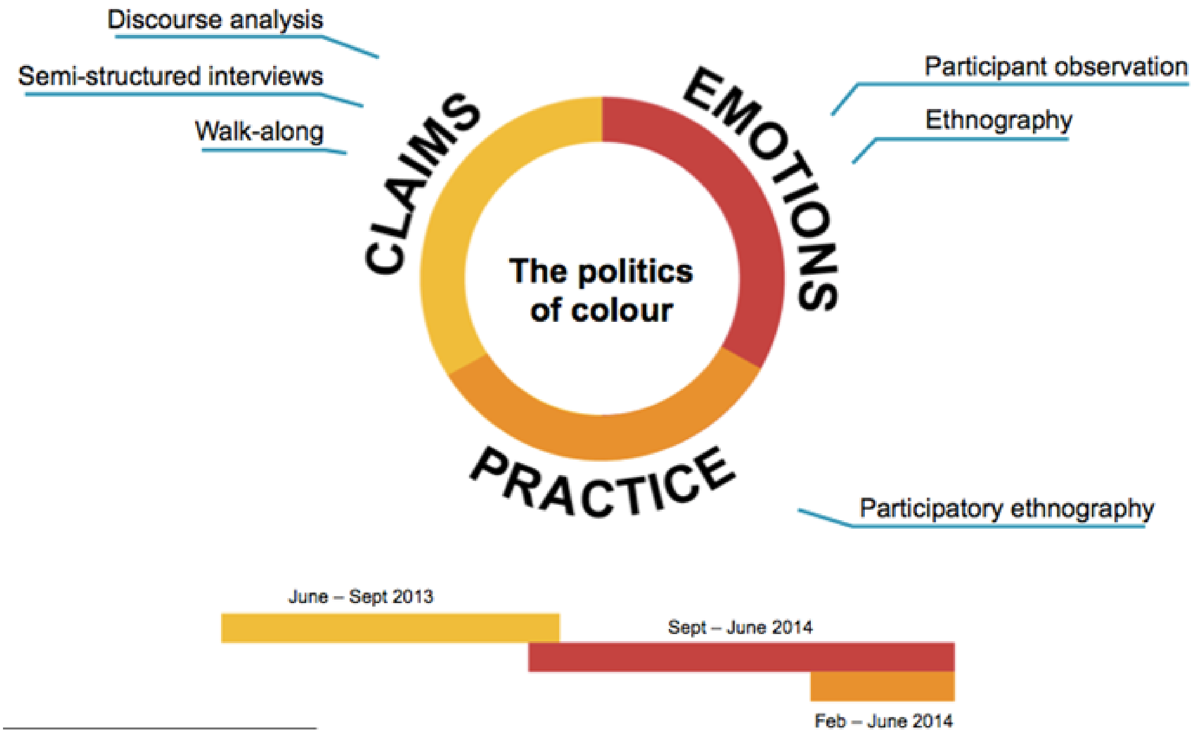

Figure 1. Diagram of research focus, methodological approach and timeline.

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A Study on the Modernized Korea Traditional Color

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ABSTRACT

Modernized application of traditional colors through reinterpreting is shown from various fields including architecture, products, fashion and media. There are many studies on the method to analyze such actual applicative cases and extract modernized traditional colors. However, there are few studies for actual application through research on the range of modernized traditional colors. So, this study aims at setting a range of traditional colors generally regarded by people, traditional colors reinterpreted as modern with modern colors and future colors. And then, its secondary aim is to conduct comparative analysis of the color range in the real cases. As for the method of the first research, comparative analysis was done by item, traditional colors, modernized traditional colors, modern colors and future colors through the questionnaire. As the result, the range of modernized traditional colors shows various color areas including light grayish, grayish, dark grayish, soft, dull. In addition, while representative traditional colors have vivid Y-series tone, modernized traditional colors have soft YR-series tone. The saturation of modernized traditional colors is lower than that of traditional colors so there has been a change of recognition.

1. INTRODUCTION

According to Mun Eun-Bae (2012), traditional colors refer to colors developed under the background of regional historicity, adding that Korean traditional colors were established and developed by itself under influence of the regional culture and natural environment based on Eastern Yin-Yang & Five Elements idea. Furthermore, Kim Ki-Young (2007) mentioned that traditional colors reflect Korean cultural area and national idea, ideology, consciousness, taste, and our nation has been influenced by Obang Colors directly in the daily life. From the past to the present, with the long cultural tradition, colors also have been harmonized and developed toward a new direction. Modernized traditional colors are being reinterpreted and used in many fields including dressing and architecture. As such, there are many existing studies on the analysis and comparison of certain cases but it seems that there are few on the range of traditional colors used through modernized reinterpretation. Therefore, this study intends to examine the range of traditional colors regarded by domestic people and reinterpreted as modern.

2. METHOD

This study focuses on identifying the range of traditional colors, modernized traditional colors , modern colors and future colors through the questionnaire and conducting a comparative analysis. The questionnaire was done for 11 ordinary people. Research was conducted as follows. As the first step, conduct random sampling of 500 colors from 1533 colors specified on the Korean Color Standard Palette based on indication by three attributes of color, KS A 0062. Classify items of the questionnaire into traditional colors, modernized traditional colors, modern colors, future color and others and make respondents see one color and check it on the relevant item. Double check of the item is allowed but only for 2 and less. As the second step, as for each item, regard colors majority of the subject selected significant and adopt them as the range of analysis. As the third step, conduct a comparative analysis on the characteristics of tone and color range by item and within an item.

3. RESULTS AND DISCUSSION

3.1 Results of Questionnaire

Only colors that more than 50% subjects selected by item were adopted as the analytic range and converted into a percentage. As the result among 500 colors, traditional colors got 6% (30 colors) and modernized traditional colors for 23.6% (118 colors), modern colors for 9.4% (47 colors), future colors for 1.8% (9 colors) and others for 0%. It may be because recognition on modernized traditional colors has a wide range. Modernized traditional colors composed of two words may have a tendency to think meaning of the 'modern' and 'traditional' multiply. It's thought that frequent contact with modernized colors expressed diversely through many media led to extraction of relatively more colors than those of other items. On the other hand, a very small number of future colors were adopted as 1.8%. Only 1 color was selected by more than 70% subjects and 8 colors were selected by a majority, very small in number from the entire. In future colors showing an outstandingly smaller number than others, perhaps it's difficult to derive colors appealing to subjects in common because they have to select imaginary colors past experience or knowledge is excluded. Also it's regarded that such a character of other colors resulted in the result of 0%.

3.2 Inter-item Comparison (Analysis of Range of Tone & Color)

Inter-item comparison is done dividing into the tone and color areas. First, tone area is analyzed. If applied the L*C* graph of each item to KS Tone Table, it shows as following <Fig. 2>.

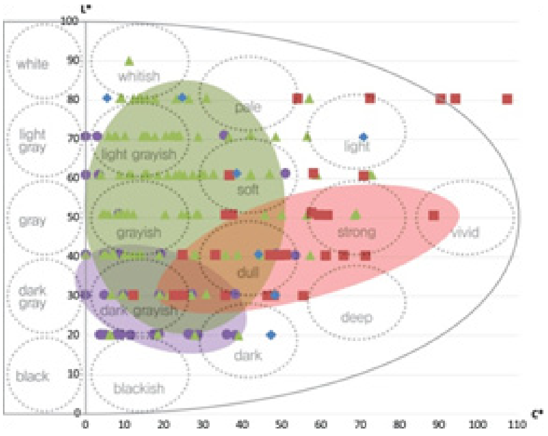


Figure 2: Tones area-specific questions.

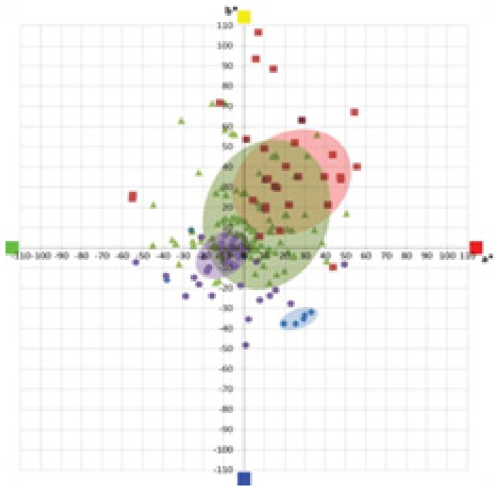


Figure 3: Questions specific areas of color.

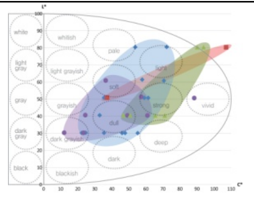
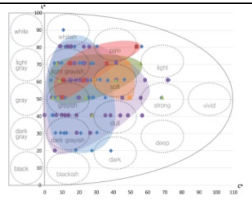
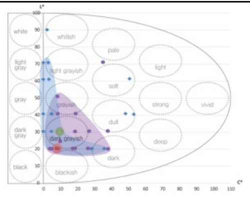
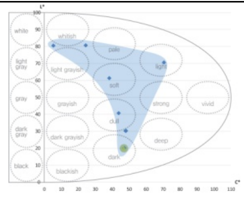
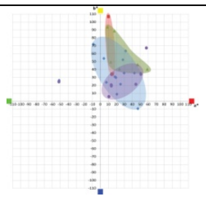
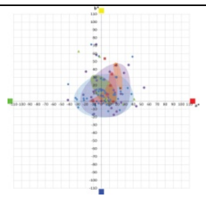
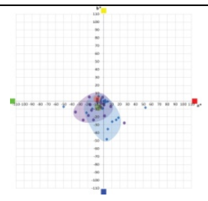
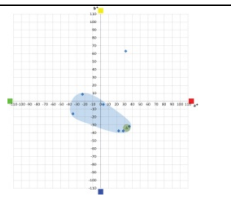
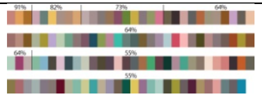
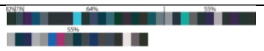
As the indicative method, traditional colors are classified as the square(🟥), modernized traditional colors as the triangle (▲), modern colors as the circle (●) and future colors as the diamond(◆). Traditional colors are mainly located at strong, dull and vivid with rare tone of high-luminosity and low-saturation. Modern colors are mainly located at dark and grayish and dispersed gradually among grayish, light grayish, dull, dark. Modernized traditional colors, containing both dull, strong areas of traditional colors and dark, grayish areas of modern colors, are located widely at grayish, light grayish, whitish, soft, dark. If inspected closely, while traditional colors lean to medium- luminosity, medium· high saturation area of vivid, strong, dull, modernized traditional colors show movement of the center of the gravity toward low-saturation of light grayish, grayish, dark grayish. In other words, it means changing into grayish with lowered saturation. Furthermore, judging from the fact that modern colors are mainly composed of colors with low-saturation, low-luminosity of dark grayish, it's regarded that colors representing the modern are achromatic color series. Main area of three items was different but it showed an overlapping area centered on modernized traditional colors.

As the result of analyzing colors by item in the CIELAB area, most of traditional colors are located at Y, YR R series, and most of modern colors at BG, B, RB series. In addition to color areas of the foregoing two items, modernized traditional colors are also located at the rest R, GY series. Above all, it shows that weight of warm color series is as high as that of traditional colors. Unlike the tone area without special predisposition, future colors show a dense distribution at RB series.

3.2 Within-Item Comparison (Analysis of Range of Tone & Color)

Among colors selected by a majority, within-item comparison is done through ranking according to the percentage of selection by subjects. Color selected by 91% will be ranked as No.1 (✕), color by 82% as No.2 (🟥), color by 73% as No. 3 (▲), color by 64% as No. 4 (●) and color by 55% as No. 5 (◆).

Table 1. Tone & Color Area and Color Palette by Ranking Within Each Item.

	traditional colors	Modern traditional colors	modern colors	the future colors
tone				
hue				
color				

In the analysis of the tone area, colors of higher ranking show that there's representative tone by item. Traditional colors are vivid, strong, modernized traditional colors are soft, light grayish, and modern colors are dark grayish. Considering by age, there's a tendency that saturation and luminosity get lower. It shows that modernized traditional colors are diffused to lower ranking color of low-luminosity and high-saturation area centered on higher ranking color of light grayish and soft area. Modern colors are diffused to lower ranking color of high-luminosity and medium-saturation centered on higher ranking color of dark grayish area. Unlike modernized traditional and modern colors, two colors show the highest selection rate of 82% in traditional colors, located at vivid and dull area respectively. Judging from the graph of each item classified as ranking, traditional colors move to YR, R series centered on Y series and become wider. Modernized traditional colors, centered on YR series, come to have widened area and contain certain part of G, B series. Future colors are mainly located at RB series, showing a sporadic distribution at BG, GY, YR series.

4. CONCLUSIONS

Through researching the range of colors used in modernized traditional colors along with traditional, modern and future colors, this study intends to know the color recognition range of people related to each item and set it comprehensively. So, conclusions as follows are derived. First, modernized traditional colors take an intermediate and inclusive position of traditional and modern colors in the tone or color area. Modernized traditional colors are mainly distributed at light grayish, grayish, dark grayish, soft, dull area, showing a distribution at most areas excepting the area of vivid. Such inclusive areas result from softness with lower saturation than traditional colors, a variety of colors with higher saturation and luminosity than modern colors. Therefore, in terms of the number of colors, it's possible to interpret that modernized traditional colors are overwhelming. However, it is noteworthy to remember that modernized traditional colors don't include both traditional and modern colors and there's part not to be included. It shows there's color of the age its own according to certain age and suggests use and preference of color change according to the times. Based on these above, it's possible to present colors fitting for the age to be used in the various fields. Further study is required to present a range of the color field through multilateral comparative analysis and research recognition changes on colors according to the material considering CMF.

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Mun Eun bae (2012), *Korea's traditional color sample and antagonistic coexistence sample study on the yisusin side and rallying around the series* - and Korea Institute of colors.

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Harmonizing Mosque Prayer Hall by Using Light to Create a Sacred Atmosphere

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ABSTRACT

The appropriate design and mixture of daylighting techniques can significantly help in improving the interior space design. Light plays an important role in famous mosques around the world but it is ignored in new built mosques of Malaysia to make a dynamic feeling and sense of God in the religious space. It is proved that natural daylight design with light hierarchy and harmony has an important role in interior environment which is be able to make the human to reach the sense of serenity and concentration. The main aim of this study is to investigate and review the fundamental aspects of daylighting for evaluating how daylight as a sacred element was used in implicated mosques. For this reason mosque prayer hall was analysed the by collected data from literature and observation to evaluate the current situation. The results indicate that the openings for daylight entrance should be designed in a way to achieve hierarchy, harmony and designed patterns with daylight during the pray time in the prayer hall. Methods, techniques and designs which have discussed in this paper are suggested solutions to enhance the sense of sacred by using natural daylighting in mosque prayer hall.

1. INTRODUCTION

Light, a visible immaterial element, can demonstrate great meanings and affects in a spatial structure. Beauty and power of light are depended upon on how it is scattered into the designed space. It can be considered as an architectural element to create a pleasant visual environment by making the building soulful. Light does not only facilitate the visual task, but also augments and contributes to the feelings of human.

When the light flows in the space, hardness and coldness of the place will be reduced and will make it a shelter for attendances spirit (Hutt & Harrow, 1977). Light is like the soul for a solid structure and was known as appearance of divine, so architects used it in the religious places as miraculous substances (Plummer, 1997).

Daylighting was defined as interplay of natural light and building form to provide a visually stimulating, healthful, and productive interior environment (Galasiu & Reinhart, 2007). Daylight is a source that is most closely light which matches the human visual response and provides a more pleasant and attractive element for indoor environment (Alrubaih et al., 2013).

In this research we probed and evaluated harmony, hierarchy of daylight and sacred space design in mosque's prayer hall with natural daylight. The aspects were studied were the way of using the light, the way daylight entered in to the prayer hall and the light patterns and designs made by natural light.

2. METHOD

Research method designed for this study was based on case-study, combined with descriptive-analytic and comparative-analytic tactics. The data collection process was restricted to analyzing collected data from observed case study mosques. This study has done in three phases of data collection to gain all objectives. As illustrated in figure1, the first phase was collecting information from reading sources. Second phase was observation from case study mosques and third phase was analysing case studies by plan and section (Figure1).

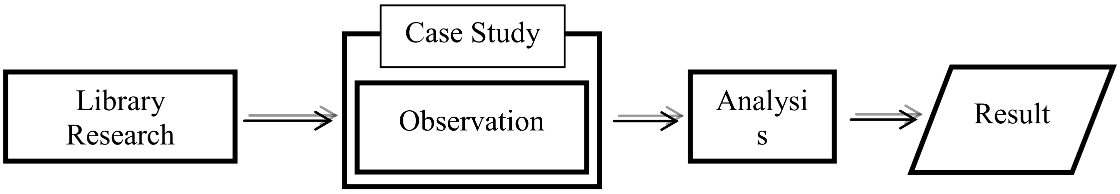


Figure 1: Flowchart illustrating the process of research.

2.1 Case Studies

For this research four case studies from Malaysian mosques were chosen in order to investigate the lighting in details, define the relations and identify differences and similarities. Criteria for choosing these case studies were; being a federal territory mosque with capacity of holding over 15,000 people in city of Kuala Lumpur or Putrajaya, two cities where cultures, religions and politics of Malaysia met and interacted (Table 1).

2.2 Observation

Library research method was applied as the data gathering to find lighting techniques, lighting effects and psychological perceptions of light.

Observation was employed to study and evaluate implicating daylight in prayer hall of mosques. The observation was carrired out in prayer hall around 1:30 p.m. and around 4:30 p.m. (time for afternoon and evening prayer) studying on daylight, observation was for spots that people chose to stay for their pray, the hall size, number of light-openings, types of openings, characteristics and position of the windows, size and depth of windows, shape of the space, role of light, prayer-hall's height, practical light usage in defining zones and boundaries with light, light expands, distinguishing and accentuates spaces, creating links to guiding peoples movement and delineates one area from another with light, hierarchy of light and shadow.

3. RESULTS AND DISCUSSION

As Table 1 illustrates, chosen Malaysian mosques are open-round mosques with shadings around the main hall. There are two main parts which has the most opening, one is under the dome and the seconde one was around the prayer hall instead of the walls. In three mosques except Besi mosque, parayer hall was surrounded with shadings, so the prayer halls have an indirect light, a light which is reflected from environment around the prayer hall. As shown in Table 2, light does not have a independent role as an element and its just used for a simple lighting with same value the prayer hall, there is no light border, no pattern designed with light. There was no special controled daylight from openings designed considering annual sunpath to have direct sunlight during the prayer time.

Table 1 Case Study Mosques.

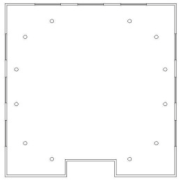
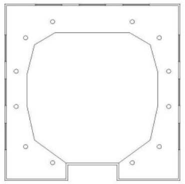
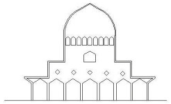
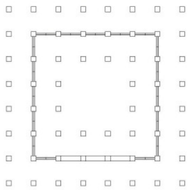
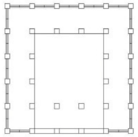
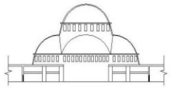
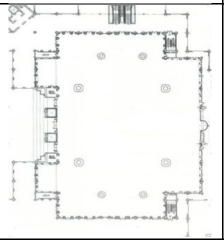
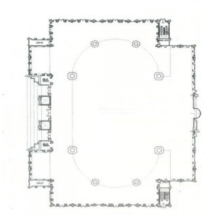
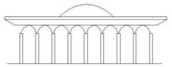
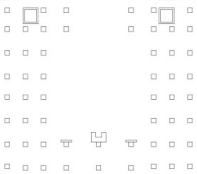
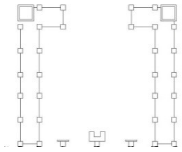
No	Name of Mosque	Section	Ground Floor Plan	First Floor Plan	Mosque Position (latitude and longitude)	Year	Capacity	Location	Architectural Style
1	National Mosque (Masjid Negara)				3° 8' 30.255" N 101° 41' 28.964" E	1965	15,000	Kuala Lumpur	Modern
2	Putra Mosque				2° 56' 10.018" N 101° 41' 20.260" E	1999	15,000	Putrajaya	Mixed
3	Wilayah Mosque				3° 10' 19.416" N 101° 40' 13.949" E	2000	17,000	Kuala Lumpur	Ottoman
4	Besi Mosque (Masjid Tuanku Mizan Zainal Abidin)				2° 55' 9.507" N 101° 40' 52.086" E	2009	24,000	Putrajaya	Modern

Table 2. Mosques Analysis

No.	**Mosque**	**Role of light openings**	**Light making zone & boundaries**	**Hierarchy of light & shadow**	**Proportion of the walls with widows**	**Patterns made by light**
1	National Mosque	Just illumination of interior considered	No zones or boundaries designed with light	No playing with light and shadow	High amount of widows used under the dome and walls	No patterns
2	Putra Mosque	Just illumination of interior considered	No zones or boundaries designed with light	No playing with light and shadow	High amount of widows used on the walls but with shades	No patterns on floor, Just in the dome
3	Wilayah Mosque	Just illumination of interior considered	No zones or boundaries designed with light	No playing with light and shadow	High amount of widows used	No patterns on floor, Just in the dome
4	Besi Mosque	Just illumination of interior considered	No zones or boundaries designed with light	No playing with light and shadow	High amount of widows used	No patterns on floor, Just on the walls

The importance of light hierarchy and harmony is to imagin the meanings for attendants and prepaire them psychological for the pray by visual effect of light, giving them serenity to concentrate on their pay.

4. CONCLUSIONS

Light can be considered as an sculpture to give different effects to space depending on how its designed in that space. Daylight is a lighting obtained from direct sunlight source and provides the best source which comfortably matches with human visual response. In cases such as identifying acceptable and convenient ways for increasing effective daylight in prayer hall as an architectural element to design a sacred space for the attendants, questionnaires, light measurement and simulation are useful for further results.

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The Color Complexity of Interior and Intimate Cultural Experience in *Rumah Bapang*

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ABSTRACT

The aim of this paper is to know the influence of color in *Rumah Bapang*, the traditional house of Betawi Tribe in Indonesia. *Rumah Bapang* has grown since hundreds years ago in Jakarta. The things are never missed in the house is the touch of decorative elements with colorful. Rumah Bapang's interior elements with the culture of Betawi Tribe are affected by Indonesian, European, Chinese, Arab, and Indian culture. Those cross cultural create a unique blend of colors from Betawi tribe. It is due to the influence of Chinese and Indian culture with yellow and red, the Arabic with green, and light blue which is identical with the Netherlands. The color has the aesthetic and the psychological affect. Furthermore, the colors are used to describe the characteristic of Betawi society which is very welcome to people. The society also adjusts the color selection in the interior of this house with tropical Indonesian context. In addition to create an atmosphere of space, color is also an important element of interior in intimate experience between the culture and its users. Therefore, color is not simply related to the aesthetics of the room, but also comfortable, cultural values, contextual, and intimacy.

Keywords: Betawi, color, interior, Rumah Bapang

1. INTRODUCTION

Indonesia consists of many tribes and cultures, each of which has distinctive characteristics that portray their residence. One of the groups that exist in Indonesia is Betawi tribe. The term Betawi is derived from the word Batavia which was created by the Dutch in the colonial era to point the original residents of Jakarta. According to Ismet (1991), in the end of the 15th century, various tribes and nations can be said to have completely lost their identity and become a new society which is later known by Betawi. Basically, the development of Betawi tribe is originated from the results of inter-ethnic marriages which entered the Batavia territory, or Jakarta. In the book *Jaarboek van Batavia* (Vries, 1927), the interaction between ethnic groups such as Ambon, Malay, Bugis and Makassar which stopped at Batavia to mate with traders and soldiers from Arabia, India, China and Europe is described. In the mid-19th century the existence of the Betawi people began to be known. Architecture of traditional houses was starting to be influenced from outside the tribe, which can be seen from the tread pattern, the spatial, detail, and its decoration (Ismet, 1991). It can also be seen in the use of color in buildings that affect interiority. Those colors have their meanings and characterize the identity of the owner. This then affects the culture and arts such as dance, music, traditional dress and custom home of the betawi which highly reflects how the culture is a combination of many different cultures from different ethnicities. All cultural and ethnic Betawi arts are very interesting to discuss. One is the traditional Betawi.

In the book entitled *Color, Environment, and Human Response*, Frank H Mahnke explains that the complex process up on our experience rather than just an optical perception. One of six levels of Color Experience Pyramid is cultural influences and mannerisms. It is about color associations, symbolism, impressions and mannerisms that are characteristic of specific cultures and groups (Frank H. Mahnke, 1982). Home provides warmth and comfort for its users. Home is the place where the interaction between family members occurs. Activities such as Family's break time, family's relax time, and chat time, perform in the house. As the time passes by, home has evolved into a more meaningful place. Home is not only considered as a shelter but also a place where the users can be characterized. Thus, *Rumah Bapang* gives not only comfort, but also identity to Betawi tribe. The house's interior characteristics are the pattern of the floor, the ceiling, the use of materials and colors. The touch of decorative elements of decoration such as ornaments on the doors, windows and vents are also very supportive of the peculiarities of this *Rumah Bapang* interior. The interior has all the elements of each color which forms a distinctive atmosphere.

2. COLOR IN INTERIOR *RUMAH BAPANG*

Mostly, Brown color is applied in interior *Rumah Bapang*. The color comes from the wood which is easier to find in the surrounding, which means the Betawi is surrounded by the tropical forests. As the development of technology, the Betawi tribe has started to use paint to color the house. Yellow, green, red, and blue with brown chime in aesthetic color the interior of the house. Brown color remains the dominant colors used in the *Rumah Bapang*. It can be seen on the trim color plank, columns, 120 cm tall fence on the front porch, doors, windows, furniture to home.

Figure 1. Betawi traditional dancer costum http://rohmatsani.blogspot.com/p/budaya-betawi.html

Figure 2. Chinese traditional dancer costum http://www.livescience.com/28823-chinese-culture.html

Figure 3. Interior of Indian traditional house http://www.gharexpert.com/a/ashishbatra/1603/courtyard-houses-0.aspx

Figure 4. Nabawi Mosque in Saudi Arabia http://www.redbubble.com/people/tmyusof/works/5286897-nabawi-mosque-in-medina-saudi-arabia

Figure 5. Traditional dancer costum in Netrherland http://www.cioff.org/folkloriada-intro.cfm

The influence of foreign culture has changed the colors used in the *Rumah Bapang*. Ornaments typical of this house are list plank found on the bottom of the roof. The influence of Chinese culture on list plank (Ismet et al, 1991). List plank and columns are now using the color green. Ornaments on the ceiling using primary colors, namely yellow, red and blue. Green, yellow, and chocolate-like color applied to windows and doors. Wooden furniture is still being used in interior *Rumah Bapang*. The blue color is also used on the walls and curtains which is influenced by European culture. As it grows, motif ceramic material is used to replace wood as an element of the interior, which is floor. That is because of the Chinese and the Arabic once carried ceramics for sale in Indonesia, especially in the Batavia area. Combination color is dominant to yellow color with influences of Chinese and Indian culture, while the green color due to the influence of Arabic. Besides the beauty of the *Rumah Bapang* interior, the colors used to have a certain psychological meaning in user space. In *Interior Design*, John F. Pile explains about the psychological effect on the color.

> “Red are seen as warm, even hot, exciting, and stimulating. Limited amounts of red can augment and balance blue and greens in a color scheme, adding life and cheer. Yellow are usually associated with cheerfulness, even humor. Become Greens have a favorite for a balanced color scheme seeking to be calm and restful, peaceful and constructive. Blues are the coolest of the cool colors, suggesting rest and repose, calm, and dignity. Browns have a traditional association with a snug, clubby atmosphere. They appear homelike in their milder tones, heavier masculine in their values.” (John F. Pile, 1995)

figure 6. Rumah Bapang nowdays http://www.indonesiakaya.com/see/read/2013/02/18/1230/20006/3/Arsitektur-Eropa-di-Rumah-Tradisional-Betawi

Figure 7. Rumah Bapang in Situ Babakan (Jakarta goverment conservation area for Betawi culture) http://tugaskab.blogspot.com/2013/01/serba-serbi-budaya-betawi-di-kampung.html

Figure 8. The old one Rumah Bapang http://www.pelauts.com/rumah/rumah-adat-colorful-life.html

Effect of red, yellow, green, blue, and brown have each color psychology. Red, yellow, and brown, including the warm colors, while green and blue are cool colors that balance the class room atmosphere. This color is no longer working respectively in space, but this color combination creates warmth, vibrant, fun, as well as calm and cool as a resting place and the interaction between the family members of this cultural diversity.

3. COLOR AND BETAWI CULTURE

As we have mentioned above, the use of color in interior elements are influenced by various cultures. In the Indian and Chinese culture, the color red is the representation of good luck, happiness, ambition and widely used in the wedding ceremony as a symbol of pleasure (Guimei He, 2011). Meanwhile, according to the theory of five elements, the color yellow symbolizes the earth and is regarded as the color of royalty, as well as the symbol of imperial power (Guimei He, 2011). The green color is very significant in the Arab culture. As a traditional Islamic color, green has the meaning of truth and goodness (Amna A. Hasan, 2010). The same with the blue color symbolizes warmth in the Netherlands (Paul Sable, Okan Akcay, 2010). Brown color means Indonesian who live harmoniously with nature. Betawi residents living with farming, so the building materials used for their home usually consisted of wooden fruit trees such as jackfruit wood, durian wood, and other (Ismet, 1991). The resulting effect also gives an emotional bond between the residents with their neighborhoods. Application of these colors as one that affects the user to feel comfortable and not be part fragmented. Color variations that had been used describing the characteristics of the Betawi people which are open-minded people. Betawi people still consider the natural context of natural tropical Indonesia in home interior color selection.

Betawi society who is already familiar with merchants coming Arab, Chinese, European, Indian and also make them familiar with the cultures brought by foreign citizens is so familiar with the Betawi community atmosphere thick with the culture of these countries and considers cultural them as part of the Betawi community life. Due to the influence of the state and used premises that formed the culture was also influenced. The most seen colors around the society are the colors of the culture or everyday life of the citizens of the foreign country. They apply these colors into the house because they are familiar with these colors, and those colors have its own story to Betawi people to form a bond of intimacy. Bond of intimacy is useful to make the residents feel comfortable and familiar with the space that they use the space formed because the atmosphere makes them relaxed and happy. Bond of intimacy between user experience and culture is what makes this color plays an important role in Rumah Bapang interior.

4. CONCLUSION

Cultural diversity in Indonesian, Chinese, Indian, Arab, and Dutch is illustrated on the *Rumah Bapang* interior atmosphere. This characterizes public disclosure on the Betawi culture that influences the interior and exterior elements. Locals and migrants living in Jakarta are no longer two different things and foreigners, but the Betawi people. The warmth of family interaction as well as the joy expressed in the diversity Betawi colors gives the *Rumah Bapang* hallmark. Colors, shapes, and materials home interior create a warm atmosphere of the room, yet refreshing. Brown, red, yellow, green, and blue to the interior plays an important role in providing space at once intimate cultural experience to its users. Complexity of interior color does not only have as an aesthetic room and create the atmosphere of space but also a deeper meaning regarding contextual, cultural values, and its intimacy.

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Dual Role of Gold Color in Frescoes of Safavid Palaces in Iran

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ABSTRACT

In the survey of the motifs of Mithraism and Manichaeism, it is considered that colors had semiotic dominations and every color represents a group, character and special meaning.

The use of gold color as a sign of sacred is quite common. In the next era of Persian painting, gold color kept its divine identity beside other colors that has reflected in Iranian literature and myths.

In Safavid era the processing use of color techniques was in its peak and golden color was applied in book layout, painting, clothing and architecture. But an additional functionality was added, the show of ambition, power and nobility by means of golden color. This study applied semiotic to modify gold color in Persian painting and ultimately with the help of survey methods to search for the reasons for such dual- use –between frescos and paper paintings- in Safavid era.

1. INTRODUCTION

Colors, in Iranian culture, have always been associated with certain concepts and meanings. In the present research, looking at the use of gold on the wall paintings of Chehel-sotun palace of Safavid, we refer to the change in the conceptual load of gold from a sacred and divine color to a symbol of nobleness, a manifestation of the glory, and a display of social, economic, and political realities of the society. The present paper oversees those iconologies made based on painting style and method of Isfahan school. Actually, the author tries to discuss semantic changes in the use of gold in Iranian paintings from this period onward. We referred to mystical and literary texts of the ancient times, such as Manichaeism's beliefs in the value of gold color and its continuation in Islamic mystics' views on light and color in the manuscripts of Najmeddin Kobra and Sheikh Mohammad Lahiji, to represent the symbolic aspects of gold in Iranian paintings. "Golestan Honar" and "Araes Al-Javaher & Nafaes Al-Atayeb" are two valid references from Safavid that indicate Safavid artists had a good knowledge of pigments and their properties.

Color in Ancient Iran

The world of Iranian art is the world of bright colors. In ancient Iran, Ahura Mazda has known as the god of light, and in Islamic Iran, it is stated that "God, who is the light of heavens and earth, is praised" .In the ancient view of Persia, having in mind the ideal of releasing light, Manichaeism determined to display light in their paintings with precious metals (Corbin, 1979, 137). In his article titled "theories of light in Iranian paintings", Khoshnazar ascribes the application of metal in Iranian paintings, along the tradition of Manichaean art and with the aim of reflecting light on the viewer's spirit. In his belief, artists have never ever neglected to show pure light and luminance, interpreted as color in painter's word, and finally, he concluded that the effect of theories of light in Zoroastrianism as well as Muslim mystics and sages is fully evident in Persian paintings (Khoshnazar, Rajabi, 2009, 3).

Color in Islamic Mystics' Beliefs

In Iranian art, colors are used with wisdom and the knowledge both in terms of symbolism and the effects that they would have on the soul due to their combination or coordination with other colors. The mystical insight based on color and light has had a profound effect on painting. Drawing a space bathed in light, with no shade, and avoiding compliance with physical and real world, painters figure out another world and higher universe. The colors of gold, silver, azure, and turquoise are not painters' mental hallucination, but the product of opening his eye's mind and seeing the perfect world.

In his books, named "Favaeh Al-Jamal" and "Favateh Al-Jalal", Najmeddin Kobra knows gold and silver as the colors of purity and sincerity. "It seems that Najmeddin Kobra (1840) has been the first Sufi master, who has cast up his attitude on the phenomena of colors and the feeling of colored lights he has achieved in heavenly mood" (Corbin, 1979, 95). Najmeddin Kobra, the great Sufi of the sixth century AH has noteworthy points in explaining color and light. In his thought, a mystic gets an extra-sensory sight in the emission of colored lights. In his perception, colors are symbols through which a mystic finds his mystical-brilliant position. As the Muslim artists always draw pure, divine, and brilliant people with an aura around their head which is in gold and indicates divine light.

Feature of Color in Iranian Painting

In Iranian painting, color has had the major and central role. Stuart Cary Welch declares that: "the Iranian painting from the standpoint of authenticity and radiance of colors has practically no rival in the world. The main reason for this could be that painters believe in Mazda's symbolic insight, knows color as the first daughter of light. They have learned from making pigments that little clumpy soil made from some certain minerals refined from any impurities with complete accuracy, would be changed into a pure color upon exposure to daylight (Keworkian, 1998, 60). In Iranian painting, light encompasses the entire scene; the painter is attracted by the glory of light, and uses it all around his work.

Color in Wall Paintings of Chehel-sotun Palace

The complex of wall paintings of the original building of Chehel-sotun Palace, accomplished by Reza Abbasi in the first decade of 11th century AH is one of the valuable works of Safavid dynasty. Its architecture adapted and is representative of the fullness of the luxury living style in Safavid court. walls have been decorated with color glasses and very beautiful paintings. The subject of most of which are gathering and battle ceremonies of Safavid.

In the wall paintings of Chehel-sotun, the outstaying style of painting of Isfahan school, with the trend toward the sensible world, and the actual, objective, and material content is seen. Courtier battle scenes and concrete events have been drawn using realistic bodies in various states and based on individualism and secularism. Colors have been applied in flat, bright and contrasting, yet have to work together in harmony. The color of everything is unique and different from natural colors. A uniform light is seen in the whole image, in other words, colors are all bright and luminous and are themselves a source of light. Volume setting and shading as European painting style are seen in these wall paintings.

In his studies conducted in Isfahan on wall paintings of Safavid palaces, Aghajani Esfahani recognizes that 80percent of these decorations on the wall paintings of Chelsotun, … are azure and gold decorations on the ground (Agajani Isfahani, 2007, 27). The gold color in the wall paintings of Chehel-sotun palace has the chemical formula of Au + Cu, which had been used as a sheet or powder for making background or details. As gold is the most malleable and softest metal, thin sheets can be prepared from it, and a broader surface can be covered, which is economically important.

In previous periods of Iranian paintings, gold had a symbolic aspect; it has been used in the illumination art as a symbol of light, in the paintings with religious themes such as letters of ascension, as flames of fire around the prophet (P.B.U.H.) express spiritual space. In contrast, the wall paintings of Chehel-sotun it has taken an earthy concept. Gold as colored stains has been used in drawing objects, porcelains and clothes. Also, the extent of gold in combination is very important to make visual balance in the whole work. On the other hand, the emphasis on the use of this brilliant color in the wall paintings of Chehel-sotun might refer to the liking of the king of the time (Shah Abbas) to show the power and glory of his kingdom, and the grandeur of his court to ambassadors of other countries. Also, drawing precious golden dishes besides figures, demonstrates safety and welfare of this period.

In the study of change of the concept of gold in wall paintings of this period, the study of thought and the social and political conditions of the time as the headstock for forming these pictures could be helpful. As to the fundamentals of Isfahan painting school, Javani describes the atmosphere of the time as follows:

> The presence of religious, economic, and social representatives of European governments…, has had a significant impact on the intellectual, artistic & cultural sphere of Isfahan city (Javani, 2011, 168).

In fact, during the rule of Shah Abbas, the first, (1006-995 AH), Isfahan has become the center of power, wealth, and welfare. and in order to compete with Ottoman palaces and cathedrals of Europe, special attention was given to the decoration of Chehel-sotun.

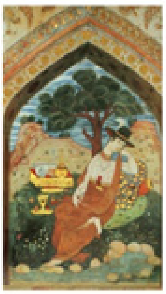
CONCLUSIONS

The application of gold in the composition coherence, relating elements and subjects is important. With special mastery, the painter takes advantage of gold, as a source of light in the picture, and while making a balance in the image, invites the viewer's eye to revolve all around the narrative space.

In terms of size and location in the picture, the spots of gold are in such a way that if we get out all other colors and elements from the work, the balance of the work composition shall be maintained due to the gold color. This fact could be observed well in the color of clothes and decorations on bedclothes, cups of fruits and wine glasses.

Alongside the features of Isfahan painting style, associated with inclination to the reality, the application of gold color in the wall paintings is an expression of the economic, political and social realities of Safavid. Unlike previous periods of Iranian paintings in which gold express spiritual space and had a symbolic aspect, the wall paintings of Chehel-sotun palace, giving earthy concepts like symbol of power, wealth, and welfare to the gold color due to competition of Shah Abbas with Ottoman palaces and cathedrals of Europe.

In most wall paintings, gold color has been displayed in the first plan of the image so visibly and obviously, their brilliance in the picture even surpass the bodies, and it has a very great visual effect.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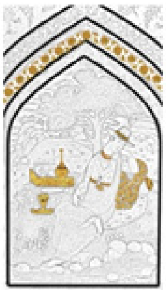
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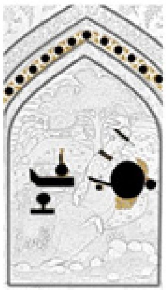
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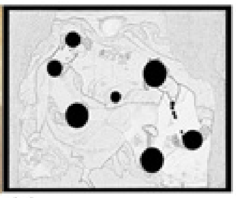
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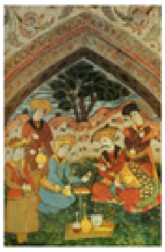
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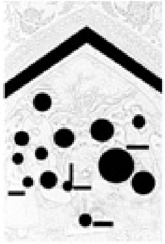
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The Role of Colour in Iranian Architecture and Environment

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ABSTRACT

The colour is an important aspect of our daily lives. In school of architecture and urban design, particularly in Iran, colour is rarely a subject of serious inquiry in design studios. In addition, in practical designing, colour often appears in the last phase of design process and the reasoning for the colour choices is almost never questioned. I started designing an elevation of a tower to observe colours effects on people's attitude and I exhibited my works level by level for 100 Iranian people that I selected them randomly and they answered patiently to my questions. In the first and second steps: most of the people could not acquaintanced the project well. In the third one, I saw a huge advance in their opinion about the project. In the last step:the issues were wonderful and 88% of people appraised the project praiseworthy. This article has been intended that from the genesis of idea to the final representation of a planning process concluded, the colour is an essential character of the language of contemporary stresses in iran. My abstract has proved that the colour plays an important role in attracting iranian visitors and also clients.

1. INTRODUCTION

The colour is an important aspect of our daily lives and It is an intangible value that affects everything around us. In school of architecture and urban design, particularly in the Iran, colour is rarely a subject of serious inquiry in design studioes. In addition,in practical designing, colour often appears in the last phase of design process and the reasoning for the colour choices is almost never questioned, opposite of this imagination, iranian architectural history showes numerous examples of products where colour is an integral part of the work itself and there may be some recurring types where the colour is not just a means of expression but the star of a defined design process and wanted. This article aims to analyze the contribution of colour in the design phase of the Iranian architectural work and understand how Iranian's ideas are influencsed by colour of architectural elements and environment.

2. METHOD

We started designing an elevation of a tower to observe colours effects on people's attitude. Therefore, we started studing on the representation of contemporary designs made by some of the most famous iranian architects of our time and tried to use their patterns for designing and exhibited our works level by level for 100 Iranian people that we selected them randomly and they answered patiently our questions that We asked them by questionnaire. All questions for all of them were the same and they answered them on the answersheet.

2.1 Sample Preparation

After we designed the elevation and around environment we presented them in four different kinds. As a matter of fact, our designing provided four steps and each step had especial features.

First step was the sketch form: The sketch in Iranian architecture is a powerful means of expression, individual expression is strongly linked to the personality of the designer but it expresses without colour.

The second step was the monocrome sketch:This form without doubt is the most traditional form of representing the Iranian architecture where all the communication and creation of idea expressed by sharp edges and shades of one colour.

The third one was the coloured sketch: It is not a simple transposition of the real colour of a project or of a place with its abstract character separates the observer from the objective image by concentrating only on the project.

The end one was realistic sketch: In this form the colour serves as a vehicle for representing reality.The aim is to come closer to reality by using solid colours, bright and clear. Blue skies, emerald green, shiny metal, ultra reflective liquid surfaces contribute to the definition of image to describe the project as the best solution possible.

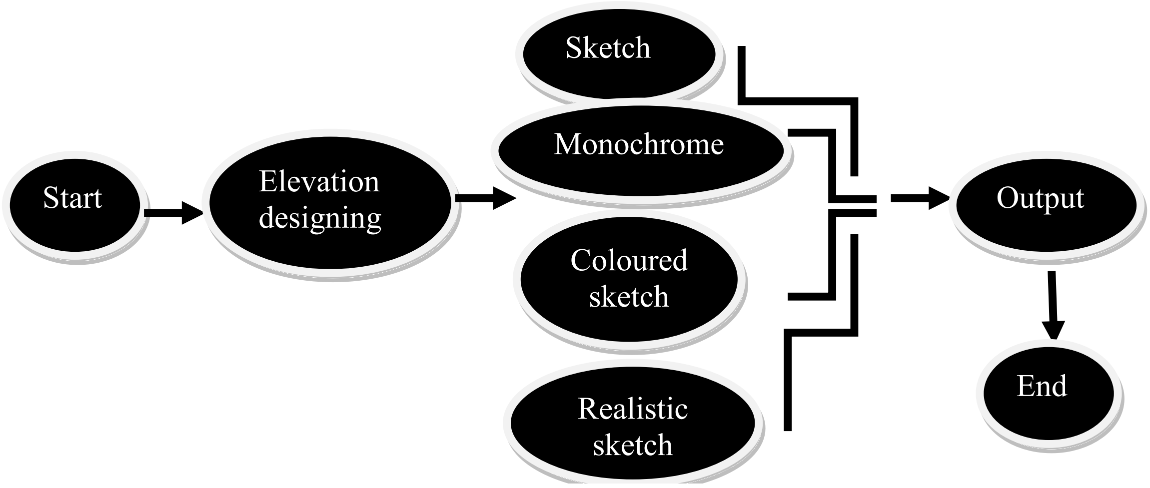

Figure 1: Flowchart illustrating the process of sample preparation.

After those steps we started processing the answers and analyzing the results and outputs to see the role of light on people's attitude.

2.2 Sample pictures

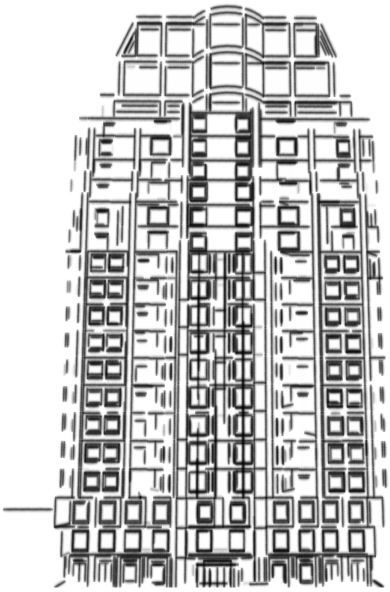

Figure 2: Sketch.

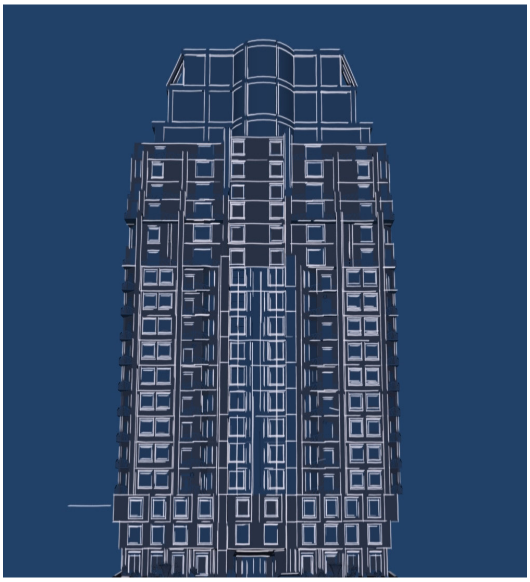

Figure 3: Monochrome sketch.

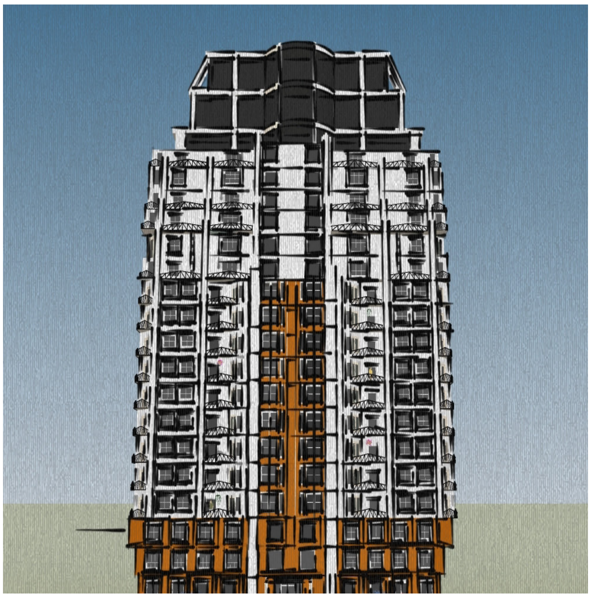

Figure 4: Coloured sketch.

Figure 5: Realistic sketch.

3. RESULTS

Cras In the first step most of the people could not acquaintanced the project well and just 7% of them were inclined to live in a place like it. In the second step again many of them could not be successful to connect between their idea and the project, therefore, only 19% of them had possitive assesments. In the third one, I saw a huge advance in their opinion about the project and 63% of them showed the positive inclination to my project. In the last step: the issues were wonderful and 88% of people appraised the project praiseworthy and vote of intent to it.

Table 1. Summary of the results.

Form	Result	Percent
Sketch	7	7%
Monochrome sketch	19	19%
Coloured sketch	63	63%
Realistic sketch	88	88%

4. CONCLUSIONS

This article has been intended that from the genesis of idea to the final representation of a planning process concluded, the color is an essential character of the language of contemporary stresses in Iran, thereby contributing both concepts show the development that the communication of idea. As I said, Iranian architects do not believe the colour as an integral part of work and designing these days, however, my abstract has proved that the colour plays an important role in attracting iranian visitors and also clients. In addition, an architect in Iran should exhibits their work on realestic environment to help the second person to connect with project better and if he did not consider the colour at the beginning of designing phase, he would lose many positive votes and it can be perlious for an architect in Iran.

The result is a reflection on its importance, not only in a purely constructive work, but also in the stages prior to the construction site to better evaluate the effects and make the most of opportunities in iran.

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Harmonies of Colour in Chinese Architecture: A Reflection of the Symbolic use of Colour in West and East

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ABSTRACT

Colour is an inseparable element of our daily lives, generating emotions and sensations. We can say that the wish to reproduce the colours of nature in everything that surrounds us is an ancient concern of mankind. However, predilection for certain harmonies of colour has been changing throughout history, according to cultural factors, to evolution of taste and especially the influence and guidance of fashion and art. Man's reaction to colour is subject to his physical condition and his cultural influences, which are specific to each society. Although the transcendental thought on the symbolic value of colour is reflected in all cultures from East to West, it is our intention with this study to highlight the importance of colour in Chinese culture and how it is reflected in its architecture, in light of the theories based on *Feng Shui*, an aesthetic philosophy that values the importance of the harmonization of spaces through colour. With this our project, we aim to foster the academic reflection on the importance of harmony and proportion of colour present in the memory and the cultural identity of places as elements that will encourage and develop avenues for the development of a modern, global architectonical understanding.

1. INTRODUCTION

Colour, inseparable element of our everyday life, has special importance in Visual Arts, assuming protagonism in fields as diverse as Architecture, Painting, Sculpture, Fashion, Ceramics, Graphic Arts, Photography, Cinema, etc. Colour is life and has always attracted human beings. However, predilection for certain harmonies of colour has been changing throughout time and places, according to cultural factors, to evolution of taste and especially the influence and guidance of fashion and art. We can say that the wish to reproduce the colours of nature in everything that surrounds us is an ancient concern of mankind. In this sense, the symbolic transcendental thought on colour is reflected in all cultures from East to West. In this study, our intention is to highlight the importance of colour in Chinese culture and how it is reflected in its architecture, in the light of the theories based on *Feng Shui*.

2. PRESENTATION

Consider the wide possibilities that colour offers. Its potential has, firstly, the ability to free stocks of human creative imagination. It acts not only on who builds the image, but also on who observes the image. About the subject that receives the visual message, colour exerts a triple effect: it impresses, it provokes emotions and evokes memories. Colour impresses the retina: therefore is seen; colour is felt: provoking an emotion; colour is evocative, because it links a physical sensation to specific meaning, creating a symbolic value and, therefore, has the ability to evoke a language that communicates an idea[1].

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[1] Cf. Josef Albers, *La interacción del color,* Alianza editorial, Madrid, 2001.

The action of each colour by itself is the foundation on which many values are harmonized. Kandinsky says that colour has a direct influence: “Colour is the touch, the eye, the hammer that vibrates the soul, the instrument of thousand strings” (Wassily Kandinsky 2002). In reality, colour is an independent language and can cause sensations and memories to people. Men react to colour according to their physical condition and their cultural influences specific to each society. Given these ideas, we can say that despite chromatology have evolved fairly for several centuries[2]; the symbolism of colour maintains all his traditional value. The symbols assigned to each colour change depending on the meanings given to it by various cultures, i.e. distinct cultures may have different meanings for certain colours[3]. Worldwide, colours describe emotional characteristics. Thus, in Western societies, for example, blue relates to melancholy, green to envy and yellow to cowardice[4].

Therefore we can say that man dived in colours from the beginning of times, recall herein only the most ancient civilizations, such as China, India, Egypt, among others, who documented the symbolic system that they created for colours. In this sense, the symbolic transcendental thought on colour is reflected in all cultures from East to West. In this study, our intention is to highlight the importance of colour in Chinese culture and how it is reflected in its architecture, in the light of the theories based on *Feng Shui*. One of the definitions of *Feng Shui* is the “understanding of how the geographical features of a site and its topography affect buildings internally and externally” (Evelyn Lip 1995), in view of the harmonization of heaven, earth and man in social, cultural and political domain.

In China *Feng Shui* is rooted in the ancient belief that the lives of men and their destinies are intertwined with nature and the universe. The force that binds these three entities is *chi*, which we can interpret as being the cosmic energy. This energy is essential to balance the physical, emotional and environmental aspects of life. One way to influence the chi is through the use of colour. Colours along with shapes and numbers represent the elements that allow the materialization of the symbolic concepts of *Feng Shui*, like *Ying and Yang*, or the *Five Elements* in our constructed world. All these forms of expression are interconnected and can occupy symbolically the places of each other, or when used cumulatively reinforce each other.

In Chinese highly ritualistic culture, colours play a prominent role in ceremonies and religious practices and policies since ancient times. From the second millennium (BC), the Chinese began to use colours to indicate the cardinal points, the seasons, the cyclical passage of time, and even the internal organs of the human body. This symbolism is incorporated into their architecture, through shapes and colours.

In this perspective, colour is used in Chinese architecture as a tool for establishing harmony with the universe, allowing or forcing the flow of vital energy – *chi* – in the manner considered the most auspicious. The addition of a new colour to an environment generates, according to Chinese view, a reaction, reaction which can be either positive or negative. Hence the choice of colours for the decoration of buildings, especially important buildings, such as palaces and temples, is a very serious matter and reserved to specialists – the masters of *Feng Shui*. It is up to them to identify the energy in need of an individual, environment,

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[2] Cf. Harald Küppess, *Color. Origem metodología sistematízación aplicación,* Editorial Lectura, Barcelona, 1973.

[3] Vid. Frédéric Portal, *El simbolismo de los colores. En la Antigüedad, la Edad Media y los tiempos modernos*, Sophia Perennis, Barcelona, 2000.

[4] Cf. Jean Chevalier; Alain Gheerbrant, *Dicionário dos símbolos*, Editorial Teorema, Lda, Lisboa, 1994.

space or building and, according to this need, choose the appropriate colour or combination of colours to apply.

Let's take as an example for the symbolic importance of colours in Chinese architecture the Imperial Palace (*Gugong*) in Beijing. The construction of the Imperial Palace, located in downtown Beijing, was started in 1420 and since then served as the official residence of 24 emperors[5]. The entire complex was planned and executed on the precepts of *Feng Shui*, it is possible to establish symbolic relations of the locations of the various buildings with the orientation of the sun, the dominant winds and the flow of water. These relationships are enhanced by the use of colour. All elements used in the construction were carefully selected, nothing was left to chance, everything is planned to make this place symbolically auspicious.

There are four dominant colours in the *Gugong*: red, applied to columns, walls, doors and windows; yellow, dominant colour on the roofs of the main buildings; green, mainly used in the linings of the ceilings inside the buildings; white, the colour of the stones used in floors, in staircases, bridges and on the walls of protection decorated with low relief.

Figure 1: Imperial Palace Gugong. Main residence of the Emperor. Photo by Maria do Céu Rodrigues.

Figure 2: The Hong Yige building in the Forbidden City. Photo by Maria do Céu Rodrigues.

In Chinese culture the colour red is considered particularly auspicious – it is a source of energy, a stimulant and positive force to be used for the expulsion of adverse Chi, the essence of masculinity, a symbol of the South, of the sun, of happiness and wellbeing. Red is represented by the Phoenix, the mythical bird; it is associated with the element of fire and has a yang nature. Due to its auspicious symbolism, red is present in many Chinese ceremonies and rituals. For example, at the sacred rituals related to nature performed regularly by emperors and at wedding ceremonies, imperial and civilian, most objects, vessels and vestments were predominantly red.

Green means tranquillity, hope and freshness. Green is the colour of the element "Wood". It represents the direction "East" and symbolizes the rapid and vigorous growth of vegetation in the spring; it indicates the Chi of the healthy land. Green represents balance, harmony, peace and longevity, thus the reason why some buildings of the *Gugong*, such as *Nan Sansuo*, are covered with green tiles.

The colour gold represents power. Gold is the colour of the element "metal". It represents the direction "west" and symbolizes wealth, status and leadership. The emperor wore golden robes embroidered with golden dragons. It finds that the use of these colours has always been closely linked to the imperial house and is considered the colour of the Emperor.

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[5] Evelyn Lip *Environments of Power. A study of Chinese architecture*. Academy Group, Ltd., Singapore, 1995.

The colour yellow is the colour of the element "earth"; it represents the earth and the centre, reaffirming the concentration of power. Yellow represents union, mental energy, wisdom, patience and tolerance, all the virtues that the emperor should incorporate. The use of yellow and the golden tiles on the main building of the *Gugong* complex indicates the buildings in which the emperor governs, where he dedicates himself to the work for the good of the nation. It marks the centre of the realm, from which the emperor ruled, sitting with his back turned to the barbarians of the north to rule his vast kingdom in the South.

White represents for the Chinese, winter, a dead or dormant state, which is why it is associated with mourning, for that reason white is not used often, however, it also represents the element "metal" and symbolizes restraint and self-control. It is in this sense that it is applied on the accesses and on elements of containment and protection.

3. CONCLUSION

To conclude, we can say that in the Chinese imperial architecture, the colours used, were used to symbolically emulate the Chinese ideal vision of cosmic order and thereby ensure stability, harmony and good luck for the emperors, dynasties, their entire nation and the following generations.

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Cultural Traditions of Colour Designing in Urban Space: The Case Study of Smolensk

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ABSTRACT

The article is devoted to the analysis of the chromatic peculiarities of the external decoration of Smolensk architecture. On the basis of this analysis the colour layers of the architectural objects were reconstructed and defined on samples. The descriptions and the colour schemes of the architecture of Smolensk in the period of the Middle Ages (the 12-17th centuries), the Pre-Revolutionary period (the 18-19th centuries) and the Soviet period (the 20th century) were developed.

1. INTRODUCTION

The thesis that each town has its own special colour sound serves as the starting point for the research. Like people, each city is unique and has its own characteristics, its own unique image, which arises not only from its social infrastructure and the features of the landscape but also its architecture, both historic and modern. Colour plays an important role in the creation of a city image. It bears a powerful emotional effect while perceiving the architectural form, but it cannot influence without other art means of expression and properties of forms. After all, the cultural traditions of colour designing in urban space and special colour sound derive from the interaction of the natural environment and colour technology.

2. METHOD

The Russian city of Smolensk, built on the river Dnieper in 863, has become the object of the research.

During the direct fieldwork on gathering samples of colour, photos and descriptions the coloration of separate quarters and the city as a whole was established. Not only the general characteristic of coloration tendencies, but also colour deviations were analysed. The results of the field research of Smolensk colour image were added to the data of the polls which provided the idea how the inhabitants perceive the colour of the native city (Griber 2008: 130-137).

Historical and biographical methods were used to determine the evolution of architectural colours. The historical method was used to study the colour settings by local historical research, periodicals, photo documents, museum exhibits. The biographical method was used for the reconstruction of colour according to literary sources, folklore, paintings, and graphic works.

The study of the spectral structure and dominating colours of the residential buildings was realized with the help of content analysis. The prepared form of content analysis consisted of three sections: the first described the geography of the house, the second contained information about the appearance of the construction (number of storeys, material), the third fixed the colour scheme of the building. In course of the research not only the basic colours of the houses, but also the number of colours used in decorations (multi-coloured design) were fixed. Great attention was paid to the following elements of a house – the ornamental panels, window apertures and doorways, verandas, porches, balconies, fences and roofs of the architectural constructions. They were used as decoration in particular, because traditionally in Russia, as Efimov (1990: 25) explains “the outside painting of housing constructions concentrated, for the most part, on the lower surfaces of overhangs and roofs and on the upper surfaces on walls, window trimmers, porch pillars, in other words on those parts of buildings, which were protected from the damage of rain and snow”.

The selection of houses was regionalized according to the general number of properties and the population of the villages. The procedure of a two-step cluster investigation was also used. As clusters certain streets were chosen. Every cluster was researched with the help of the serial (complete) investigation of all the constructions. Such a selection of houses guaranteed the representativeness and validity of the research.

3. RESULTS AND DISCUSSION

3.1 The period of the Middle Ages (12-17th centuries)

According to the studied archival and iconographical materials, ancient Smolensk was a wooden city. Its colour image was created by the soft brownish and grey-silvery tones of various local tree species. Coniferous breeds (pine, fur-tree) and also the elm, aspen, oak were used as a material for building. Till the 18th century the shape of Smolensk was formed by the constructions which were rather poor in colour. Stone temples towered over a wooden housing estate and had white, slightly pinkish general colouring (Figure 1).

The colour of brick (painting a la brick or brick itself) underlined decorative elements. The harmony of white semitones was not broken by the lead silvery coverings of roofs.

Figure 1: The Cultural Traditions of the Colour Designing of Smolensk in the 12th Century. Reconstruction.

3.2 The Pre-Revolutionary period (18-19th centuries)

On the boundary of the 18-19th centuries basically that part of the city that for today is central was formed. There was not only an intensive territorial growth but also growth in the concentration of existing spaces. New buildings were constructed adjacent to historical ones and thus created the problem of correlation of historical and new buildings. At the same time the design of newly constructed buildings used multiple compositional principles and devices, and most importantly a rich colour palette. The colour choice, in almost all the cases, did not correlate with the existing colour context. Merchant houses and manors in classical style that were constructed at that time brought new colour tones: yellow, yellow-orange, white.

The last third of the 19th century was characterized by a variety of architectural objects created in different styles. Eclecticism added yellow, light orange, pink, yellow-orange, red-orange colours to the Smolensk palette.

During the last decade of the 19th century domestic folk art, the traditions of national folklore, wooden carving, ornaments in "Russian style" became popular. New buildings were erected mainly of brick and had grey, grey-violet and blue shades in colouring.

3.3 The Soviet period (20th century)

At the beginning of the 20th century the style varied: decorative "eclectic" facades and picturesque forms of Modernism gave way to the simplicity of a new style of the Soviet epoch.

The revolution changed not only the political system but also the ideology of people. Architects worked at the creation of a visual environment that corresponded to the new socialistic structure. A rather exact and idealized image, which was brought to life over several years and which transformed the architecture itself, was produced.

Kosenkova (2001: 56) supposed that the town planning design of that time in Russia was determined by two theses, united by the ideology of creating a "great society" (the notion of a *great society* in this context, as Achiezer explains (1993: 4), points mainly to quality rather than size): the priority of industry over people's interests and the tendency of general unification of the town-planning architecture. There was a need to find means to unite a number of historically formed local associations with lives of their own.

Constructivists in actuality reduced architecture to engineering. They followed the Socratic identification of beauty and practicability. The new aesthetic ideals of that time were maximum simplicity, functionality, artistic minimalism and constructability of architectural forms. The austerity of forms was connected with the spirit of the age and the "image of the epoch" and also corresponded to the principles of the proletariat in one more point: the new style was unlike the architecture of classicism and the Slavo-Byzantinesque style, which to the new authorities, were symbols of imperialism.

The following period (the 30s of the 20th century - the first half of the 50s of the 20th century) was characterized by constructions in the style of neoclassics, or "a Stalin empire style". In the colouring of the buildings of this period grey, yellow, yellow-orange shades were mainly used.

Between the 1960s and the 1980s the colour of building facades was determined by stylistic traditions: ochre, green. However, red colours prevailed in the design of urban space. The colour of roofs, light, landscaping (paving, "green" architecture, retaining walls), easily built constructions (small shops and stalls), city designs (bridges, fences, stops), works of monumental decorative art and outdoor advertising were overwhelmingly coloured. The majority of the buildings in the city centre had red roofs. Some of the facades of the city buildings were emphasized with red and specially used for placing posters on them. Photographic evidence proves that all the buildings of higher significance in the city were additionally marked with red decorative plants.

4. CONCLUSIONS

The combination of different methods makes it possible to determine that the appearance of architectural constructions changes slowly. The overwhelming majority of the individual wooden houses in the region in fact have not changed at all, it means that the houses, fulfilled in the traditions of local folk architecture, have preserved Slavic-Krivich ideas, which began to develop in ancient times. In course of the lives of several generations town properties have preserved their traditional colours.

In the development of the official architecture were detected colour layers. Transformations of cultural traditions of colour designing in urban space were connected with the political evolution of the city and had evident social influential opportunities. Therefore, the study of the colour layers of the city has not only theoretical but also practical significance. The results of the research have been cited in monument protection and restoration, in the development of scientific foundation clusters of urban policy in Russia and in programs of colour panoramas of cities for drawing up specifications and colour passports of buildings.

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The Study on Environmental Color Features Analysis for Preservation of Regional Image Identity
- Focused on #47, Okin-dong, Jongro-gu –

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ABSTRACT

Okin-dong is in danger of mass extinction under the pretense of redevelopment by lack of awareness as cultural assets. In this study, the color practical information was established for the preservation of regional images by surveying and analyzing the status of environmental color focusing on #47, Okin-dong. Total 122 structures are investigated and roof, wall, fence, street floor, window frame and door which are considered having a major influence on landscape image were colorimetric targets. Investigated color were reproduced as digital color for analysis by NCS digital palette [NCS Palette 2[1].0 Creative] and classified by constituents of landscape and analyzed by being divided into information on single color and color arrangement respectively by using an analytical frame, NCS color circle and triangle for analysis of solid color, Ostwald's and Chevreul's color harmony theory for analyzing color arrangement. As a result, the area to be investigated showed the status of using very similar colors overall, it had an uniformed landscape image. The solid color palette could be arranged into total 46 units and the coloration palette could be arranged into total 65. In addition, it could be known that the coloration of buildings in the area to be investigated had probability of coloration visually.

1. INTRODUCTION

The current center of Seoul is differently changed day by day due to many kinds of construction projects and redevelopment projects and historical and cultural landscape resources are also rapidly damaged or become extinct. Okin-dong is in danger of mass extinction under the pretense of redevelopment by lack of awareness as cultural assets even though they are living cultural assets that vividly deliver modern and contemporary Seoul's intrinsic residential culture since they are mixed with improved Korean traditional houses, alleys, Japanese style houses and villas. Therefore, in this study, the color practical information was established for the preservation of regional images by surveying and analyzing the status of environmental color focusing on #47, Okin-dong that keeps well images of residential areas of Seoul in 1960s to 1970s.

2. RESEARCH METHOD

2.1 Research Range

Target region for investigation includes 122 structures that observation is comparatively easy among more than 150 structures in the site. The target places for the systematic investigation were divided into five, from A to E, and the colors which were observed by the orders of buildings when the researchers moved were analyzed and recorded.

2.2 Colorimetric Method

2.2.1 Selection of Landscape Constituents

This study looked into a variety of constituents of landscape shown in the target region by dividing into visual importance, commonality and fixity that are the factors affecting landscape image. As a result, factors were able to be divided into group 1 through group 4 depending on the importance of constituents of landscape within the target region. This study carried out colorimetry targeting constituents of landscape only in group 1 and 2 which are considered having a major influence on landscape image. Roof, wall, fence and street floor are in group 1 and window frame and door are in group 2.

2.2.2 Colorimetric Method

This study minimized the range of visual sensitivity color error according to time difference of investigation by conducting on-site colorimetry during a same time slot from 11:00 through 15:00 on a rainless clear day. As a tool for on-site colorimetry, NCS INDEX Original color sample was used. This study also carried out photographing and sample collection simultaneously with colorimetry.

2.2.3 Color Analysis

NCS digital palette [NCS Palette 2[1].0 Creative] was used to reproduce color information of target region. Reproduced colors were classified by constituents of landscape and analyzed by being divided into information on solid color and color arrangement respectively by using an analytical frame. NCS color circle and triangle were used for analysis of solid color, and Ostwald's and Chevreul's color harmony theory were used for analyzing color arrangement.

3. RESULTS AND DISCUSSION

3.1 Status of Building Arrangement

Figure 1: Building status in the site.

3.2 Status of Solid Color Chip

The colors used for outer walls were total 20 solid color palettes and total 19 solid color palettes for fences and outer walls and fences showed the status of using very similar colors.

Colors of YR order with medium brightness and medium chroma, YR order with medium brightness and low chroma, N order with high brightness and B order with high brightness and low chroma were mainly used for outer walls and fences. The colors used for roofs could be arranged into total 10 solid color palettes and colors of YR order with medium brightness and low chroma, YR order with high brightness and low chroma, N order with hight brightness, RB order with low brightness and low chroma were mainly used. The colors used for floors could be arranged into total 2 solid color palettes and the colors of YR order with high and medium brightness and low chroma were mainly used. The colors used for gates could be arranged into total 16 solid color palettes and colors of RB, BG, G order with low brightness and low chroma were being used with high frequency. The colors used for window frames could be arranged into total 6 solid color palettes and colors of N order with high brightness and YR order with low brightness and low chroma were being used with high frequency.

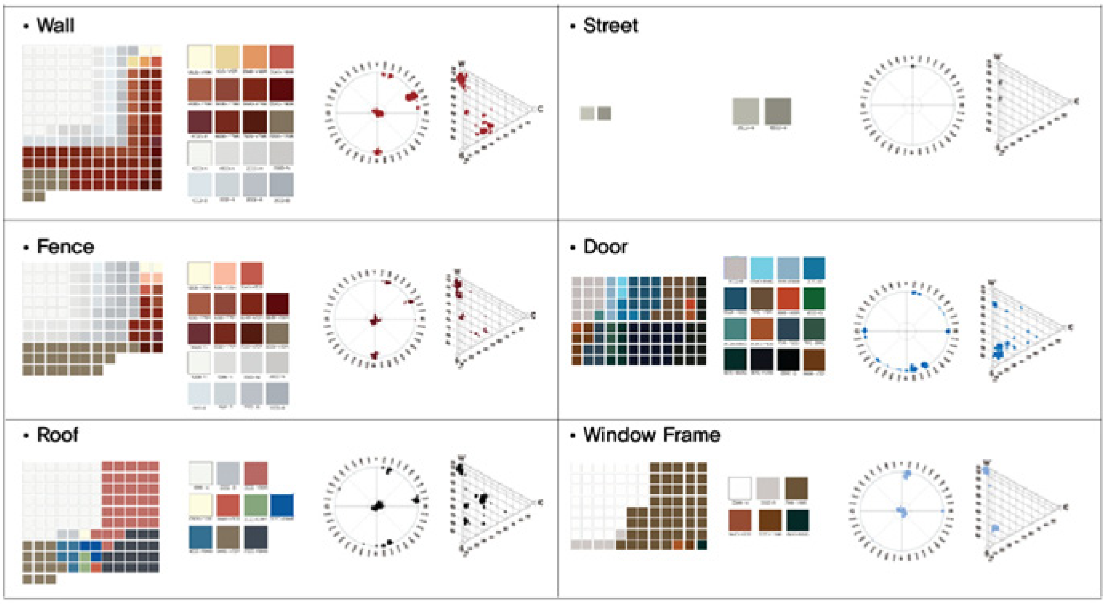

Figure 2: Solid color status of main landscape constituents.

3.2 Status of Coloration Palette

The coloration palette that is shown at the area to be investigated could be arranged into total 65 types and the arrangement of 3 colors were being used with the highest frequency in general.

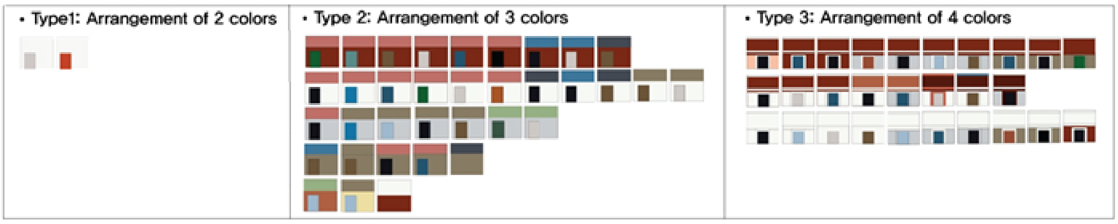

Figure 3: Coloration status of main landscape constituents.

In tone relationship, the same chromaticness coloration order was dominantly shown with high frequency and this coloration order between outer walls and roofs was shown most frequently. In hue relationship, the harmonization of similar colors was shown with the highest frequency and especially this harmonization principle was shown most frequently between colors of outer walls and gates or between fences and gates.

4. CONCLUSIONS

First, since the area to be investigated showed the status of using very similar colors overall, it had an uniformed landscape image.

Second, the solid color palette that was shown in the area to be investigated could be arranged into total 46 units.

Third, the coloration palette that is shown at the area to be investigated could be arranged into total 65 types and the arrangement of 3 colors were being used with the highest frequency in general.

Fourth, as a result of analyzing the coloration palette that is shown at the area to be investigated, it could be known that the coloration of buildings in the area to be investigated had probability of coloration visually.

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Assessing Color Differences in a Wide Range of Magnitudes

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ABSTRACT

In order to investigate the effect of color-difference magnitude on the evaluation of color difference, Stevens' power law was applied in assessing color difference with the structure of $\Delta E' = \boldsymbol{a}\Delta E^{\boldsymbol{b}}$. The ***a*** and ***b*** coefficients were optimized from 16 color-difference datasets, which were divided into three groups according to different magnitudes of color difference, threshold, small and large color difference, with average ΔE^*_{ab} ranged from 0.55 to 1.10, from 1.36 to 3.03, and from 8.9 to 14.3, respectively. In statistics, the modified formulae performed better than their original forms for all 16 tested datasets or even significantly better than their original forms for most of 16 datasets in terms of *F*-test at a 95% confidence level. Especially the modified formulae significantly improved all threshold datasets. In general, the proposed formulae may be used to evaluate color differences for a very wide range of color-difference magnitudes.

1. INTRODUCTION

CIELAB color space and its extensions have been proposed to evaluate color difference in industry. However, new experimental results show that the performances of those formulae were different for different magnitudes (Melgosa 2008), e.g. threshold, small and large color difference. In industry application, while assessing color pairs with color differences of different magnitudes, people are simply to choose a formula without considering the range of magnitudes strictly, not to speak of the formula recommended by CIE for the corresponding magnitudes.

In this study, 16 exisiting color-difference datasets were selected and examined using different formulae to assess color differences in a wide range.

2. COLOR-DIFFERENCE DATASETS AND MODELING

The details of the datasets with different magnitudes and substrates are summarized in Table 1. Those datasets were divided into three groups according to different magnitudes of color difference, threshold (TCD), small (SCD) and large (LCD) color difference, with average ΔE^*_{ab} ranged from 0.55 to 1.10, from 1.38 to 3.04, and from 8.9 to 14.3, respectively.

Stevens' power law describes the relationship between the magnitude of a physical stimulus and its perceived intensity (Stevens 1957). The general form of the law is

$$\psi(I) = a\, I^{\,b} \qquad (1)$$

where *I* is the magnitude of the physical stimulus, $\psi(I)$ is the psychophysical function relating to the subjective magnitude of the sensation evoked by the stimulus *I*, ***b*** is an exponent that depends on the type of stimulation and ***a*** is a proportional constant that depends on the type of stimulation and the units used.

Table 1. Summary of color-difference datasets used in the study.

	Dataset	Pairs	Mean ΔE^*_{ab}	Max ΔE^*_{ab}	Material	Reference
TCD	BIGC-TS17	890	1.10	4.88	Semi-gloss Print	Huang *et al*. 2012a
	BIGC-TM05	399	0.70	2.75	Matt Print	Huang *et al*. 2010
	BIGC-TS05	446	1.08	4.28	Semi-gloss Print	Huang *et al*. 2010
	BIGC-TG05	379	0.82	2.62	Gloss Print	Huang *et al*. 2010
	Wang	100	0.55	1.36	Matt Paint	Wang *et al*. 2012
SCD	BIGC-SS17	446	3.04	7.98	Semi-gloss Print	Huang *et al*. 2012b
	RIT-DuPont	312	1.44	4.41	Gloss Paint	Berns *et al*. 1991
	Leeds	307	1.63	4.74	Gloss Paint	Kim 1997
	BFD	2776	3.00	18.21	Various materials	Luo & Rigg 1986
	WITT	351	1.38	2.97	Gloss Paint	Witt 1999
LCD	OSA	128	14.30	21.65	Colored Tiles	MacAdam 1974
	Munsell	844	10.06	22.62	Gloss Paint	Newhall 1940
	A&P	1308	8.91	26.21	Photographic Paper	Attridge & Pointer 2000
	GUAN	292	11.43	20.88	Wool Dyeing	Guan & Luo 1999
	ZHU	144	9.92	19.80	CRT Colors	Zhu *et al*. 2001
	BADU-P	238	11.75	35.81	Nylon Dyeing	Badu 1986

As studied by Attridge and Pointer (Attridge and Pointer 2000), Stevens‘ power law was revisited in the study to modeling the magnitude effect on the evaluation of color difference. In Equation (1), the constant ***a*** is only used to adjust the scale between the visual and calculated color difference; it has no influence on the *STRESS* measure (García *et al*. 2007). The exponent ***b*** of the function decides the degree of compression between the visual and numerical color differences, which resulted in the direct effect on the *STRESS* measure. The coefficients ***a*** and ***b*** for each tested formula were optimized to give the minimum average *STRESS* value of the 16 selected datasets. Finally, constant ***a*** values of 1.26, 1.43, 1.41 and 1.34, and exponent ***b*** values of 0.55, 0.70, 0.70 and 0.66 for CIELAB, CIEDE2000, CIE94 and CMC, respectively, were obtained.

3. RESULTS AND DISCUSSION

The CIELAB and its three extensions, CMC, CIE94, and CIEDE2000, were tested with respect to their performances in predicting the wide range of color-difference magnitudes. The performances of the original and optimized formulae in terms of the *STRESS* value are summarized in Table 2. The significance of difference between the original formula and its optimized form was also tested using the *F*-test, and the results (*F*) are also given in Table 2. The bold and italic values of *F* ratio in Table 2 indicate that the improvement was not significant compared with critical values (F_C) at a 95% confidence level.

In statistics, the modified formulae performed better than their original forms for all 16 tested datasets or even significantly better than their original forms for most of 16 datasets.

Especially the modified formulae significantly improved all threshold datasets, which was a headache problem for assessing color difference in this range over the past years. In general, the proposed formulae may be used to evaluate color differences for a very wide range of color-difference magnitudes.

Table 2. Performance of color-difference formulae in terms of STRESS and F-test.

Dataset		**CIELAB**			**CIEDE2000**			**CIE94**			**CMC**			***FC***
		Old	***New***	***F***	***Old***	***New***	***F***	***Old***	***New***	***F***	***Old***	***New***	***F***	
TCD	BIGC-TS17	55.3	35.8	0.42	46.1	35.9	0.61	45.1	35.1	0.60	47.2	35.3	0.56	0.88
	BIGC-TM05	55.3	40.8	0.55	45.8	38.2	0.70	46.3	38.5	0.69	47.6	38.4	0.65	0.82
	BIGC-TS05	51.9	36.9	0.51	48.8	39.6	0.66	46.5	38.6	0.69	50.1	39.1	0.61	0.83
	BIGC-TG05	55.6	45.3	0.66	50.3	44.1	0.77	48.7	43.0	0.78	50.7	43.6	0.74	0.82
	Wang	33.2	20.2	0.37	18.3	13.4	0.54	31.0	22.6	0.53	21.5	15.5	0.52	0.67
SCD	BIGC-SS17	42.2	32.6	0.60	29.4	22.5	0.58	29.0	23.8	0.67	31.8	24.1	0.58	0.83
	RIT-DuPont	33.4	17.6	0.28	19.5	13.4	0.48	20.3	14.2	0.49	27.4	17.9	0.43	0.80
	Leeds	40.1	29.9	0.55	19.2	17.6	***0.84***	30.6	24.5	0.64	24.9	20.2	0.66	0.80
	BFD	42.5	37.2	0.77	29.6	28.5	0.93	33.9	31.1	0.84	31.0	29.9	0.93	0.93
	WITT	50.1	44.9	0.80	29.9	28.5	***0.91***	31.9	31.6	***0.98***	35.0	33.2	***0.90***	0.81
LCD	OSA	24.5	21.8	***0.79***	22.2	19.1	***0.74***	19.7	17.3	***0.76***	27.3	22.2	0.66	0.71
	Munsell	17.2	12.8	0.55	30.2	23.9	0.63	33.5	26.2	0.61	33.1	24.4	0.54	0.87
	A&P	29.7	26.5	0.79	34.0	28.1	0.68	31.1	26.5	0.73	38.3	30.0	0.62	0.90
	GUAN	25.0	21.2	0.72	19.5	14.8	0.58	18.5	13.8	0.56	24.8	19.0	0.59	0.79
	ZHU	26.3	20.7	0.62	31.3	21.4	0.47	33.3	21.7	0.43	47.3	30.0	0.40	0.72
	BADU-P	30.7	27.4	***0.80***	18.8	17.9	***0.90***	20.1	19.0	***0.89***	24.4	22.0	***0.81***	0.77

4. CONCLUSIONS

Stevens' power law was applied to predict color difference with a wide range of magnitudes. The relationship between the visual difference and the corresponding modified color difference was improved in terms of *STRESS* and *F*-test at a 95% confidence level. Especially the modified formulae significantly improved all threshold datasets. In general, the proposed formulae may be used to evaluate color differences for a very wide range of color-difference magnitudes.

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Assessing Colour Differences near the Neutral Axis

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ABSTRACT

The performance of colour-difference formulae for assessing colour differences near the neutral axis were studied by retrieving neutral colours from existing colour-difference dataset BFD. The results showed that all tested formulae predicted the hue difference near the neutral axis better than that of other differences on lightness, chroma and chroma-hue interaction. Comparing two weighting parameters k_L and k_C, the lightness parameter k_L had more influences on the balance of total difference than the k_C.

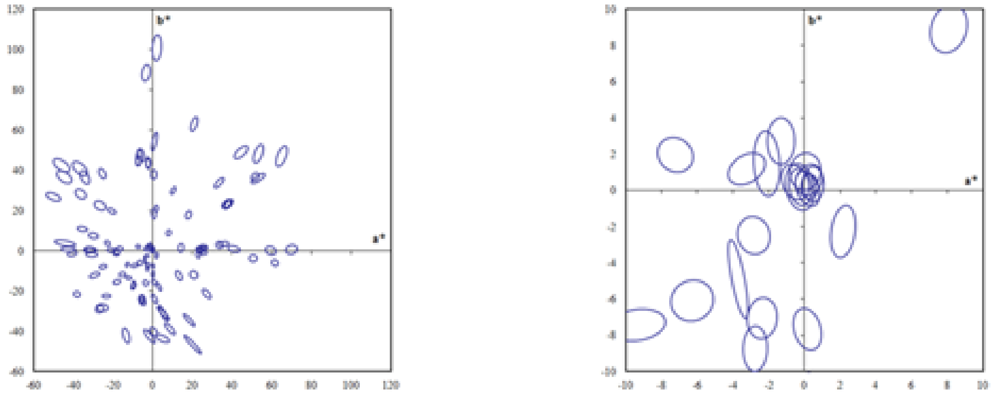
1. INTRODUCTION

It is well known that the three-dimensional colour space of CIE tristimulus values (X, Y, Z) is not visually uniform, nor is any linear transformations of them. Equal distances in these spaces do not represent equally perceptible differences between colour stimuli. For this reason, the CIE has standardised two approximate uniform colour spaces, CIELAB and CIELUV (ISO 2008), whose coordinates are non-linear transformations of X, Y and Z. Hence, simple Euclidean distances in these spaces can approximately describe the relative magnitude of colour differences. Some more sophisticated colour-difference formulae were developed later for further improving the correlation with the relative perceived size of differences, such as CMC (Clarke *et al.* 1984), CIE94 (CIE 1995), CIEDE2000 (Luo *et al.* 2001), DIN99d (Cui *et al*. 2002), and CAM02-UCS (Luo *et al*. 2006). For example, the CIEDE2000 formula is an extension of the CIELAB colour-difference formula with corrections for variation in colour-difference perception dependent on lightness, chroma, hue and chroma-hue interaction. In addition, a new redness-greenness scale (a') was derived to improve the performance of the CIEDE2000 formula in predicting chromatic differences in the neutral region.

The use of a grey or near-neutral scale to set the tone reproduction of a printing device is growing in its global adoption. The requirement for making this method of "press calibration" work is the ability to map near-neutral colours from the white point of the substrate to the black point of the full tone black ink or three-colour overprint ink. The primary interest in the work of CIE Division 1 by ISO Technical Committee 130 "Graphic technology" is in the area of colour differences and colour tolerances. The latter reported that the recent colour-difference metrics, both from the CIEDE2000 and CMC, have been shown to have major flaws in assessing colours near the neutral axis, although it is supposed that CIEDE2000 is corrected for evaluating colour differences near the neutral axis (Luo et al. 2001). In both traditional process printing and digital process printing, there is a good chance that the tone reproduction curves of three-colour (or more) overprints do not consistently lie along a line on one side of the neutral axis. They have requested the CIE Division 1 to investigate the visual differences between two grey stimuli, that may be different in chroma and hue, and in obtaining a definition of the percept of grey that is linked to a CIE colour metric.

2. EXPERIMENTAL DATA

In 1986, Luo and Rigg (Luo and Rigg 1986) accumulated most of the available experimental data relating to small to medium colour differences of surface colours. The data accumulated included various surface media: textile, paint, ink, etc. Over 120 colour discrimination ellipses were fitted from these data sets and were first investigated in CIE x, y chromaticity diagram. It was found that the ellipses formed a consistent pattern in terms of their shapes and orientations, but not sizes, mainly due to different psychophysical methods and different anchoring pairs being used in various experiments. Luo and Rigg then prepared over 600 pairs of wool samples close to these colour centres, and carried out psychophysical experiment using the grey-scale method. A panel of 20 observers assessed each pair. The data was used to adjust the sizes of the ellipses obtained earlier, and the adjustments merely altered the visual scale used in one data set relative to the other data sets. It has no effect neither on the ellipses' shape and orientation derived from the data, nor on the relative size of differences (and ellipses) within any one dataset. Finally, a consistent pattern of ellipses was generated. Figure 1a shows these ellipses plotted in the CIELAB a*b* diagram.



(a) BFD ellipses *(b) neutral ellipses*

Figure 1: BFD experimental colour discrimination ellipses plotted in a b* diagram.*

*Table 1: The neutral samples (C*ab ≤ 10) in BFD data.*

Sub-data	Conditions	Pairs	Mean ΔE	Max ΔE
All Neutral	C*ab≤10	423	1.7	8.3
ΔL only	|ΔL/ΔE|^{3}90%	88	2.3	6.2
ΔL+ΔC+ΔH	|ΔL/ΔE|, |ΔC/ΔE| and |ΔH/ΔE| are < 90%	64	1.7	8.3
$\sqrt{\Delta C^2 + \Delta H^2}$	$\sqrt{\Delta C^2 + \Delta H^2} / \Delta E \geq 90\%$	271	1.5	5.1
ΔC only	|ΔC/ΔE|^{3}90%	88	1.4	4.3
ΔH only	|ΔH/ΔE|^{3}90%	70	1.5	5.1
ΔC+ΔH	|ΔC/ΔE|<90% and |ΔH/ΔE|<90%	113	1.6	4.3

Figure 1(a) clearly indicates that CIELAB is a poor uniform colour space at least where small colour differences are concerned. For a perfect agreement between experimental data and CIELAB space, all ellipses in Figure 1 should be constant size of circles. It can be seen in Figure 1a that ellipses close to neutral axis (enlarged in Figure 1b) are the smallest; ellipses are larger and longer when chroma is increased; and most ellipses point towards the neutral point except for those in the blue region. It also can be seen in Figure 1b that for the majority of ellipses near the neutral axis, they are orientated towards around 90^o, not constant-diameter circles. This is the main reason for introducing a new redness-greenness scale (*a'*) in the CIEDE2000 formula for improving the prediction of chromatic colour differences in the neutral region. In this study, BFD data was revisited. The neutral samples with chroma ≤ 10 in BFD data were retrieved and listed in Table 1 according to different groups.

3. RESULTS AND DISCUSSION

The performances of six colour-difference formulae or uniform colour spaces, CIELAB, CMC, CIE94, CIEDE2000, DIN99d, and CAM02-UCS, were tested in terms of *STRESS* using the neutral colours listed in Table 1 and full BFD data, the results are shown in Table 2. The performances of formulae with optimised lightness parameter k_L, and optimised k_L, k_C are summarised in Table 3 and 4, respectively.

Table 2: Summary of formulae's performance in their original forms.

Sub-data	CIELAB	CMC	CIE94	CIEDE2000	DIN99d	CAM02-UCS
BFD	42.5	30.6	33.9	29.6	31.7	32.4
All Neutral	30.2	23.7	31.3	25.1	23.6	28.6
ΔL only	28.9	21.8	29.0	28.2	23.3	25.6
ΔL+ΔC+ΔH	31.6	27.7	31.4	27.8	27.5	28.2
$\sqrt{\Delta C^2 + \Delta H^2}$	24.2	22.7	23.2	21.2	21.4	24.6
ΔC only	26.5	24.0	25.6	21.9	21.4	24.1
ΔH only	**17.9**	**18.9**	**18.0**	**16.6**	**18.4**	**22.6**
ΔC+ΔH	25.7	24.2	24.5	22.0	22.7	25.3

Table 3: Summary of formulae's performance with optimised lightness parameter k_L.

Sub-data	CIELAB	CMC	CIE94	CIEDE2000	DIN99d	CAM02-UCS
All Neutral	26.2	23.6	25.2	24.9	23.1	24.6
ΔL only	26.4	21.3	25.8	27.7	22.3	22.8
ΔL+ΔC+ΔH	28.7	27.1	27.3	27.1	26.5	25.7
$\sqrt{\Delta C^2 + \Delta H^2}$	24.4	22.8	23.3	21.3	21.5	24.7
ΔC only	26.6	24.1	25.7	22.0	21.4	24.2
ΔH only	**18.0**	**18.9**	**18.1**	**16.5**	**18.4**	**22.7**
ΔC+ΔH	25.7	24.3	24.4	22.2	22.8	25.6
k_L	1.5	1.1	1.7	1.1	1.1	1.5

It can be seen from Tables 2-4 that all tested formulae performed better for different neutral subsets than for BFD full data, and the best performance for each formula appeared for the samples with only hue difference in the tested subsets. Comparing the results between Tables 2–4, it was found that a suitable lightness parameter k_L could improve the balance between lightness difference and chromatic difference in the total difference, but it had little improvement by further changing k_C, although the chroma difference was the dominant part in the chromatic difference.

Table 4. Summary of formulae's performance with optimised parameters k_L and k_C.

Sub-data	CIELAB	CMC	CIE94	CIEDE2000	DIN99d	CAM02-UCS
All Neutral	26.2	23.6	25.2	24.5	23.0	24.6
ΔL only	26.4	21.3	25.8	27.5	22.3	22.8
ΔL+ΔC+ΔH	28.5	27.1	27.3	27.4	26.6	25.8
$\sqrt{\Delta C^2 + \Delta H^2}$	24.3	22.8	23.3	20.7	21.3	24.5
ΔC only	26.8	24.1	25.7	21.1	20.9	23.8
ΔH only	**17.9**	**18.9**	**18.1**	**16.6**	**18.4**	**22.7**
ΔC+ΔH	25.8	24.3	24.4	21.5	22.4	25.5
k_L	1.6	1.1	1.7	1.0	1.1	1.5
k_C	1.0	1.0	1.0	0.9	0.9	0.9

4. CONCLUSIONS

The performances of six colour-difference formulae in assessing colours near the neutral axis were investigated by retrieving neutral colours with C*ab ≤ 10 from BFD dataset. Near the neutral axis, all tested formulae performed the best in predicting mainly hue difference, but not well enough for the mixture of different tolerances, especially for mixing with lightness difference.

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Colour-Discrimination Ellipses in the ULAB Colour Space

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ABSTRACT

A new colour space ULAB was developed for industrial colour-difference evaluation. The Luo and Rigg's chromaticity-discrimination ellipses were transformed to ULAB. The parameters of ellipses in ULAB were calculated and analysed.

1. INTRODUCTION

Chromaticity-discrimination ellipses compiled by Luo and Rigg (1986) are useful data for checking the uniformity of the new colour spaces. The ellipses were originally given in CIE (x,y,Y) space and later translated to CIELAB by Melgosa et al. (1994). Recently, a new colour space ULAB, approximately more uniform than CIELAB, was devised by Kim. It was obtained by optimising for the colour-discrimination data used to develop the CIEDE2000 colour-difference formula. This article describes the ULAB colour space, the method of ellipse transformation to ULAB, and the parameters of translated ellipses.

2. METHOD

The methods of calculating ULAB colour coordinates and colour-discrimination ellipses are given.

2.1 The ULAB Colour Space

ULAB coordinates (L_U, a_U, b_U, C_U, and h_U) are computed from CIELAB coordinates.

$$L_U = 10 \cdot \ln\left(1 + 1.2Y + 0.02Y^3\right) \tag{1}$$

where Y is the CIE tristimulus value and transformed from L^*:

$$Y = Y_n\left(\frac{L^* + 16}{116}\right)^3 \quad \text{if } L^* > 8$$

$$Y = Y_n\left(\frac{3}{29}\right)^3 L^* \quad \text{if } L^* \le 8$$

$$C_U = \frac{\ln\left[1 + 0.065\left(eC^*\right)\right]}{0.036} \tag{2}$$

where e is the chroma pre-scaling factor and calculated by using the data in Table 1:

$$e = e_i + \left(e_{i+1} - e_i\right)\left(\frac{h_{ab} - h_i}{h_{i+1} - h_i}\right) \quad \text{if } h_i \le h_{ab} < h_{i+1}$$

h_U is calculated by using the data in Table 1:

$$h_U = h_{U,1} + \left(h_{U,i+1} - h_{U,i}\right)\left(\frac{\frac{e_i}{e} - 1}{\frac{e_i}{e_{i+1}} - 1}\right) \quad \text{if } h_i \leq h_{ab} < h_{i+1} \tag{3}$$

$$a_U = C_U \cos\left(h_U\right) \tag{4}$$

$$b_U = C_U \sin\left(h_U\right) \tag{5}$$

Table 1. The relation among h_{ab}, e, and h_U.

i	h_i (h_{ab})	e_i	$h_{U,i}$
1	0	1	0
2	80 + 0.2L*	0.95 - 0.004L*	90
3	195 - 0.25L*	1.05	180
4	260 - 0.15L*	1.6 - 0.0075L*	240
5	312 - 0.2L*	0.12 + 0.0075L*	300

2.2 Calculation of Colour-Discrimination Ellipses

The centroid and the 360 regularly spaced peripheral points of an (x,y) ellipse, were computed and translated to (a_U,b_U). The ellipse equation in $a_U b_U$ plane is given by

$$\left(\Delta E\right)^2 = u_{11}\left(\Delta a_U\right)^2 + 2u_{12}\left(\Delta a_U\right)\left(\Delta b_U\right) + u_{22}\left(\Delta b_U\right)^2 \tag{6}$$

To calculate the u_{jk} values in eq. (6), the sum square difference between ΔV values (visual differences) and DE values (calculated differences by eq. (6)) are minimised. That is,

$$S^2 = \sum_{i=1}^{n}\left(\Delta V_i - \Delta E_i\right)^2 \tag{7}$$

where S^2 is sum of squares to be minimised, and n is the number of sample pairs.

Procedures were applied to the diffferences between the 360 peripheral points and the centroid, assuming ΔV = 1. The parameter E was used to check the goodness of fit.

$$E = \sqrt{\frac{S^2}{n}} \tag{8}$$

3. RESULTS AND DISCUSSION

Table 2 shows the orientation (q), shape (a/b), and size (πab) of the ellipses in ULAB. Unlike those of Luo and Rigg (1986: 33) and Melgosa et al. (1994, 13), the centres (L_U,a_U,b_U) of ellipses are omitted in the table. The mean values of $\left|\Delta\theta\right|$, a/b, and size/p are 40.5, 1.6, and 1.5, repectively. For CIELAB ellipses by Megosa et al. (1994), these are 18.6, 2.1, and 3.9, respectively. ULAB ellipses are more randomly rotated, less elongated and more close to circles than CIELAB ellipses. It can also be seen in Figure 1.

The average and greatest values of E (the goodness of a fitted ellipse) are 2.6% and 22.5%, respectively. These values for CIELAB ellipses are 0.8% and 5.1%, respectively.

Table 2. Parameters of colour-discrimination ellipses in ULAB.

Set	θ	a/b	Size	E(%)
VVVR B	149.8	1.9667	2.5334	1.31
VVVR Y	30.2	1.8189	5.9762	2.86
VVVR PK	132.0	1.2537	3.4131	1.23
VVVR DG	150.6	1.3594	3.8239	1.90
VVVR DP	13.8	2.7655	4.8492	2.58
VVVR GY	50.3	1.7918	3.5453	1.22
VVVR W	47.8	1.3624	6.3083	4.44
VVVR R	92.2	3.3397	7.4293	3.49
BFD RCK1	78.0	1.3196	6.3505	1.90
BFD RCK2	59.8	1.6674	5.9464	1.38
BFD RCK3	67.2	1.1534	4.2172	1.53
BFD RCK4	105.0	1.3425	5.0475	1.96
BFD RCK5	63.8	1.3912	4.8901	1.56
BFD RCK7	105.1	1.0960	2.5805	1.34
BFD RCK8	88.5	1.1327	4.3381	1.65
BFD RCK9	5.0	1.2395	3.2654	1.48
BFD RCK10	127.3	1.3936	4.4364	1.35
BFD RCK11	78.1	1.5679	3.2252	1.11
BFD RCK12	63.2	1.6533	3.2220	3.55
BFD RCK13	28.5	1.8012	5.2469	**7.00**
BFD RCK14	113.2	1.0224	4.2759	1.50
BFD RCK15	22.7	1.2307	3.9669	1.62
BFD RCK16	9.3	1.4057	4.7840	1.52
BFD RCK17	14.0	1.0908	4.9490	1.59
BFD RCK18	31.7	1.5375	2.7630	1.14
BFD RCK19	63.4	1.3597	3.5213	1.27
BFD RCK20	67.5	2.0978	6.1166	1.78
BFD RCK21	23.4	2.0529	4.0340	1.34
BFD KPC22	165.6	2.9382	5.5796	2.62
BFD KPC23	123.0	1.5015	4.1921	0.78
BFD KPC24	168.2	2.4596	5.0982	3.46
BFD KPC25	175.3	1.8417	5.1436	3.42
BFD KPC26	60.9	1.2573	6.1819	1.32
BFD KPC27	73.8	1.5902	3.2861	1.04
BFD TFC28	161.7	1.2369	5.1471	1.25
BFD TFC29	68.2	1.7388	5.2616	4.59
BFD TFC30	67.3	1.5406	7.5385	1.93
BFD TFC31	62.9	1.4499	4.3054	0.80
BFD TFC32	18.0	1.1424	4.9137	1.62
BFD TFC33	133.8	1.6815	3.0494	1.00
BFD AAK34	170.4	2.1655	5.1254	2.38
BFD AAK35	9.9	1.3138	5.8480	1.53
BFD AAK36	4.4	1.3760	4.3357	1.79
BFD AAK37	79.6	1.7194	7.8895	2.39
BFD AAK38	71.1	1.4756	3.5922	1.24
BFD AAK39	178.3	1.3934	4.7587	1.82
BFD CA40	58.9	1.1141	3.6494	1.37
BFD CA41	41.9	1.3666	3.3661	1.37
BFD CA42	11.6	1.2652	5.3125	1.37
BFD CA43	97.8	1.2028	5.2647	0.99
MMB BC	102.4	2.5291	6.2824	0.99
MMB FG	13.4	1.4558	8.6882	2.42
MMB RC	10.3	1.2590	6.5343	1.22
MMB GY	34.9	1.6877	3.8623	1.54
MMB MC	92.3	1.5475	3.9475	1.12
MMB MCB	167.2	2.2379	4.0162	2.09
MMB MM	108.6	1.2608	2.8078	**22.51**
MMB OC	162.6	1.5205	5.5155	1.10
MMB OG	38.6	1.3133	5.9786	1.84
MMB PR	91.8	2.3484	7.5242	4.05
MMB RO	123.5	2.0972	4.0373	1.25
MMB RG	24.2	1.3091	8.2305	2.11
MMB RR	87.0	2.1873	6.3031	2.83
MMB SCG	6.5	1.2243	7.8279	2.01
MMB SG	130.5	1.3647	4.7533	2.53
MMB SP	76.9	1.1525	2.5223	0.82
MMB DG	55.4	1.3377	2.7979	**12.25**
CISCC Y	43.0	1.7056	3.3170	2.01
CISCC O	27.3	1.4098	3.5409	1.13
CISCC P	179.5	1.0511	6.6665	2.63
CISCC B	44.5	1.6106	3.6710	1.33
CISCC GR	138.5	1.1057	5.5062	1.99
CISCC GY	85.4	1.2739	5.6440	**8.46**
CIE GY	70.9	1.3049	3.5654	4.60
CIE R	49.6	1.4091	3.7011	1.12
CIE Y	5.6	1.6886	5.8207	**12.26**
CIE GR	1.0	1.5071	5.0652	**5.43**
CIE BL	108.3	1.6358	6.6212	1.73
STROCKA	142.6	1.0335	5.0232	1.18
WITT	167.6	1.6876	5.0464	3.42
DF B	146.9	1.9937	3.6194	1.21
DF D	176.0	1.1347	6.4536	2.32
DF H	132.4	1.4183	5.3854	1.39
DF I	109.4	1.2625	4.6344	1.58
DF L	73.0	1.4493	6.0214	1.45
DF M	37.7	1.0889	2.7143	0.88
DF N	95.3	1.2444	3.7161	0.85
DF O	99.0	1.3044	5.4537	1.40
DF Q	177.4	1.1994	6.1022	2.27
DF R	159.8	2.1551	5.5977	2.48
DF S	120.2	1.2142	3.9792	**12.66**
DF T	86.5	1.3227	5.0754	1.62
MCD 4	174.9	1.5507	3.9026	2.91
MCD 6	44.9	1.4617	3.2773	1.23
MCD 8	155.1	1.3267	5.0525	2.09
MCD 9	20.6	1.3154	4.0316	1.62
MCD 14	48.9	1.3367	2.6871	1.87
MCD 18	89.4	1.1881	4.0593	1.28
MCD 20	174.4	1.5170	4.4140	2.10
MCD 21	13.1	1.4028	3.0721	1.47
MCD 23	18.7	2.3313	4.7222	**10.91**
MCD 29	151.9	1.5133	5.1463	**10.03**
MCD 33	25.1	1.1370	5.0082	2.63
MCD 39	155.3	1.6349	3.7444	1.84
MCD 40	17.4	2.6425	2.2243	4.30
MCD 43	169.1	3.4751	5.2107	1.63
MCD 51	10.1	1.7112	2.6624	**5.60**
MCD 53	170.5	1.9848	4.3293	1.77
MCD 58	45.1	1.6921	4.0511	1.75
K R	14.5	1.3332	4.4835	1.25
K G	2.7	1.9872	4.4239	2.11
K B	105.1	2.3331	6.2229	**7.22**
KMET A	158.2	1.4302	8.7635	2.31
KMET B	6.5	2.4349	3.7571	1.64
KMET C	40.7	2.3117	5.3797	1.28
KMET E	148.2	1.3593	5.1802	1.95
KMET G	171.8	1.0621	5.7045	1.63
KMET I	146.9	1.4967	4.4399	1.04
JK 10	10.5	1.5431	7.4189	1.75
JK 11	167.4	1.4868	4.4263	1.29
JK 17	35.3	2.2762	1.6604	0.89
JK 23	172.1	1.9392	7.1930	2.11
JK 25	171.8	2.0418	6.5025	2.62
JK 33	179.9	1.6154	7.2420	2.06
JK 000	171.6	1.8292	3.8990	4.46
JK 300	135.2	1.2126	3.8521	**6.15**
JK 700	52.3	1.3726	1.8578	2.47
W J	47.0	1.3488	5.2094	1.40
W N	159.7	1.0897	4.0171	0.91
W Q	174.4	1.2101	4.2066	1.90
W S	56.1	2.0381	2.2480	1.40
W W	80.2	1.2533	9.8025	2.17

In Figure 1, ellipses with E > 5% are mainly shown around hue angles h_U = 0 and 240. It is thought to be originated from the sudden change of the hue-angle near the key hue-angle positions in Table 1.

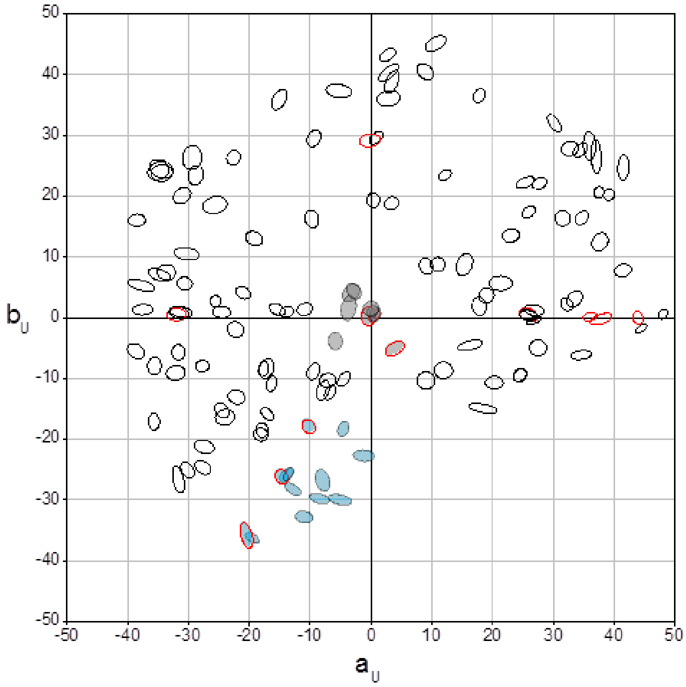

Figure 1: Colour discrimination ellipses plotted in $a_U b_U$ diagram. Ellipses for grey colours (C_U < 7) are filled with light grey colour, and those for blue colours (240 < h_U < 270) are filled with sky blue colour. When E > 5%, ellipses are plotted in red colour.

4. CONCLUSIONS

Colour-discrimination ellipses in the ULAB colour space showed more even sizes and shapes close to circles compared with those in CIELAB. In some colour regions, the goodness of fit of ULAB ellipses was poorer than that of CIELAB ellipses. It seems to be required that more refined methods of hue angle conversion from CIELAB to ULAB.

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Preliminary Comparative Performance of the AUDI2000 and CIEDE2000 Color-difference Formulas by Visual Assessments in a Directional Lighting Booth

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ABSTRACT

The calculation of color differences has been developing over the years with the aim of getting robust and adapted models for new colorimetric challenges. A clear example is found in the special-effect pigments. For this type of materials is not enough to measure the color in a single measurement geometry but different measuremet geometries are needed to study their complete behavior. For this reason, the aim of this study is to compare two color difference formulas commonly used in the automotive sector (CIEDE2000 and AUDI2000). Preliminary results indicate that, for measurement geometries closer to the specular direction, AUDI2000 performs better than CIEDE2000 with STRESS rates of 55, 34.21 and 46.33 respectively; on contrast, for measurement geometries away from the specular direction, CIEDE2000 performs better than AUDI2000 with STRESS rates of 34.27, 39.97 and 39.19 respectively.

1. INTRODUCTION

Nowadays, it is possible to do color measurements and color quality control in any situation. However, in many industrial applications, it is not only important to know the color of a given material, but it is also important to evaluate color differences between samples. The classic form to evaluate color differences is by using a gray scale formed by different gray pairs with specific contrasts according to the Adams-Nickerson color difference formula. During the last years, this method has been proven to be effective, so it is universally spread. However, to measure color differences it would be ideal to use any color difference formula, establishing for each case appropriate scales. For this reason, the International Standards Organization (ISO) has published a large number of recommendations. Logically, we should agree with the scales to use on each field, but once they are established, everybody would be able to use the same formulas (Artigas et al. 2002). In this paper, we use the gray letter pairs of the Society of Dyers and Colourists.

In many coloring materials industries, it is important an exhaustive color quality control and specifically, it is important to be able to replicate colored materials in the same way. In the automotive industry, the reference mathematical model used for predicting color differences is the AUDI2000 color difference formula (Eq. 1). Before this formula, and always based on the CIELAB color space, the AUDI95 color difference formula was developed. However, AUDI95 formula was not adequate to predict correctly the tolerance weights for some effect colors, thus Audi was forced to develop a new model to predict tolerances for both solid and effect colors. The new color tolerance model, AUDI2000, solved the problem by using the characteristic flop to predict tolerances (Dauser 2012). On the other hand, since several years the International Commission on Illumination (CIE), recommends to be used the CIEDE2000 color difference formula (Eq. 2). This formula provides an improved method to calculate color differences and it is based on statistical optimization of several visual assessments databases of numerous colors pairs

$$dE_{\gamma} = \sqrt{\left(\frac{dL_{\gamma}}{S_{dL,\gamma}g_{dL}}\right)^2 + \left(\frac{dC_{\gamma}}{S_{dC,\gamma}g_{dC}}\right)^2 + \left(\frac{dH_{\gamma}}{S_{dH,\gamma}g_{dH}}\right)^2} \qquad \text{(Eq. 1)}$$

$$\Delta E_{00} = \sqrt{\left(\frac{dL}{S_{dL}k_{dL}}\right)^2 + \left(\frac{dC'}{S_{dC}k_{dC}}\right)^2 + \left(\frac{dH'}{S_{dH}k_{dH}}\right)^2 + R_T\left(\frac{dC'}{S_{dC}k_{dC}}\right)^2\left(\frac{dH'}{S_{dH}k_{dH}}\right)^2} \qquad \text{(Eq. 2)}$$

CIEDE2000 predicts visual assessments without taking into account different measurement geometries. By contrast, AUDI2000 predicts color differences for six measurement geometries (45as-15 45as15, 45as25, 45as45, 45as75, 45as110). However, to develop AUDI200, it was not used an optimization and testing phase based on visual assessments.

The objective of this work is to evaluate the preliminary performance of CIEDE2000 and AUDI2000 color difference formulas by using different pairs of normal and gonio-apparent colors by doing visual evaluations in a specific lighting booth.

2. METHOD

A set of 13 different color pairs were selected with three different kinds of colors: solid, metallic, and pearlescent. To measure the colorimetric behavior of these goniochromatic samples a multi-angle spectrophotometer, named BYK-mac, was used. From CIELAB values and every measurement geometry, it was calculated the total and partial color differences according to each color difference formula (AUDI2000 and CIEDE2000).

A directional lighting booth was used for the visual assessments to test both color differences formulas, AUDI2000 and CIEDE2000. This cabinet was the byko-spectra effect cabinet (Figure 1), which allows color comparisons in the six measurement geometries of the BYK-mac multi-angle spectrophotometer. Visual assessment data (ΔV) were obtained by placing each pair of samples in the cabinet and by using as reference the card SDC Color Change with 9 gray pairs.

Figure 1: Byko-spectra-effect lighting booth.

To assess the correlation degree between the visual color difference and the instrumental color difference was used the STRESS parameter (García et al. 2007, Huang et al. 2012). It is a statistical parameter that evaluates both the degree of adjustment between two data sets and the statistical inference. The lower STRESS value, better the correlation degree. STRESS is calculated using the following equations:

$$STRESS = \sqrt{\frac{\sum_{i=1}^{N}\left(\Delta E_i - F_1 \cdot \Delta V_i\right)^2}{\sum_{i=1}^{N}\left(F_1^2 \cdot \Delta V_i^2\right)}} \qquad \text{(Eq. 3)}$$

$$F_1 = \frac{\sum_{i=1}^{N}\Delta E^2}{\sum_{i=1}^{N}\left(\Delta E_i \cdot \Delta V_i\right)} \qquad \text{(Eq. 4)}$$

3. RESULTS AND DISCUSSION

Preliminary results, but obviously with very few pairs of colors, indicate that:

1. for measurement geometries closer to the specular direction, i.e. 45as-15, 45as15 and 45as25, AUDI2000 performs better than CIEDE2000 with STRESS rates of 55, 34.21 and 46.33 respectively;
2. for measurement geometries away from the specular direction, i.e. 45as45, 45as75 and 45as110, CIEDE2000 performs better than AUDI2000 with STRESS rates of 34.27, 39.97 and 39.19 respectively.

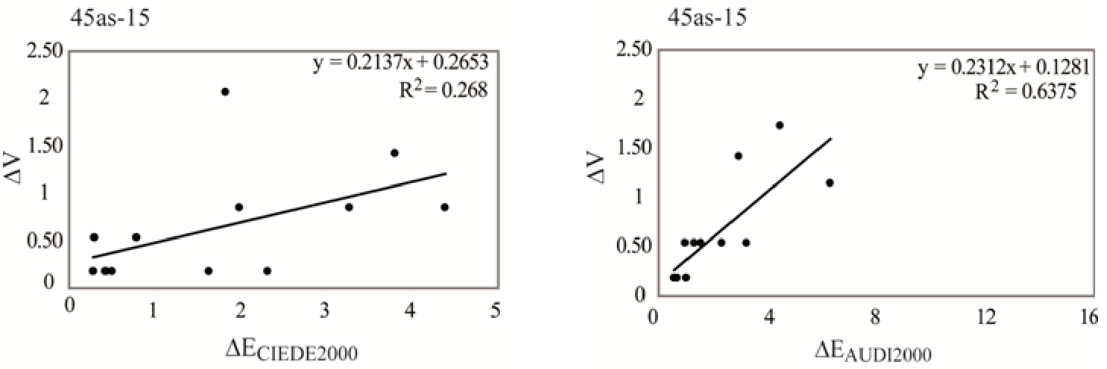

Figure 2: ΔV vs CIEDE2000; ΔV vs AUDI2000 for the measurement geometries 45as-15 (left) and 45as-15 (right).

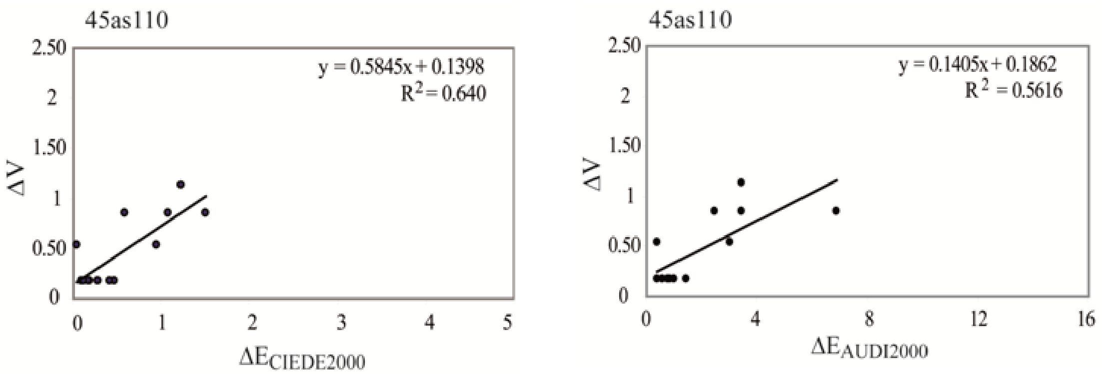

Figure 3: ΔV vs CIEDE2000; ΔV vs AUDI2000 for the measurement geometries 45as110 (left) and 45as110 (right).

Obviously, the worst perceptual prediction results always correspond to metallic and pearlescent colors. In general, there are over-estimates of the visual evaluations, i.e. $\Delta V < \Delta E$ (linear correlation slope ΔV vs ΔE less than 1) – see Figure 2 and 3.

4. CONCLUSIONS

Therefore, from this work, despite its small amount of data, it is possible to conclude that it is necessary to unify the strengths of both color-difference formulas to predict better color differences between gonio-apparent colors for any measurement geometry, which is demanded by several industrial sectors, such as the automotive sector.

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Dependency of Visual Color Difference to Background Lightness

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ABSTRACT

One of the parametric effects which influence visual assessment of color difference is the color of background. In our previous research (Gorji 2011), the effect of background lightness was evaluated for four color centers using printed samples. In the present study, we carried out more completed test with 28 polyester sample pairs prepared in seven color centers. The visual assessment experiments were conducted by 20 observers using gray scale method in three separated phase. In each phase, the observers assessed the color difference between the pairs on one of the three neutral background included black, gray and white.

It was found that for yellow and orange samples the perceived color differences on white background had the largest values and the black background showed the smallest ones. For the other samples, white background led to the smallest values of the perceived color difference and gray background led to the largest values. It is somewhat because of the Crispening effect. In the other part of this study, the correlation between the visual color difference and the computed color difference using CIELAB 1967 was investigated for each background. It was found that increasing the lightness of background leads to decrease the degree of correlation between the perceived and computed color difference. The best correlation between visual and computed color difference was obtained for black background.

1. INTRODUCTION

One of important issue in instrumental color control process is finding a reliable color difference formula. There are many color difference formulae such as CMC (Clarke 1984), BFD (Luo 1986), CIE94 (CIE 1995), and CIELAB. The other issue refers to viewing conditions. Each of the formula performs best under a specific set of conditions (CIE 1995). In visual assessments of color difference, viewing conditions such as sample separation, background color, sample size, sample lightness, and texture affect the results. Therefore, in 1989, CIE TC 1-28 committee has been organized for researching about parametric effects in color-difference evaluation (CIE 1993). The visual assessments almost conduct in two methods; Gray scale and Pair comparison. In a study by Guan and Luo (Guan 1999) it was shown that the method of visual assessment does not affect perceptual color difference. Guan et al. (Guan 1999) used three backgrounds in color of white, black and gray to investigate the influence of background on visual color difference. Their sample pairs were prepared in five color centers with the average ΔE of 3.0 CIELAB unites. Their results indicated that perception color-difference on white background is 15% more than gray background. Xin et al. (Xin 2001) have also done another study using medium color-difference pairs and three backgrounds in color of mid gray, green and blue. They found that much larger parametric effects belongs to green sample pairs on the green background and blue sample pairs on the blue background, which indicates the crispening phenomenon. Crispening is the increase in perceived magnitude of color differences when the background on which the two stimuli are compared is similar in color to the stimuli themselves (Fairchild 2005).

In the present study, the influence of background lightness on visual color difference was investigated for seven color centers and three backgrounds.

2. METHOD

2.1 Sample pair preparation

Dyed polyester samples were prepared in seven color centers consisted of yellow, orange, red, purple, green, blue and brown. In each hue, the samples were prepared in five different depths. The CIELAB a*, b* diagram and L* value of the samples under D65/ condition are shown in Figure 1 and Table 1 respectively.

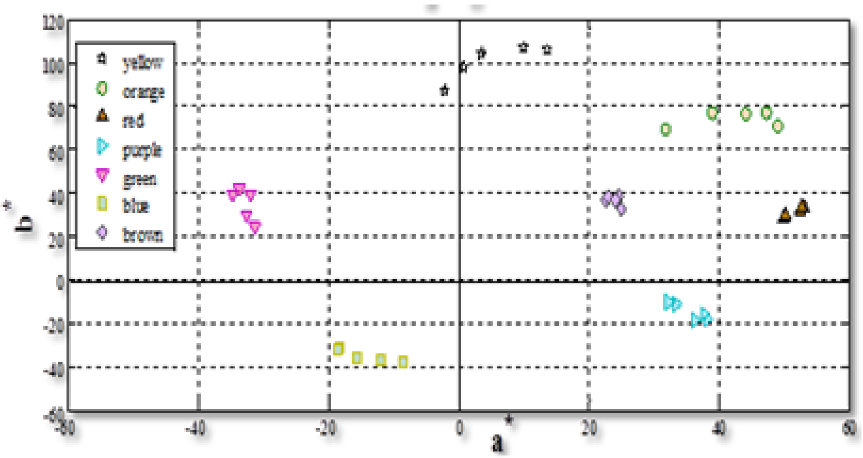

Figure 1: 2D plot of the color samples in CIELAB color space.

Table 1: L value of the samples.*

Color center	Sample number				
	1	**2**	**3**	**4**	5
Yellow	86.73	85.57	84.54	81.34	79.81
Orange	71.88	67.58	62.57	61.54	58.13
Red	52.20	45.50	42.17	38.51	35.65
Purple	43.91	36.55	29.36	22.94	22.79
Green	60.32	54.19	46.51	35.55	33.44
Blue	63.13	58.09	48.31	41.36	37.40
Brown	54.36	50.89	45.64	42.00	37.38

2.2 Visual assessment of color-difference

The visual assessment of color-difference was conducted using ICS-TEXICON light cabinet with D65 light source and illuminating/viewing geometry of 0/45. A panel of 20 observers (10 men and 10 women) assessed each pair. All the observers ware checked to have normal color vision based on Ishihara test. The Gray scale method was used for visual assessments. The visual assessment of color difference was conducted on three backgrounds included a white, a gray and a black one with lightness value of 95, 41 and 24 respectively.

After visual assessment, the gray scale grade (G) for each pair was transformed to visual color-difference scale (ΔV) according to the CIELAB color-difference formula using Equation 1:

$$\Delta v = 0.352G^3 - 2.287G^2 + 6.244G - 4.382 \qquad (1)$$

3. RESULTS AND DISCUSSION

3.1 Evaluating the Performance of Color-difference Formula

Performance factor is an important index for investigation of the agreement between instrumentally measured color-difference (ΔE) and visual assessment (ΔV) (AATCC 1999).

The PF/3 values for the three backgrounds are given in Table 2. As shown in this Table, white background indicates very different and high PF/3 value rather than the other backgrounds. It might be because of that the lightness value of the gray and black backgrounds are rather close to each other but the white background lightness is far from the others. Finally, it can found that in this case, decreasing the lightness of background leads to better agreement between CIELAB color-difference formula and visual results.

Table 2: The PF/3 value on three backgrounds.

Background	White	Gray	Black
PF/3	36.42	20.42	18.94

3.2 Evaluating Parametric Effect

Figure 2 shows the average of ΔV for each color center and each background.

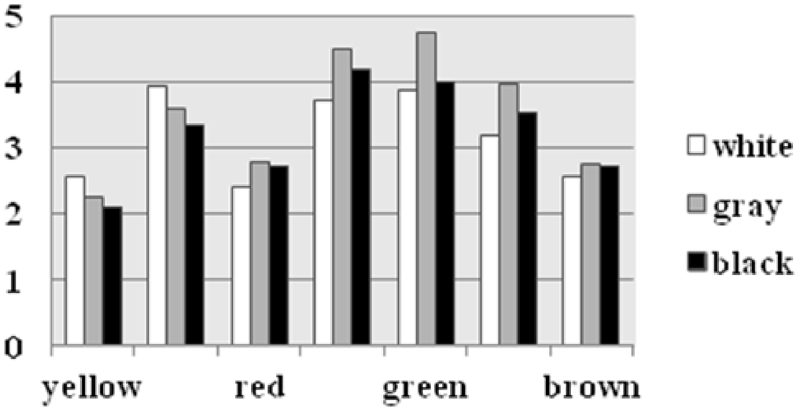

Figure 2: The average of ΔV for each color center on three backgrounds.

As shown in Figure 2, for all color centers except yellow and orange the largest ΔV value belongs to gray background and the lowest ΔV belongs to white background. However, for the yellow and orange pairs, increasing the lightness of backgrounds leads to increasing color-difference perception. Considering the lightness value of the samples, the results clearly show the crispening phenomenon. The yellow and orange sample pairs with higher lightness values shows larger color difference on white background. The average of the L* value for the other samples are mostly near the L* of the gray background and far from the white background so they have the largest ΔV on the gray background and the lowest ΔV on white. In this study, the largest parametric effect belongs to green sample pairs. The average of perceived color-difference for green pairs on the gray background is around 20% larger than when they were assessed on the white background.

4. CONCLUSION

In this study, we investigated the effect of background lightness in color-difference perception as a parametric effect. The prepared sample pairs in seven color centers were assessed on three backgrounds in color of white, gray and black. Sample pairs mostly indicated larger color-difference on a background which has L^* value closed to the samples lightness. In other words, the results were in agreement with the crispening effect. In terms of the correlation between CIELAB color-difference formula and visual assessment on three backgrounds, the results indicate that decreasing the lightness of background almost leads to a better agreement (lower PF/3 value) between visual assessment and instrumentally measured color-difference using CIELAB color-difference formula.

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Analysis of Color Difference Depending on Fabric through Digital Media: Focusing on the Color in Blue Series

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ABSTRACT

This study deals with color difference between object color and color shown through digital media. Ultimate objective is to reduce the color difference between real object color and color shown through digital media. As the basis for the development of digital color correction theory, the aim of this study is to investigate correlation of the color difference on digital media screen with color elements. The samples are ranged blue hue series in fabric material according to received wisdom that blue is more different than red or green. . Digital media devices are LCD TV and computer monitor. The research have been divided into four steps: sample collecting, photographing, measurement and analysis.Resultingly, there is significant difference between object color and color shown through digital media. Result shows The more red-purple than green-blue is, the larger color difference is. the higher chroma is, the larger color difference is. In follow research, it is demanded to supplement material theory and widen the spectrum of the color, so that for development of correction method. This is further expected to be able to prevent the loss of the cost of the digital media industries.

1. INTRODUCTION

In accordance with the rapid development of IT technology, the business through digital media has been expanded. Moreover, this industry through digital media is expected to grow continually. It has resulted from a competitive price and increase of digital media device usage. The business through digital media includes home, on-line and mobile shopping. There are TV, computer, mobile phone and etc. as digital media. Specially, fashion product family is demanded to try on as being itself among many product transacted. Therefore, it is very important to correspond real object with object shown on digital media screen. As the part of correspondence process, this study will contribute to convey product color information clearly.

2. METHOD

As shown in Fig. 1, the research have been divided into four steps; at the 1st step, sample collecting: The fabric samples were collected in blue color and various materials. The second step is photographing the samples in D65 light booth as preparation for color measurement on digital media screen. The camera was set as standard mode. The third step is measurement: Object color and color shown through digital media were measured. LCD TV and LCD computer monitor were selected as digital media. The fourth step is analysis: Color difference is calculated based on CIE 1976 formula CIEDE. Although there is an advanced color difference equation as CIEDE2000, CIEDE was used as blue hue region was only used in this study. After that, color difference was analyzed by hue, lightness and chroma.

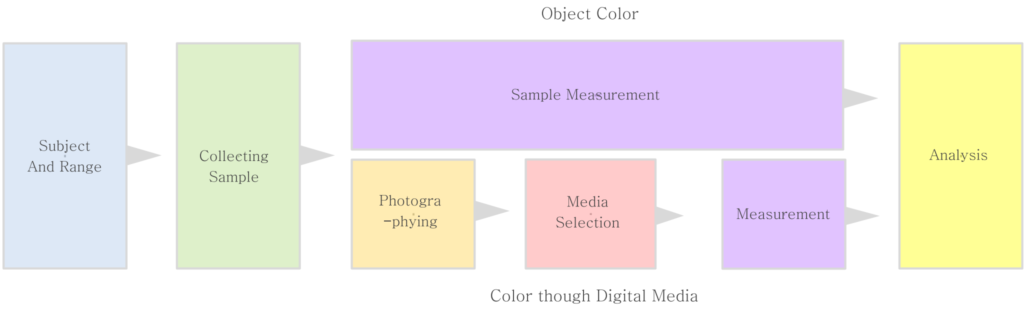

Figure 1: Flowchart illustrating the process of the study.

2.1 Sample Preparation

This is the first step in the sample preparation. The objects are ranged blue hue series in fabric material according to received wisdom that blue is more different than red or green. Samples are selected in various fabric materials. Table 1 shows $L^*a^*b^*$ and $L^*C^*h_{ab}$ data of 13 samples. This is measured in the width of the 2° field of view using by Color Eye 7000A.

Table 1. $L^*a^*b^*,C^*h$ *data of 13 samples.*

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13
L^*	31.5	30.4	27.4	22.7	21.2	26.8	26.9	22.7	27.7	24.5	25.2	28.6	22.5
a^*	5.1	7.31	7.92	-2.7	11.2	8.14	3.21	-5.7	7.4	-3.4	0.57	-1.3	5.05
b^*	-36	-35	-40	-17	-29	-28	-19	-17	-32	-16	-19	-19	-26
C^*	36.6	36	40.4	17.3	30.9	29.5	18.9	18.2	32.7	16	19.2	19.4	26.4
h	278	282	281	261	291	275	286	280	252	269	272	266	281

2.2 Photographing Setting and Apparatus

The second phase of the research experiment is photographing the samples in order to use during the third step, measurement. These pictures will use to measure shown color through digital media. Samples are set in the center of lighting booth sized 68 cm wide and 34 cm in height with D65 light source. The pictures are taken from the top of a 45-degree angle as shown in Fig.2. Canon 'DSC-HX200V' is used as photo-device with standard setting.

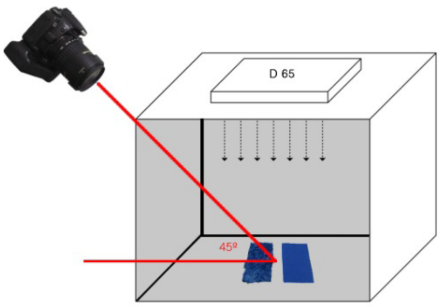

Figure 2: The experimental environment.

2.3 Measurement Setting and Apparatus

Environment and measurement apparatus corresponding to the third stage are as follows: Object color is measured with 2° field of view using the Color Eye 7000A. In the case of shown color through digital media, the photos are measured by a light meter taken earlier in step 2. This study was used to LG Electronics LCD computer monitor and Samsung Electronics 55" LCD TV for digital media. TV is set in standard mode. Computer monitor is set in resolution 1280×1024. The digital media was measured by spectroradiometer CA-210.

3. RESULTS AND DISCUSSION

As a result, when viewed through the digital media, the blue color is different with real object color. The volume of chrominance per digital media is not the same. However the result shows the ranking is almost the same except for the 10 samples as shown in Table 2. Therefore, it is expected that the characteristics of the samples affect the chrominance besides the characteristics of the media. There are color characteristics and characteristics of material in the characteristics of a sample. This study inquires into the relevance of the elements of color and color difference. So, the chrominance is analyzed by three elements of color.

Table 2. Ranking of Color Difference.

	Big					ΔE^*					Small		
TV Monitor	2	1	3	6	5	9	13	10	4	8	11	7	12
Com. Monitor	1	2	3	6	9	5	13	4	8	11	7	10	12

3.1 Hue Analysis

The aim of this section is to investigate correlation of the color difference on digital media with color element, hue. There is a slight difference between TV and LCD monitor, but the result show the same tendency. Overall, the bigger chrominance is, the more Red-purple than Green-blue in both of media devices.

3.2 Tone Analysis

The aim of this section is to investigate correlation of the chrominance on digital media with color element, chroma and lightness. Tone is sum of chroma and lightness. As a result, TV and LCD monitor show the same tendency except for a slight difference. Color difference between object color and shown through digital media seems to be larger, when the chroma of object color become bigger.

4. CONCLUSIONS

It was to this study as the basis for the development of digital color correction theory. Therefore, color difference between object color and shown color is analyzed depending on the hue, tone and material. The object is clothing fabric in blue color. Resultingly, there is color difference between object color and color shown through digital media. The color difference of each media was seen to be nearly the same rank, even though there is a difference of volume. This being so, it can be expected that any characteristics of the fabric affects color difference. It was a significant relationship between the chrominance and color elements. In the case of hue, the more RP from GB, the larger color difference is. In the case of tone, the higher chroma is, the larger chrominance is. In follow research, it is demanded to supplement material theory. Consequently, the more practical result is expected by sum of material theory and color elements.

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Which Delta E? A Review of the Options

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ABSTRACT

This paper is a review of the colour difference equations which have been developed to best suit industry requirements for the quality control of colour and appearance. Colour sells and companies spend considerable sums of money ensuring that the colour of the products which they produce and their corporate branding is consistently of a high quality. To control colour quality it needs to be measured and quantified and the preferred instrumental method to use is CIELAB $L^*a^*b^*$ colour space, published in 1976 and which was based on the work of many researchers including Adams, Hunter, Judd, MacAdam, Muller, Nickerson, Billmeyer and Saltzmann. Since the original CIELAB 1976 ΔE^* derived from the differences for $L^*a^*b^*$ a number of colour difference equations have been developed for example ΔE_{CMC}, ΔE_{2000} and $DIN_{6175\text{-}2}$. A number of delta E values based on three of these colour difference equations will be compared and discussed.

1. INTRODUCTION

In my activities of supplying spectrophotometers for the colour quality control of a diverse range of manufactured and natural products such as automotive parts, building products, cereals, foods, inks, paints, plastics and textiles, the big questions from users of these instruments are what tolerances should be set for PASS/FAIL requirements and which colour difference equation should be selected. A manufacturer does not want to use multiple equations. They need simple measurement protocols for quality control.

CIELAB has since 1976 been the three dimensional mathematical colour space used by industry for colour quality control. The CIELAB axes are L^* lightness, a^* the red-green opponent axis and b^* the yellow-blue opponent axis. I will be comparing the results of three colour difference equations for 48 sample sets. The equations are: i. CIELAB ΔE^* based on ΔL^*, Δa^* and Δb^* ii. ΔE_{CMC} based on ΔL^*, ΔC^* and ΔH^* and iii ΔE_{2000} based on $\Delta L'$, $\Delta C'$ and $\Delta H'$. The complexity of these equations increases significantly from the first to the latter.

2. METHOD

Two sets of colour samples were used: i. four colour tolerance sets produced by NCS Colour AB. Each comprised a reference sample plus six samples which were considered to be within the required visual tolerance and ii. twenty four colour pairs eight of which were pastel or whitish, eight highly chromatic and eight which were dark or blackish. These were also produced by NCS Colour AB. The sample sets are available for visual assessment.

A BYK Gardner spectro-guide sphere gloss with d/8° geometry, CIE illuminant D65 and a 10° observer was used to measure each of the samples. The results were recorded using CyberChrome OnColor Premium QC software.

3. RESULTS AND DISCUSSION

When considering which ΔE to use one must first consider the range of colours that are being produced. Are they mostly achromatic for example cereals and grains or highly chromatic such as plastic toys?

CIELAB ΔE^* values are significantly higher than those for ΔE_{CMC} and ΔE_{2000} for highly chromatic colours and this is illustrated with the results for the red and yellow tolerance sets. Whereas for tinted greys the reverse is the case where the results obtained for the latter two equations are weighted by the differences in hue. For the achromatic grey sets the three equations are essentially in agreement.

If we consider the spokes of a bicycle wheel, a 20° radial difference between two spokes at the rim of the wheel is clearly visible whereas close to the hub of the wheel the spokes become 'bunched up' and there is not good differentiation between them. The same applies to the hue angle in CIELAB colour space. For automobile interiors which are normally grey many manufacturers prefer to use CIELAB ΔE^* because of the influence of hue. In CIELAB hue is defined by the hue angle. A hue angle difference of 20° becomes increasingly more significant as a colour becomes more chromatic. Where as close to the achromatic 'hub' one gets similar bunching as with the spokes of the bicycle wheel and it is difficult to differentiate colour differences. The colour diference equations ΔE_{CMC} and ΔE_{2000} include hue difference.

BYK Gardner spectro-guide sphere gloss D65/10° ΔE_{CMC} *l:c 1:1* ΔE_{2000} *KL:KC:KH 1:1:1*								
NCS Notation	**L^***	**a^***	**b^***	**C^***	**h°**			
S 6000-N	**50.43**	**0.55**	**0.11**	**0.56**	**11.76**			
	ΔL^*	**Δa^***	**Δb^***	**ΔC^***	**ΔH^***	**ΔE^***	**ΔE^*_{CMC}**	**ΔE_{2000}**
5800-N	**1.83**	**-0.59**	**-0.16**	**-0.50**	**-0.35**	**1.92**	**1.90**	**2.02**
6200-N	**-1.72**	**-0.60**	**-0.06**	**-0.49**	**0.35**	**1.82**	**1.81**	**1.93**
6001-R	**-0.38**	**0.50**	**0.38**	**0.60**	**0.19**	**0.74**	**1.00**	**0.89**
6001-G	**-0.27**	**-1.21**	**0.43**	**0.30**	**1.25**	**1.31**	**1.93**	**1.87**
6001-B	**-0.44**	**-1.08**	**-1.02**	**0.49**	**-1.40**	**1.55**	**2.24**	**1.95**
6001-Y	**0.21**	**-0.82**	**1.45**	**1.02**	**1.31**	**1.67**	**2.48**	**1.87**
Name	**L^***	**a^***	**b^***	**C^***	**h°**			
Peach	**82.19**	**19.61**	**27.59**	**33.85**	**54.59**			
	ΔL^*	**Δa^***	**Δb^***	**ΔC^***	**ΔH^***	**ΔE^***	**ΔE^*_{CMC}**	**ΔE_{2000}**
Peach TL	**-0.22**	**0.01**	**1.10**	**0.90**	**0.62**	**1.12**	**0.92**	**0.61**
Peach TR	**-0.28**	**0.44**	**-0.48**	**-0.13**	**-0.64**	**0.71**	**0.85**	**0.53**
Peach R	**-0.18**	**0.85**	**-0.44**	**0.15**	**-0.95**	**0.98**	**1.23**	**0.74**
Peach BR	**-0.19**	**0.22**	**-0.72**	**-0.45**	**-0.60**	**0.78**	**0.82**	**0.51**
Peach BL	**-1.67**	**-0.40**	**-0.55**	**-0.68**	**0.01**	**1.80**	**1.25**	**1.17**
Peach L	**-0.15**	**-0.34**	**-0.17**	**-0.33**	**0.18**	**0.41**	**0.31**	**0.22**

Name	**L^***	**a^***	**b^***	**C^***	**h°**			
Matte Red	**39.65**	**40.71**	**20.89**	**45.76**	**27.16**			
	ΔL^*	**Δa^***	**Δb^***	**ΔC^***	**ΔH^***	**ΔE^***	**ΔE^*_{CMC}**	**ΔE_{2000}**
Max Chroma	**1.18**	**4.86**	**3.15**	**5.77**	**0.55**	**5.91**	**2.68**	**2.12**
Min Chroma	**0.60**	**-3.21**	**-2.04**	**-3.79**	**-0.37**	**3.85**	**1.68**	**1.40**
Max Red	**-0.48**	**0.06**	**-1.46**	**-0.60**	**-1.34**	**1.54**	**1.14**	**0.96**
Max Yellow	**1.57**	**1.44**	**2.46**	**2.43**	**1.49**	**3.26**	**2.21**	**1.85**
Max Black	**-1.48**	**-1.31**	**-0.55**	**-1.42**	**0.11**	**2.05**	**1.65**	**1.37**
Max W	**2.27**	**0.28**	**-0.08**	**0.21**	**-0.20**	**2.29**	**2.38**	**2.03**
Name	**L^***	**a^***	**b^***	**C^***	**h°**			
Yellow	**74.06**	**15.37**	**76.71**	**78.23**	**78.67**			
	ΔL^*	**Δa^***	**Δb^***	**ΔC^***	**ΔH^***	**ΔE^***	**ΔE^*_{CMC}**	**ΔE_{2000}**
Yellow TL	**0.64**	**-0.66**	**-0.77**	**-0.89**	**0.50**	**1.20**	**0.64**	**0.59**
Yellow TR	**2.26**	**0.57**	**4.97**	**4.99**	**0.40**	**5.49**	**2.37**	**1.98**
Yellow R	**-0.14**	**2.11**	**0.20**	**0.64**	**-2.02**	**2.12**	**1.27**	**1.21**
Yellow BR	**1.40**	**0.16**	**4.10**	**4.05**	**0.63**	**4.33**	**1.73**	**1.40**
Yellow BL	**-1.22**	**-0.17**	**-2.39**	**-2.38**	**-0.31**	**2.69**	**1.22**	**1.07**
Yellow L	**0.19**	**-1.84**	**1.48**	**1.11**	**2.08**	**2.37**	**1.34**	**1.27**

BYK Gardner spectro-guide sphere gloss D65/10° ΔE_{CMC} *l:c 1:1* ΔE_{2000} *KL:KC:KH 1:1:1*								
Pastel-Whitish	**ΔL^***	**Δa^***	**Δb^***	**ΔC^***	**ΔH^***	**ΔE^***	**ΔE^*_{CMC}**	**ΔE_{2000}**
A1	**0.16**	**0.02**	**0.03**	**0.03**	**-0.01**	**0.17**	**0.12**	**0.10**
A2	**1.69**	**-1.68**	**-0.12**	**-1.24**	**1.14**	**2.39**	**2.50**	**2.10**
A3	**0.45**	**0.44**	**1.14**	**-1.09**	**-0.56**	**1.30**	**1.36**	**1.10**
A4	**0.63**	**0.25**	**-0.94**	**-0.97**	**0.01**	**1.16**	**0.77**	**0.68**
B1	**0.31**	**-0.91**	**-1.41**	**-1.57**	**0.58**	**1.70**	**1.29**	**1.22**
B2	**0.21**	**0.30**	**-0.19**	**0.05**	**0.36**	**0.41**	**0.67**	**0.41**
B3	**-1.29**	**0.61**	**0.85**	**-0.92**	**0.49**	**1.66**	**1.51**	**1.37**
B4	**1.15**	**-0.24**	**-0.16**	**-0.06**	**0.29**	**1.18**	**0.83**	**0.77**
Chromatic	**ΔL^***	**Δa^***	**Δb^***	**ΔC^***	**ΔH^***	**ΔE^***	**ΔE^*_{CMC}**	**ΔE_{2000}**
A1	**0.06**	**-1.73**	**0.13**	**-0.19**	**1.73**	**1.74**	**1.25**	**1.18**
A2	**1.10**	**-1.61**	**0.02**	**-1.08**	**1.20**	**1.96**	**1.51**	**1.25**
A3	**-0.03**	**0.88**	**0.31**	**-0.81**	**0.46**	**0.93**	**0.50**	**0.45**
A4	**0.65**	**0.72**	**-1.30**	**-1.33**	**0.66**	**1.62**	**0.85**	**0.77**
B1	**-0.69**	**-1.80**	**-2.28**	**-2.36**	**1.69**	**2.98**	**1.50**	**1.41**
B2	**-0.07**	**-0.63**	**-0.09**	**-0.53**	**0.35**	**0.64**	**0.38**	**0.30**
B3	**-0.77**	**1.03**	**2.02**	**-2.26**	**0.20**	**2.39**	**1.25**	**1.16**
B4	**-0.51**	**2.15**	**-0.26**	**-2.16**	**0.07**	**2.22**	**1.04**	**0.91**
Dark-Blackish	**ΔL^***	**Δa^***	**Δb^***	**ΔC^***	**ΔH^***	**ΔE^***	**ΔE^*_{CMC}**	**ΔE_{2000}**

A1	**1.30**	**-0.89**	**-0.38**	**-0.45**	**0.86**	**1.62**	**1.48**	**1.48**
A2	**0.33**	**0.22**	**-0.05**	**0.08**	**-0.21**	**0.40**	**0.43**	**0.36**
A3	**0.99**	**0.37**	**1.31**	**-1.32**	**0.35**	**1.68**	**1.35**	**1.18**
A4	**1.28**	**0.52**	**-0.57**	**-0.68**	**0.37**	**1.50**	**1.43**	**1.19**
B1	**0.57**	**-0.74**	**-1.55**	**-1.70**	**0.24**	**1.81**	**1.02**	**0.92**
B2	**0.66**	**-1.45**	**-1.26**	**-1.82**	**0.63**	**2.03**	**1.33**	**1.12**
B3	**0.28**	**0.09**	**-0.31**	**0.32**	**0.00**	**0.43**	**0.36**	**0.27**
B4	**-0.16**	**-0.57**	**-0.20**	**0.52**	**0.30**	**0.62**	**0.39**	**0.36**

4. CONCLUSIONS

As a very general rule CIELAB ΔE^* is more appropriate for colours which have low chromaticity and either ΔE_{CMC} or ΔE_{2000} are more appropriate for highly chromatic colours. The C^* values for the Grey, Peach, Pastel -Whitish and Dark-Blackish sets are all below a value of 35. For these colours the difference between the three equations is mostly not large and the user has the option to select the one they feel to be the most suitable for their application.

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Course "Nordic Light and Colours" held at NTNU in April 2012

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ABSTRACT

This paper presents and discusses an intense six day PhD course held in 2012. One of its aims was to contribute to the formation of *colour and light* as a coherent field of knowledge. Both lecturers and participants represented a variety of professional and disciplinary approaches, and to create a common platform for fruitful interchange there was a pre-course reading task and test. The course included lectures, workshops, and an essay task. It gave a broad interdisciplinary understanding of colour and light and their spatial interaction, as well as a network for possible future collaboration.

1. INTRODUCTION

Our visual experience of space is formed in an interaction between light, colour and human perceptual ability. Even in a worldwide perspective there are, however, very few research projects or educational initiatives that investigate this interaction as a coherent field of knowledge (Fridell Anter 2013). In April 2012, a unique PhD course on light and colour was held at Norwegian University of Science and Technology (NTNU) in Trondheim, with funding from NordForsk and participants from four Nordic countries.

The PhD course was initiated from the large Nordic research project *SYN-TES.: Human colour and light synthesis: Towards a coherent field of knowledge* (www.konstfack.se/SYN-TES), which was carried out during 2010-2011 by an interdisciplinary group of researchers and practical light and colour experts from Nordic universities and companies. One of the aims of the project was to enhance collaboration and understanding between different professions and disciplines working with colour and light; education at the PhD-level is a very suitable arena for this.

2. GENERAL PRESENTATION OF THE COURSE

The course in Trondheim had a genuinely interdisciplinary approach, with as much emphasis on light as on colour and involving a diversity of approaches such as physics, architecture, perception psychology, performance art, lighting design and health and care sciences. Not only the lecturers but also the course participants represented a very broad competence. The course was open to PhD candidates at Nordic universities, with the demand that their thesis work should deal with light and/or colour. The seventeen participants were active in Norway, Sweden, Denmark and Finland and belonged to professions and disciplines such as civil engineering, art, architecture, nursing, design, environmental psychology, and architecture. This opened for many possibilities to learn from each other and to develop valuable professional connections for the future.

3. TO CREATE A COMMON PLATFORM

One of the aims of the course was to create the preconditions for interaction between people with different professional and academic perspectives, and the course was open for PhD candidates within any subject, as long as their thesis work dealt with colour and/or light. Thus the field and level of knowledge differed much between the participants. This created an initial challenge to establish a common platform of knowledge, from which lectures, workshops and group discussions could start.

We identified three important aspects of this knowledge platform: Firstly, a theoretical understanding of the fact that colour and light can be approached and studied from many different perspectives, and a recognition of the differences between them. Secondly, an understanding of the Natural Colour System (NCS), which was to be used as the language for descriptions and analyses of colour during the course (Hård et al. 1996). Lastly, an understanding of basic photometric concepts and terminology, which were necessary for understanding lectures and assignments.

To achieve this, all participants were asked to read a number of texts and had to pass a pre-course test before being admitted. The main text dealt with the three knowledge traditions of perception, physics and psychophysics, and the colour and light concepts belonging to these traditions (Fridell Anter 2012). The same words – for example the basic ones of *colour* and *light* – are used within all these traditions, but they do not refer to the same thing. These conceptual ambiguities had to be made clear, in order to make it possible to follow lectures and workshops and to facilitate communication between course participants from different knowledge traditions.

Once the course started, it became clear that the pre-course literature and test had not been enough to convey the basic understanding intended. The photometrical concepts gave the least difficulties, which was obviously due to the fact that practically all participants had already worked with light issues. NCS, on the other hand, was new to several participants and others had only used NCS samples and codes instrumentally without considering the system behind them. During the course it appeared that the introduction of NCS was not enough to give the understanding that would make it useful in workshops and discussions, and some extra time was allotted to explaining it.

We can conclude that to make the course optimally valuable for students with so different backgrounds, more time must be used for creating a common conceptual platform. This could be done before the course or as its first part, possibly with two special sessions: *light for colour people* and *colour for light people.*

4. LECTURES AND WORKSHOPS

The schedule of the six course days was very intense and included all meals, jointly for lecturers and participants. All participants and several of the lecturers stayed in Trondheim during the course. The typical day included two lectures in the morning and two workshops in the afternoon. The lectures covered the following themes:

Perception of light and colour. Prof. Arne Valberg (Biophysics, NTNU) presented what is known and what is still not known about the complex relationship between physical stimuli and visual perception. Assoc. prof. Ulf Klarén (SYN-TES group, Konstfack, Stockholm) demonstrated and discussed different levels of human perception and experience. Their joint conclusion was, that an understanding of human perception cannot be based solely on physical data.

Light and colour in Nordic countries. Prof. Barbara Matusiak (Light & Colour Group, NTNU) presented criteria for daylight evaluation and classification in general, and showed the specific visual character of northern daylight, such as low mean elevation angel of the Sun, low mean colour temperature of sunlight, high occurrence of cloud cover and the impact of snow and ice. Assoc. prof. Karin Fridell Anter (SYN-TES group, Konstfack) presented the typical colour scales of vegetation and ground in mid-Sweden and the exterior colour tradition of Swedish buildings, and discussed this in relationship to other Nordic countries. Prof. Alex Booker (Light & Colour Group, NTNU) showed his art exhibition *Trondheim Derivé* with photos and prints exploring the visual character of Trondheim. All this gave starting points for reflective viewing and consideration of the light and colours that form the outdoor environment that surrounds us and has formed our set of references.

Spatial interaction of light and colour. Prof. Monica Billger (Architecture, Chalmers, Gothenburg) showed, among other things, how colours in a room influence each other through induction and interreflection. PhD Cecilia Häggström (Lighting Design, Jönköping University) demonstrated how our perception of form and space affects and is affected by our perception of colour and light. Assoc. professor Karin S*øndergaard* (Lighting lab, Royal Danish Academy of Fine Arts) showed how light can create spatial zones that relate to our body, feelings and behaviour. All this supported an understanding that the perceptual and experienced aspects of colour and light could not be analysed in a meaningful way without considering the spatial context.

Light, health and well-being. The non-visual aspects of light are essential for our health and diurnal rhythm. In the course program this topic was presented by Assoc. professor Thorbjörn Laike (Environmental psychology, Lund University). Assoc. prof. Helle Wijk (Health and care sciences, Gothenburg University) presented research an applications showing how colour and light can function as a support for visually and/or cognitively impaired persons. This gave a further understanding that light and colour should be seen as fundamental aspects of architecture and interior design.

Daylighting and electric light. Prof. Jan Ejhed (KTH Lighting lab, Stockholm) presented different possibilities to use artificial light and Prof. John Mardaljevic (Building Daylight Modelling, Loughborough University) demonstrated methods for adequate prediction of daylight effects in buildings. This emphasised the importance of adequate technical knowledge in the process of lighting planning, and showed both advantages and limitations inherent in the digital methods aimed to favour this process.

Most of the workshops were based on the themes of the lectures and were held in the two well-equipped laboratories of the NTNU Light & Colour Group. The daylight laboratory is meant for model studies and has an artificial sky that provides diffuse light as from the sky and two artificial suns that provide parallel light radiation and can be set in the accurate angel for any geographical place, date and hour. The room laboratory has large windows in two directions, but can also be made dark. It is equipped with material for easy building of full scale spaces and a large number of different light sources. See www.ntnu.edu/bff/laboratories. Two workshops were held in the historic parts of Trondheim. The nominal and perceived colours of facades were assessed, using the methods of Fridell Anter (2000), and the light situation in the Nidaros cathedral was evaluated, using the PERCIFAL method developed within SYN-TES (Klarén 2013).

5. FINAL ESSAYS

The last part of the course was to write an essay, discussing a topic relevant for the person's own thesis work from the joint perspective of colour and light. These essays came to cover a wide variety of research questions such as a full scale study on the use of virtual environments to study daylight and colour, a survey on how the colour rendering properties of light sources have been presented to customers and an interview investigation on professionals' thoughts about light and colour in nursing home facilities. Some of the essays were published in a peer reviewed publication together with articles by some of the lecturers (Matusiak & Fridell Anter 2013).

6. CONCLUDING REMARKS

One important aim with the course was to contribute to the formation of *Colour and light* as a coherent field of knowledge. We can conclude that the interdisciplinary approach and the diverse backgrounds of participants and lecturers have favoured an interaction between fields of expertise and, more concretely, between people. All participants now have a broader understanding of issues concerning colour and light, and they have also got an interdisciplinary network for future work and collaboration.

When looking at the concrete realization of the course, we can conclude that it included too much of scheduled work and too few opportunities for the participants to share and discuss each other's work. Also, more time should have been allotted to free interaction in workshops, thus making better use of the available laboratories. This will be considered in the planning of the next course, which we hope to give in 2014.

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Teaching to Use Color in Design and Textile Engineering: Between Technique and Sensitivity

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ABSTRACT

How should color be taught to students of textile design and textile engineering? How should technical aspects and industrial requirements be combined with the non-transferable feeling that comes from color as pleasure and emotion? I will not attempt to solve these issues, but only expound my experience in teaching color included as a topic in design courses for textile engineering and in the Textile Design degree at university in the hope that rethinking about this matter will contribute to the discussion and to improving our educational proposal.

In this revision of the teaching methodology, the solution of three priority needs has been identified:

- to create a common communication space among designers, engineers, commercial agents, and users.
- to provide the tools related to the most technical characteristics of the topic, directly related to professional requirements.
- to guide the student to accomplish the transfer of theoretical knowledge to the actual development of a project.

Taking these three aspects into account, a product design exercise students usually do has been redesigned, whose objective is the use of dye as added value in textile design.

1. INTRODUCTION

Both in the Textile Design degree course and in Textile Engineering, students receive basic knowledge of the technical aspects concerning color to be applied in the professional performance of this discipline. Nevertheless, the difficulty in this respect is manifest and was, in fact, discussed in previous congresses (e.g. Vezzani 2011). This led to reconsider teaching approaches that deal with aspects regarding color related to the practice of textile design and to redesign an implementation exercise that would allow observing, reflecting upon and proposing an improvement of the teaching methodology of the chair and of the students' work. Its main objective is to solve a design project of a textile product or series of products, whose added value is the use of color through dyeing means. It takes into account various features, to include material, symbolic, commercial and productive, as well as the user's perception.

This exercise has been carried out several times within the framework of some research work on the use of natural colorants (Nirino 2010, 2011, 2012); however, the emphasis on the production of colorants and dying formulas has made the reflection on the use of color as a sign and its strong identity mark be pushed into the background in certain cases. Therefore, the intention has been to recover a space for reflection on the symbolic aspects of color, typical of the students' personal and national culture, partly lost owing to the commercial importance attributed to international trends and homogeneity that this produces in the color experience – an estrangement that interferes with the appropriation and incorporation of color as design value.

2. METHOD

The students were divided into seven groups, and each group was assigned a color: yellow, red, brown, green, blue, purple, and black. There was a theoretical class to review certain basic aspects about color theory (physical aspects) and textile dyeing. In this respect, we agree with the following statement:

> "not to overwhelm the students (…) by the complexity of the subject, and cram all the information (…) into the available number of hours, but to show them the beauty and the intellectual challenge of the subject." (Hirschler y Gay 2002)

In this regard, we can observe that an excess of information without a correlation between experience and information does not generate learning that can be incorporated and sustained over time.

2.1 First Stage

Objective: to create a corpus of materials associated to the assigned color.

Development:

2.1.1. Bibliographical research on aspects related to culture, symbols, and color materials. Preparation of reading cards of at least five texts considered relevant. Result: list of connotations and meanings ascribed to the color of reference in different cultures and periods.

2.1.2. Preparation of a color notebook. Images ranging from drawings, lyrics, sayings and proverbs (e.g. black list, black sheep) to literary texts and references to movies can be added to it. Result: personal diary containing color sensation.

2.1.3. List of words used for referring to the assigned color. The fact that color emerges from the intertwining of diverse disciplines and experiences is manifested in the existence of coexisting vocabularies (technical, artistic, commercial)—a problem of the study on color that has a longstanding tradition. We sought to denature the use of certain everyday terms. Result: at least two vocabularies that identify different usage areas and levels of language.

2.1.4. Stockpile of materials that either naturally or artificially are of the assigned color and that can be found in the environment and/or the local market. Result: archive of materials.

2.1.5. Survey of labels and packaging. Identification of groups of kinds of products and services associated with each color (e.g. black is used for high-end products; brown, for products that contain coffee). Result: list of most common uses and local associations.

2.1.6. Survey of natural dyeing materials. Exploration of the connection between color, texture, and materiality. Result: sampling of dyeing tests with different colorants, mordants, fixers, and bases.

2.1.7. Survey aimed at a mixed group of at least 20 people, distributed among three age groups. Require data: name, age, education, occupation. They should answer the following question: "If I say (color name), what comes to your mind?" Result: list of users' associations and perceptions.

2.1 Second Stage

Objective: to create a series of alternative proposals of products, starting from the correlation of different elements obtained in the first stage.

Creativity techniques that follow certain aspects of the work methodology of Design Thinking were applied (ascription to new meanings to the products, services or relations).

2.1.1. Generation of ideas. Inspired in IDEO method of the use of cards, an activity of association of concepts was carried out. Six sets of ten cards were used, grouped according to the following subject matters: association concepts (according to surveys), symbolism (according to bibliography), uses (according to surveys and surveys of products), dyeing materials, groups of users and application bases. Three groups of associations were performed at random and three associations chosen rationally, using in each case a card belonging to each list. In all, there were six groups of six cards each. For each association, there were three products, which turned out to be coherent regarding the interrelated aspects.

2.1.2. The 18 resulting products were evaluated according to the controlled convergence method or DATUM[1], using the following criteria: manufacturing feasibility, relation with the concepts associated to color, availability of material bases, and cost.

2.1.3. A survey conducted of 36 individuals of both sexes, three age groups, and a wide variety of occupations, using the six strongest resulting designs. Each respondent was requested to place six selected objects within an assessment scale, where 1 was the object with fewer possibilities of being the studied color, and 6, the one with greatest possibilities.

2.1.4. Implementation of a new comparative DATUM of the three designs with higher positive assessment, using the following assessment parameters: production time, cost of materials, consumption of material, distribution channels, complexity of implementation, suppliers of materials, available technologies, number of users, competition, and environmental aspects.

3. RESULTS

The students gave a presentation of the selected design, which included a folder containing all the stages of the process, a series of the product prototypes, the corresponging production index cards, materials, suppliers, and costs. The products are: underwear sets for black, “walls of light” for yellow, carpets for red, bathroom set for purple, recycled cloth for blue, set of bags for mate products for green, silk scarfs for brown. From the teachers’ point of view, the results were very satisfactory in terms of product coherence relative to the previous research work. From the students’ point of view, they assessed as very positive the experience of thinking the object in connection with color, instead of deciding the color as an already established object attribute. In this last modality, they consider more feasable the ascription of color according to preconcepts: “One may free oneself from the object, from the obligation of ascribing something to the object.” In general, they perceived the achievement of a more meaningful relation between color and object; furthermore, they valued it as a positive aspect, which made them think color, together with the areas and application modes, as a real added value.

4. CONCLUSIONS

With regard to the three aforementioned needs that have to be solved, firstly the sudents considered problematic the use of different vocabularies, which raised awareness regarding the necessity to interpret and convey the meanings of color, according to the communication context, with the purpose of achieving productive results closer to the objectives. Secondly, the need to increase the information about dyeing processes was identified, but not the one regarding the more general aspects of color theory. To conclude, the “appropriation” of a

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[1] Alternative selection method developed by Pugh, 1981.

color, particularly on behalf of the students, improved the understanding of symbolic aspects and, therefore, the transference of theoretical concepts towards practice.

Although it is understood that the exercise does not respond to the way the work on color is normally carried out in the industry, it turned out to be very positive in terms of commitment to the task and regarding the incorporation of learning of the communicative and symbolic aspects of color, considered as an important value linked to the object. Accordingly, it would be worth deepening the activity even further. With this aim in view, results should be evaluated more systematically. Besides, the resulting improvement should be verified to see if it also appears in the exercises linked directly to the work with cards, palettes, and color variants in the textile industry.

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LED Lighting for Educational Environment: Focusing on Math and Multimedia Based Tasks for 4th Grade Elementary School Students in South Korea

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ABSTRACT

This study investigates the effects that variations in illumination and color temperature have towards creating an optimal domestic educational environment. A field experiment was conducted with two groups of fourth graders, a control group (N=32) and an experimental group (N=35), that lasted for two weeks. In week 1, students evaluated learning conditions for math and multimedia sessions under fluorescent lighting (approx. 5000 K–500 lx). In week 2, the same experiment was repeated; however, the experimental group was exposed to four variations of lighting conditions using LEDs. Quantitative analyses on the students' math performance and surveys showed that 1) although both groups improved in math scores, the improvement was significantly higher for the experimental group, particularly under 6500 K–600 lx, and 2) students significantly preferred dimmed lighting conditions for multimedia-based learning. A supplementary long-term observation was conducted to confirm the two-week experiment results. However, the surveys for multimedia sessions showed inconsistencies from the two-week experiment, indicating a need for more extensive study. As such, the empirical findings of this research can be used as basis for further research in educational lighting development.

1. INTRODUCTION

Along with the advancements in technology and increasing demands for higher qualities of living, the role of light has been extended to the purpose of inducing emotional or aesthetic satisfaction (Lee, 2012). LED lightings in particular, can emit a greater assortment of colors compared to standard lighting. One of the main benefits of LED lighting is the ability to easily manipulate its color temperature and luminosity, giving users greater control over light settings. Thus, excessive efforts are being invested into utilizing this advantage and making it possible to create befitting lightings for specific user situations. For example, Philips Lighting has conducted a study to determine the proper lightings for schools in Germany (Wessolowski *et al.*, 2009). In this study, users' behaviors are investigated under variations of LED lighting to determine which lighting maximizes learning efficiency, thereby ascertaining the appropriate color temperature and luminosity for different subjects.

2. PRELIMINARY STUDY

The purpose of the preliminary study was to derive different types of learning scenarios that exists within the domestic educational environment. Surveys with educators and students as well as an ethnography study was conducted to collect information in regards to the classroom environment and students' learning capabilities. From the preliminary study, the level of concentration and the rate of concentration recurrence for learning different class subjects were determined. Based on these results, three types of learning activities were extracted; 1) 'watching multimedia contents' as the most frequent used teaching method, 2) 'math and problem solving' as the most representative form of high-concentrative studying, and 3) 'group discussion while facing colleagues' as the newest form of interactive teaching.

4. EXPERIMENTAL STUDY I (TWO-WEEK)

The main experimental study aimed to investigate the changes in the learning efficiency when the original fluorescent lightings (approx. 5000 K, 500 lx) are replaced with LEDs. The field study was conducted in two 4th grade classrooms in a Korean elementary school (Daejeon Daedok Elementary School), in which one classroom consisted of the control group (N=32) and the other consisted of the experimental group (N=35). During a period of two weeks, a total of six experiments were conducted, all in the morning time. In week 1, the experiment was conducted under fluorescent lighting for both classrooms. In week 2, the fluorescent lighting in the experimental group was replaced with LEDs.

4.1 Method

For this study, the two class scenarios from the preliminary study that involve the greatest amount of visual task, 'watching multimdeia' and 'math class', were selected for experimentation. In week 1, two lighting conditions were evaluated; one with the fluorescent lights turned on, and the other with the lights turned off. In week 2, the experiment from week 1 was repeated, ceteris paribus. However, the lighting in the experimental group classroom was replaced with LEDs and the experimental group was asked to perform their tasks under each of the four lighting conditions (3500 K – 300 lx, 5000 K – 600 lx, 5000 K – 1200 lx, 6500 K – 600 lx) as shown in Figure 1.

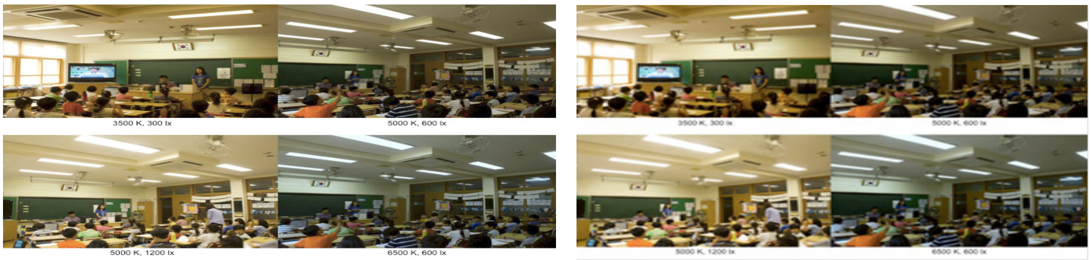

Figure 1: The classroom of experimental group lit with LED lighting.

To give validity to the evaluation results, both cognitive and subjective analysis methods were employed. For multimedia session, students completed surveys, subjectively evaluating levels of comprehension, attention and focus, comfort, and appropriateness of the lightings. For math, students solved arithmetic problem sets so that a cognitive assessment could be made by analyzing the number of correct answers. The problem sets were followed by the completion of surveys similar to that of the multimedia session.

4.2 Results

Statistical analysis of the means scores for the surveys and the arithmetic problem sets indicate that changes in lighting conditions affect the learning capabilities and emotional responses of the students (Table 1). A One-way ANOVA test was conducted to determine if there was a significant difference between the means scores of week 1 and week 2. The results indicated that for the experimental group, there were significant differences between mean scores for all of the five lighting conditions (including fluorescent lighting).

Moreover, for the experimental group, paired T-tests showed that there was a significant difference between the mean scores from week 1 and week 2 as well as between the mean scores of the arithmetic problem sets. The results indicated that when watching multimedia contents, LED lighting conditions of 3500K–300lx, 5000K–600lx, and 6500K–600lx are significantly more appropriate relative to fluorescent lighting ($p<0.05$). Paired T-test results for both the arithmetic survey and problem set scores confirmed that for math class 5000K–600lx and 6500K–600lx lightings are most appropriate. For the controlled group, there were no significant differences between the mean scores of the surveys. However, there was a significance difference in the mean scores for the arithmetic problems from week 1 to week 2. Still, this increase in mean score was relative less than that of the experimental group and can be seen as a result of a learning effect, in which students became accustomed to the problems and found them easier to solve over time. Particularly, when comparing the improvement rate of the math scores (lighting conditions of 6500K–600lx for the experimental group), the rate of increase in mean score for the experimental group was approximately 1.5 times higher than that of the controlled group.

Table 1. Mean scores of the survey results for multimedia and math, as well as the arithemetic problem set.

Group	Experimental Group					Controlled Group	
Week	Week 1	Week 2				Week 1	Week 2
Lighting	Fluorescent	3500K 300lx	5000K 600lx	5000K 1200lx	6500K 600lx	Fluorescent	Fluorescent
Multimedia Survey	3.99	4.24	4.19	3.95	4.21	3.64	3.69
Arithmetic Survey	3.85	4.03	4.17	4.01	4.21	3.52	3.52
Arithmetic Problem Solving (# of answers)	10.41	11.89	12.49	12.45	12.48	12.31	13.50

5. EXPERIMENTAL STUDY II (THREE-MONTH)

Due to the possibilities that the high preference for LED lightings over fluorescent lighting was a result of a “wow” effect in the relatively short time period (two weeks) of the main study, a supplementary long-term based observation was conducted. The study lasted for three months, with surveys being carried out by the experimental group every two weeks. During the experiment, students were exposed to a lighting condition and asked to engage in four class activities (watching multimedia, reading texts, reviewing textbook images, and facing colleagues). Upon finishing each activity, students completed a 5-point Likert scale survey to evaluate the appropriateness of the lighting condition for performing the given activity. A total of eight lighting conditions were evaluated (3500K–300lx, 3500K–600lx, 5000K–300lx, 5000K–600lx, 5000K–1200lx, 6500K–300lx, 6500K–600lx, OFF).

The results of the one-way ANOVA test indicated that there were significant differences between the mean survey scores of the different lighting conditions for each activity type ($p<0.05$). The significant differences were found for all four activities. Unfortunately, the results of the long-term experiment were inconsistent with that of the two-week experiment. Based on the final results, the most appropriate lighting for multimedia was 6500K–600lx. The most appropriate lighting for reading (both text and images) was 6500K–600lx, and 5000K–1200lx for group discussion.

6. DISCUSSION

To some disappointment, the evaluation results on the appropriate lighting conditions for multimedia-based classes were inconsistent in the two-week and the three-month experiments. This could have resulted due to the differences in evaluation methods. For the two-week experiment, where only lighting for multimedia and math were assessed, students engaged in each class activity for 3 minutes. However, in the three-month experiment, due to the increase in number of activities assessed to four activities, the time in which students engaged in each class activities was reduced to 20 seconds. This could have been too short of a period for students to truly recreate the learning situation and accurately evaluate the influence of the different lighting conditions on their visual task performance. Hence, further study with adjustments to the evaluation method is needed to accurately assess the long-term effects of LED lightings on students' learning capability.

7. CONCLUSIONS

This study investigates the effects that variations in illumination and color temperature have towards creating an optimal domestic educational environment. The experiment was conducted in actual domestic elementary school classrooms, where students were asked to evaluate the appropriateness of different lighting conditions (under both fluorescent and LED lightings) for various class activities, with particular focus on multimedia sessions and math. The experimental results showed statistical significance that students performed particularly well in math under 6500 K and 600 lx lighting, and that students preferred dimmed lighting conditions for multimedia-based learning. A supplementary long-term based observation was conducted to confirm the results of the two-week experiment. There were inconsistencies between the results from the two-week experiment and three-month experiment, most likely due to procedural error. However, the empirical findings of this research can be used as basis for further research in educational lighting development.

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Color in Educational Thought of Rudolf Steiner, Maria Montessori and Josephine Pizzigoni

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ABSTRACT

This paper aims to explore the theme of color in the thought of three distinguished scholars: Rudolf Steiner (1861-1925), Maria Montessori (1870-1952) and Josephine Pizzigoni (1870-1947). They were all united by a passionate interest in pedagogical issues which led each of them to create special schools where they directly implemented their teaching methods. These figures were chosen due to their diversity of approaches to the theme of color. For Rudolf Steiner (Steiner R., 1919, 1970), color was a key element which permeated his whole thought. Maria Montessori (M. Montessori, 1909, 1935, 1951) made it into a concrete component of her materials, while for Josephine Pizzigoni (Pizzigoni G. 1914, 1922, 1931) it became a precise corollary of the school building and furnishings. In each of their **approaches/methods**, color takes on different roles, leading to specific educational activities (J. Dewey 1949, 1951, 1995) which highlight the great potential that this aspect can and must have within the different schools of pedagogical thought and education. The paper concludes with a series of **interviews** on the theme of color with teachers who currently work in schools based on the thought of these three authors, to see whether the original premises are still current or which ones have been changed and why.

1. INTRODUCTION

Colour is a key element of children's lives: a vast amount of research, including much contemporary work, has found that infants are attracted by colour and the potential it offers right from the earliest months of life (Franklin, Pilling and Davies, 2005; Read and Upington 2009; Schulof 1979; Zemach and Teller 2007). However school curricula have often overlooked this interest on the part of children, relegating work on colour to art classes or treating colour primarily in terms of the objective interpretation of the real world (Zuccoli 2012). In this paper, I explore whether past educationalists of the calibre of Rudolf Steiner (1861-1925), Maria Montessori (1870-1952) and Josephine Pizzigoni (1870-1947) dealt with the theme of colour, and if so, how it fitted into their educational models. I chose these three scholars on the basis that they all, as well as developing their own influential and distinctive educational theories, implemented their ideas in real schools, with children and teachers who followed - and follow - specific guidelines within a framework of meaning. All three of them founded methods that are still today practised by children, teachers and parents. Their thinking has been operationalized in terms of concrete buildings, spaces, furnishings and teaching equipment, as well as in the design of educational programmes; and colour has played a key part in all of this. How therefore did each of these educationalists view colour? In what specific contexts did they promote its use? Currently do the schools that apply these methods still follow their founders' original guidelines regarding colour? These are the questions addressed in the following pages.

2. METHOD

First, the key writings of each educationalist were reviewed for references to the theme of colour: in relation to teaching equipment, teaching curriculum and school furnishings. On the basis of this preliminary investigation, current practice was then explored via the accounts of teachers working in schools applying these methods, in order to determine whether colour continues to be treated as recommended by the founders, or whether the original approach has been modified and, if so, how. Finally, interviews were conducted with a sample of 55 undergraduate students on the degree course in Primary Education to verify whether they were familiar with the approaches to colour of Montessori, Pizzigoni and Steiner, respectively.

3. RUDOLF STEINER: COLOUR AS A VITAL ELEMENT

Before discussing the theme of colour as applied in Steiner schools it is necessary to acknowledge that to speak of Rudolf Steiner (1861-1925) in relation to a single domain always implies the risk of providing too narrow a picture of his work and of failing to reflect the various components of his life's work. Having said this, a first observation in relation to colour is that: "in Steiner education, the teaching of the figurative arts plays a central and dominant role from the first through twelfth grades [..]" (Jünemann, Weitmann 1981: 9). And in this context, colour becomes a space for in-depth exploration of many aspects of human existence. Steiner recommends introducing children to colour at a very young age: “You must not be afraid to take out a box of colours and a glass of water; on the contrary it is a very good thing to do with children as early as possible.” (Steiner 1970: 58), and in relation to the first grade suggests “[...] placing the colours next to one another so that the children can feel what it means to put red next to green, yellow next to red and so on.” (Steiner 1980:154) There is a clear link between his thinking and Goethe’s theory (Goethe 2008), which Steiner had studied in depth and which suggests that teachers use colours for didactic purposes: “On what is the teaching method aspect of Goethe’s colour theory based? On the fact that Goethe attributes each individual colour with an undertone of feeling” (Steiner 1970: 41). In this context, Steiner again encourages teachers to bring their pupils into contact with colour from an early stage: “it should be endeavoured to arouse those feelings in the child that can only be born of a scientific-spiritual understanding of the world of colours” (Steiner 1970, 41) and to emulate his own work in the dome at Dornach by aiming to achieve “a living relationship with colour” (Steiner 1970, 41). A distinctive characteristic of the Steiner method is the clear separation between formal drawing and painting lessons, with the latter based on the use of water colours (Jünemann, Weitmann 1981: 13). The play of transparencies involved in the watercolour technique is linked to the soul quality of the world and human life, becoming a medium for the expression of inner emotions or emotions picked up from the context, while also bringing children into direct contact with the essence of colour. “This soul quality of colour is enhanced by the transparency of watercolour”(Jünemann, Weitmann 1981: 14). Other materials considered valuable for learning purposes include wax or oil crayons, although the latter are used differently to watercolours. Steiner refers to Goethe’s theory in very specific terms, recommending that each colour be explored and experienced in line with the “sensual-moral action of colours” (Goethe 2008:189). However this is not just a question of trying out techniques and operational methods: above all it involves experiencing colour: “Each of the children’s painting compositions must be born of the ability to live with colour and similarly the teacher must have acquired this ability before embarking on painting with the children” (Jünemann, Weitmann 1981:34). The typical painting session in most Steiner classrooms is conducted from this educational perspective. In sum, Steiner considered colour to be of the utmost importance and linked to the growth of every human being; specifically he viewed it as a means of entering into contact with the world and its spirituality – and therefore something that needs to be constantly cultivated in every child.

4. MARIA MONTESSORI: COLOUR IN CONCRETE EDUCATIONAL OFFERINGS

The perspective developed by Maria Montessori (1870-1952), which places strong emphasis on providing specific materials to foster children’s ability to act in a more independent and purposeful manner (Foschi 2012), also has a specific focus on colour, understood as one of the peculiar physical properties of the objects encountered by the child. “The sensory material is composed of a system of objects, grouped as a function of a particular physical characteristic – such as colour, shape, size, sound, roughness, weight, temperature, etc. [...] Each group represents the same quality but in different degrees [...].” (Montessori 1969: 111) This aspect of the importance of materials, including colour, is referred to in many of Montessori’s works. (Montessori 1909; 1969; 2000; 1962: 181). Furnishings are another focus for her, in which colour may play an additional role, in terms of helping the children to assess if they have made appropriate moves: this requires a certain degree of mastery, (Montessori 1969: 114). Both the objects the children work with, that is to say, the sensory material, and the furnishings used to enrich the classrooms and other contexts frequented by the child, should always be aesthetically appealing; Montessori views “colourful, shiny and harmonious forms” (Montessori 1969: 114) as playing a vital role in attracting children’s attention. The use of materials structured in this way allows the teacher to use relatively few words, given that the equipment is designed to allow children discover their own errors, and thus to understand and modify their actions as appropriate. Another aspect in which Montessori sees colour as playing a role is learning representational drawing: she does not attribute any value to children’s early attempts to draw, terming them “ those horrendous scribbles” (Montessori 2000: 500-501) – children must therefore be introduced to drawing by the teacher and colour is one of the key aspects to be learnt about. Many of activities conducted at her House of Children involved colouring games and exercises promoting the ability to recognize, differentiate between and name colours (Esercizi del senso cromatico: Montessori 1909: 195-198). She subsequently also invited her children to experiment with watercolours, crayons, coloured paper, using an “indirect method” that did not involve formal drawing lessons but constant practice (Montessori 1969: 305-306). In Montessori’s perspective, structured drawing activities also contribute to the development of manual skills and therefore prepare for writing (Montessori 2000: 550-552). Drawing thus acts as an alternative means of communication that often loses its appeal when children become more confident at writing. Finally, Montessori also viewed drawing as a medical research instrument for use with younger children in particular, in order to detect certain disorders or difficulties at an early age, and for implementing visual discrimination exercises and developing visual observational skills (Montessori 2000: 651). In sum, we may say that for Montessori colour was a key dimension of sensory and teaching materials, learning environments and their design, visual discrimination exercises and basic art education.

5. GIUSEPPINA PIZZIGONI: COLOUR IN THE OBSERVATION OF NATURE AND IN DESIGNING LEARNING ENVIRONMENTS

The last educationalist that we will discuss is Giuseppina Pizzigoni (1870-1947), well-known only within Italian educational science circles, whose work is associated with the school she founded in Milan that implements her method: the Renewed [Rinnovata] School inaugurated on 30 October 1927. For her, as for Montessori, the design of the learning environment is of vital importance, to the extent that she engaged engineers and architects to help her plan the whole school, including the outdoor areas. In her perspective, the school should be an aesthetically attractive space, in which each element dialogues with the others in a harmonic quest, and in which colour (the colour of the roofs, the walls, flower and vegetable gardens) is a key element. "Indeed the school as seen from the outside is beautiful: beautiful in its architectural design, its murals, its buildings laid out between the green of the fields, the pitches, the flowerbeds and the gazebos; beautiful in the decoration of its bright corridors and its classrooms. [...] But I was not just concerned with the architectural design and the decoration of the rooms: my major focus was on the right of the child to experience joy; and given that every form of beauty makes man experience joy, I felt that it was every child's right to receive an aesthetic education." (Pizzigoni 1971:87-88). Use of the chosen colour is carefully planned for both inside and outside spaces, becoming an objective reality to be experienced by the children on an ongoing basis. As well as the colour "experience" that children have by simply being inside the school building or outside in the school grounds, Pizzigoni suggests a series of drawing activities and exercises, discussed in her writings and illustrated by spontaneous drawings, produced by or copied from the children, for which nature is the main inspiration, along with experimentation with alternative techniques (Pizzigoni 1971:167-174). However, the distinctive trait of this educationalist, which underpins all her work, is having introduced gardening and contact with animals into her school. Colour plays a different role here: the children have the opportunity to recognize the thousands of colours to be found in nature, experiencing them daily, and to observe the thousands of transformations brought about by the seasons, climate change and anthropic factors: this provides them with another means of entering into contact with and manipulating colour, without discussing it in the abstract (Pizzigoni 1940, 1956). In sum, the small number of written works left to us by Pizzigoni, who as a priority devoted her time to the running of her school and the dissemination of her method (Cassottana 1988), imply that colour was a key element in her vision of how schools should by buitlt in terms of internal and external appearance and design; nonetheless, the key characteristic of her method is contact with nature and science education, in which colour becomes a key element within observation, learning and experimentation.

6. AND NOW? INTERVIEWS WITH TRAINEE TEACHERS AND IN-SERVICE TEACHERS AT THE SCHOOLS IMPLEMENTING THE METHODS

Having briefly examined the thinking of our three educationalists in relation to colour, we collected some accounts – certainly not exhaustive – regarding colour as it features today in the schools applying these methods, in terms of how it is used and considered by the teachers. For example, I asked whether the original guidelines of the founders had remained unchanged or whether they had been modified, for example to include new teaching methods developed over the years. The teachers interviewed all lived in Milan and worked in three different types of school. From the results of the questionnaires and the interviews, it emerged that the majority of teachers still believe the founders' guidelines to be relevant, and apply them to their own work. Many of them are also informed by additional novel experiences implemented in museums or other schools. In other words, the school system has been further enriched by recent didactic experiments on the theme of color (Atelier Raggio di Luce, Reggio Children 2006-2001; Bertagna G. Bottoli A. 2009;Burke C. 2007; Holme A. M. 2007; Read M. A. -Upington D. 2009; Riedel I. 2005); it is also clear that careful design of the school environment is still a fundamental element of teaching practice. In order to obtain an even more detailed picture, I asked 55 undergraduate Primary Education students if they were aware of any particular proposals or particular way of using colour on the part of the three pedagogists, requesting them to provide examnples in support of their answers. Maria Montessori was found to be the educationalist best remembered for her use of colour in structured materials and furnishings, cited by 55%, while Steiner was mentioned by 16% in relation to drawings and wall posters. Finally, 5% remembered Giuseppina Pizzigoni but were unable to supply a specific example of her use of colour.

7. CONCLUSIONS

In conclusion, this quick overview of the thinking of Rudolf Steiner, Maria Montessori, and Josephine Pizzigoni suggests that a key aspect shared by all three educationalists is the targeted design of the spaces and the materials encountered by children, in which color plays a particularly meaningful part. However, each of them developed this theme in a specific and original way. Rudolf Steiner was the educationalist who most anchored his teaching action to multiple specific aspects of colour. He viewed colour as a constant and also as a means of exploring the world and discovering its most secret aspects, presenting it as such to the children in his schools. For Montessori on the other hand, the potential of colour is played out in the context of sensory material, furnishings and visual discrimination. For Pizzigoni too, the environment and its colours play a key role, but contact with nature is an additional vital element, thanks to which colour may be discovered, experimented with and practiced. Many of the guidelines of the three founders are still applied today, although the schools implementing their methods are also informed by more recent experimentation in the field. Finally, the survey conducted with undergraduate students and future teachers at Milano-Bicocca University, revealed a low level of awareness regarding the relationship with colour of our three scholars.

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The Creation of an Artwork with Simultaneous Contrast

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ABSTRACT

The project described in this paper aims to illustrate the phenomenon of simultaneous contrast through a piece of artwork. The artwork is created with painted gomito pasta and Canson paper of different colours to exemplify the perception of small image elements (pixels) on different coloured backgrounds. Two colours, side by side, interact with one another and change our perception of the colours accordingly. The effect of this interaction is generally called simultaneous contrast. The colours in terms of physics and colorimetry are not altered; only human perception of them changes. Furthermore, the artwork also displays other phenomena; variations of simultaneous contrast, such as colour induction and colour assimilation. In real life, the colours we perceive generally do not remain the same when the background and viewing geometry changes, the proposed artwork provides a thought-provoking illustration of this to fact to the viewer.

1. INTRODUCTION

The human eye perceives colours from the spectrum of the light reflected, emitted or transmitted on or through the surface of an object. The mechanism of how colours are perceived has long been researched by scientists, and the physical colours as well as the perception of them are quantified and measured in many ways. The appearance of colours perceived by the human is a combination of various factors and conditions (Fairchild 2005). Different colour appearance phenomena have been introduced; examples include the Hunt Effect, where the colourfulness or the chroma of a constant chromatic colour appears to increase when the luminance is increased (Ohta and Robertson 1997; Fairchild 2005); the Helson-Judd Effect which occurs when a constant monochromatic colour, aka grey scale is illuminated by a coloured light resulting in the hue of the illuminant taken by the light grey, whilst the complementary colour is taken by the dark grey (ibid); and the Crispening Effect that refers to the different lightness perceptions of the scaled patches produced by the changing background (Logvinenko 2002).

Throughout the history of art, explicit or implicit knowledge of colour appearance phenomena has been used by artists to create their desired appearances and effects. For instance Georges de La Tour (1593-1652) used frequently the technique of light/dark contrast (chiaroscuro) to amplify the contrast between bright reddish colours of objects in the foreground and dark neutral colours in the background. Furthermore Jean-Baptiste Camille Corot (1796-1875), the French pre-impressionist, relied on the Bezold-Brücke and chromatic adaptation effects to transcribe the progressive reddishness of the evening light on the bricks of his "Le Forum, vu du Jardin Farnèse" (Hardeberg *et al.* 2004).

The artwork presented in this paper concentrates on exemplifying the simultaneous contrast and is inspired by the style of Andy Warhol's artworks, particularly his pop art painting "Marilyn Monroe". However, the related colour appearance phenomena such as colour assimilation and colour induction are also visible in the artwork.

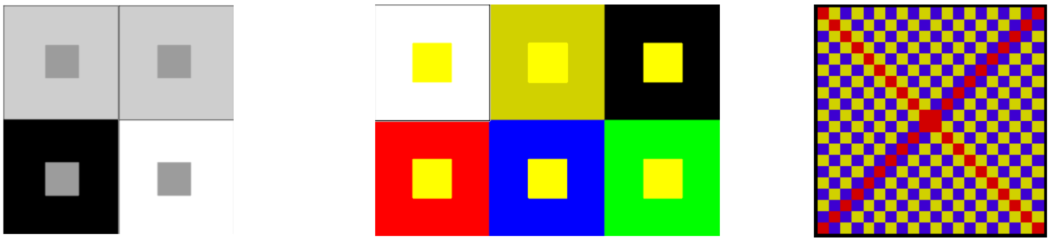
2. METHOD

Simultaneous contrast is one of the properties of human vision, it occurs when the brightness or the colour of a test stimulus is influenced by that of its background. Usually, if the presented test stimuli are surrounded by a dark background they would appear brighter than when they are presented on a lighter background.

2.1 The theory behind simultaneous contrast

This phenomenon can be explained by lateral inhibition (or lateral interaction). When we look at a lighter background, the photoreceptors on our retina are illuminated to a greater degree. The illumination causes greater stimulation of the relevant photoreceptors. Subsequently, it produces a larger level of lateral inhibition. A darker background results in less illumination to the retinal photoreceptors, thus a smaller amount of inhibition is sent to the photoreceptors corresponding to the spot on the right. Therefore, the brightness of the spot we perceived as being usually lighter than its actual brightness.

On the other hand, chromatic (colour) induction is changed from chromatic contrast (aka colour induction) to assimilation at a certain level in terms of simple square wave patterns (Bodkin 2008). Colour induction occurs when two or more colours are perceived at the same time, the appearances will be influenced. In Figure 1(a) and Figure 1(b), the identical patches in the centre appear to have different colours under the influences of surroundings with different colours. Figure 1(c) shows the colour assimilation effect. The red tiny squares from the check board are identical, whilst they are perceived very different because of the colours of the immediately surrounding squares. They are variations of simultaneous contrast. The artwork in this paper therefore is based on the simultaneous contrast with its varied phenomena of chromatic induction and assimilation.



(a) Colour Induction – monochromatic *(b) Colour Induction – chromatic* *(c) Colour assimilation*

Figure 1 Colour Induction and Assimilation
(Source: http://www.colourcube.com and Kaiser 2013)

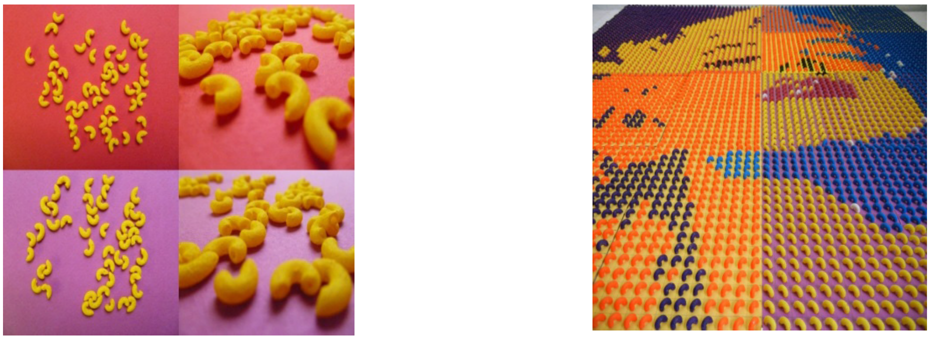
2.2 Selection of materials

The selection of the specific gomito pasta is based on the fact that each piece is small enough to be considered as a pixel when arranged systematically in a frame with limited size. According to the colour phenomena mentioned above, one same colour can produce different colour sensations under different surroundings; the initial intent for the choices of the colours therefore was inspired to achieve the same colour perception with particular spatial arrangements.

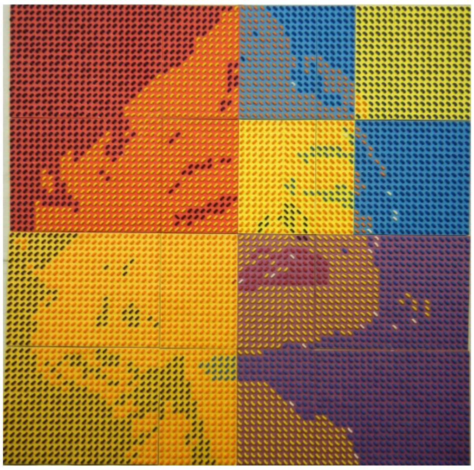
2.3 Simulation and implementation

In order to achieve the desired effect, a computational simulation was conducted before commencing the actual artwork. After numerous trials on the colours, it was considered that yellow hue could produce visible colour variations and pleasant colour perceptions when it was seen on different backgrounds as shown in Figure 2(a). In order to achieve aesthetic as well as to display maximum simultaneous contrast phenomenon, yellow was eventually considered as the principal hue for the main part of the artwork (Marilyn Monroe's face and hair). It was observed that yellow and orange colours could produce almost the same colour perception if the available red and dark-yellow Canson paper were considered as their backgrounds respectively. Therefore, the combination of yellow pasta and red paper as well as orange pasta and dark-yellow paper is arranged for the face and hair in the top left and bottom left regions. Based on the same principle and available materials, the blue and purple hues are selected for the border of the artwork (the background of the portrait).

The painted pasta were arranged accordingly so that the central horizontal band of the pasta elements covering the 50% of the vertical height is mirrored along a vertical line of symmetry that passes through the centre of Marilyn's nose. The remaining top and bottom bands have a line of symmetry running through the middle of the frame as seen in Figure 2(b). The combination of asymmetric and symmetric arrangements of the painted pasta on different backgrounds produces a 3D illusion and further colour sensations when the point of view is changed.



(a) Before *(b) After*



(c) Final work

Figure 2 Stages of development of the artwork
"When Andy meets CIMET" © Ailin Chen, 2012

3. RESULTS AND DISCUSSION

Figure 2(a) displays the materials used before the commencement of the artwork. It is observable that the colour of yellow pasta appears brighter with purple background (bottom) than that of the pasta with red background (top), which illustrates the simultaneous contrast. The corresponding pasta elements and Canson paper from Figure 2(a) can be found in the 2nd and 4th quadrants of Figure 2(b) and Figure 2(c), which are two exemplary angles of the final work.

It is visible from Figure 2(c) that the same purple pasta appears darker on the background of dark yellow paper in the 3rd quadrant than red paper in the 2nd quadrant. The yellow colours in 2nd and 4th quadrants and the orange colours in 1st and 3rd quadrants perceived in Figure 2(b) are clearly distinct colours. Nevertheless they appear to be almost the same colour in Figure 2(c). The overall view of the final work in Figure 2(b) and Figure 2(c) exhibits the phenomena of simultaneous contrast, colour induction and assimilation according to the explanation described in Section 2.1.

4. CONCLUSIONS

The interaction of colour elements side by side exemplifies the phenomena of simultaneous contrast, colour induction and assimilation, and changes the colour perception. The results of the presented artwork exhibit that the colours we perceive can be altered when the background and viewing geometry change.

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The Development of Web-based Training on Color Perception for Industrial Production in Thailand

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ABSTRACT

Knowledge of color perception and color measurement are important for variety of industries. Moreover, Specialist in color perception and color measurement are limited resource when comparing with trainee membership. But normal training program always fact of the problems such as training cost or employee can not repeat the training lesson because of training with limited time. So Web-Based Training (WBT) of color p and color measurement for industrial will be fulfill knowledge for employees, reduce training cost, flexible learning, self-learning and support lifelong learning.

The purposes of this study were: 1) compare learning achievement of trainees between pre-test and post-test. 2) evaluate efficiency of Web-Based Training. The sample consisted of randomly sampling 30 of RMUTT students. Trained by using Web-Based Training on Color perception for Industrial. The results of study indicated that 1) Web-Based Training on Color Perception for Industrial had the efficiency on criteria of 80.15/82.43 2) The post-test training achievement of teachers was significantly higher than the pre-test learning achievement at the .05 level.

The conclusion was WBT of color perception and color measurement for industrial was a successful training program. So it could be used for an efficiency training to increase the capability of the trainees.

1. INTRODUCTION

Knowledge of color perception and color measurement are important for variety of industries such as food industry, printing and plastic. Companies always have a training program to share new knowledge with employees to be more efficiency at work. Training is a management process to get a personal learning skill for development efficiency. To develop the capacity and performance of the employees within an organization. To enhance an experience throughout working life. But normal training program always fact of the problems such as training cost or employee can not repeat the training lesson because of training with limited time. So employees efficiency of is not supported with the lesson objectives. Moreover, Special employees in color perception and color measurement are limited resource when comparing with trainee membership with several days of training. The long-term training has an effect on normal working days. Place and time limitations are also made the employees in organization cannot training at the same time so the company will pay more for training. Web-based training is a form of distance learning that uses the World Wide Web to deliver computer-based instruction (Blotzer 2000). WBT can study from everywhere and every time by using internet and intranet with multimedia such as text, pictogram, animation, video streaming, sound. WBT will be influenced by other standards and design strategies that will improve learning quality for a broader audience (Kibly 2001). WBT enables businesses to cut their training costs. Efficiency of operation is another major advantage of WBT. The flexibility of time, place, and programs offered via WBT appeals to learners who must balance school with work and home responsibilities (Taher 2003). So WBT of color perception and color measurement for industrial will be fulfill knowledge for employees, reduce training cost, flexible learning, self-learning and support lifelong learning.

2. METHOD

This research is an experimental research by using One Group of pre- and Post- Design Testing. It is a with a group that is selected by randomly sampling with pre- and post-test. A research design is : (Table1)

Table1. A research Design

Group	Pre-test	Experiment	Post-test
E	T_1	X	T_2

Symbols in this experiment are:

E = Experimental group
T_1 = Pre-testing
X = Training by using website
T_2 = Post-testing

The experimental Methods:

1. Set a group of 30 is selected by random, 4th years RMUTT students
2. Researcher studies documents, books, related research of instruction, theory of instruction, related information of training, analyze the story and objective setting.
3. After design WBT with interaction with user data and feedback.
4. Sending this research to an expert inspection.
5. Using WBT with demonstrate people, a group of 6 who have never studied this lesson before. Then, finding the efficiency of E1/E2 for improvement.
6. Using WBT with a group of 30 is selected by random and analyzing the result to find an efficiency of WBT by E1/E2 with 80/80 of criteria.

3. RESULTS AND DISCUSSION

Researcher presents data analysis of WBT and steps of research process are:

Part 1: from a result of efficiency, WBT of color perception and color measurement in Thailand industrial (Table 2)

Table 2 shows the score between during and post-testing,
The result after finding the efficiency from WBT.

Score	Score during training (E_1)	Score post-training (E_2)	Effectiveness E_1/E_2
Score Average	16.03	24.73	
Percentage	80.15	82.43	80.15/82.43

After finding the efficiency of Web-based training, an average point during training was 16.03 and post- training was 24.73. The average point during training was 80.15% and post-training was 82.43% so the efficiency of WBT was 80.15/82.43

Part 2: is the result after comparing between pre - and post- testing (Table 3).

Table 3 shows the score between pre- and post-testing.

Trainees	N	$\bar{x}$	S.D.	t
Pre-test	30	8.43	3.63	
Post-test	30	23.90	2.96	-28.54

The post-test training achievement of teachers was significantly higher than the pre-test learning achievement at the .05 level.

4. CONCLUSIONS

After finding the efficiency of WBT, color and color measurement found the average point during training was 80.15% and post- training was 82.43% so the efficiency of WBT was 80.15/82.43 of 80/80 of setting criteria. Data analysis shows that trainees understand this lesson.

The result after comparing points of pre- and post-test showed that it was difference .05 in statistics because before training, trainees do not have any knowledge of color perception and color measurement but after they got WTB knowledge. So it can be used for an efficiency training to increase the capability of the trainees.

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Envision Design Thinking Process through Color Theory

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ABSTRACT

Graphic designers, like all designers, are dedicated in the thinking process until the very last moment of final production. During the design process, designers engage in brainstorming, researching, analyzing, and applying imaginative skills, using their logic and critical skills to create ideas. However, the process can be peculiar to distinct designers, which will lead to totally varied results. So, does that mean design thinking is random and unpredictable? Can we actually record the process and visualize it? If we could, would it be clearer for us to view the relationships between ideas and lead us to a better result?

Through the exploration of reverse/correlative thinking, and Yin Yang philosophy, I found it possible to relate the color theoretical components that could contribute to the design thinking process. Color theory is a perfect model for generating new visual structures and building relationships in the thinking process. This paper will focus on analyzing Yin & Yang and color theories that can contribute to building a diagram, which may provide a new way of viewing design problems within a co-relationship context and gain adjacent or opposite views to the original problem. The paper will provide a detailed analysis on three main aspects: 1) Using complementary color to define the relationship between two extreme elements. 2) Visualizing possibilities to connect elements/ideas in a system via analogous color. 3) Applying saturation and value from color theory to form a diagram that can analyze complicated and comprehensive thinking process at all levels.

1. INTRODUCTION & STATEMENT

In the book *Universal Traveler* written by Don Koberg and Jim Bagnall*,* there are seven steps in the design process: accepting, analyzing, defining, ideation, selecting, evaluating and refining. However, design process cannot guarantee one specific result as the methodology that could be applied in a project varies from designer's choices and preferences. So, design is not just a logical outcome, but also a mixture of personal choices and decisions. As a graphic designer, I formed my way of looking at an element and its surrounding contexts within the relationship to other elements. The idea of analyzing the networks around a subject intrigued me to search for a pattern of thinking in my graphic design process.

2. THEORY & DISCUSSION

Yin and Yang is one of many important philosophies in Chinese culture. It originated as a natural phenomenon from ancient China and has been applied into many other areas. Yin and Yang refers to interactions between two relationships (nature and mind, cosmic and human) in all existences. The theory emphasizes the opposing elements that co-exist and relate to each other and covers the distant beginnings of cosmos to the very end of society. Three words convey the essential idea of the Ying and Yang concept: coherency, interaction, and harmonization (Wang50). These concepts manifest the connections and actions that would be happening between two components. The relationship between two elements is either consistent with each other or through the interaction it reaches the level of balance and harmony.

3. RESEARCH AND METHOD

In the research of Yin and Yang philosophy I selected more than fifty pairs of contrasting words that could help me get a better understanding of Yin and Yang. By revealing the opposite but co-existing relationships (light and shadow, big and small, simple and complicated, moving and still), I am trying to look for variability between those different relationships. In my study of *light and shadow*, the relationship is that they can never live without each other. However, between *light* and *shadow* there should always be *surfaces* as well as *objects*. Without *surface* and *object*, *shadow* is invisible and there's no destination for light to reach. So, the relationship of *light* and *shadow* becomes the connection among four different elements. When it comes to big and small as a subject for example, I found out the interesting part is that there is always an invisible "medium size" between big and small relationships. Medium is the middle quality or state between two extremes, it's a reasonable balance. So, the focus on this pair of words is no longer two subjects, it suddenly refers to the spectrum that exists in between.

3.1 Relationships Between Complementary Colour

From light & shadow and big & small, I can see all kinds of differences that exist in the two relationships. My intention is to seek the best understanding of the relationships between two components thus exhibiting my solution in a series of "design patterns" with Yin and Yang thinking. After looking at some pairs of words, I started to think about the exact distance between two opposite elements. For example, how many steps should I take in order to reach from "big" to "small"? To visualize this, I start by using two opposite colors to demonstrate their composition. However the distance I found from a gradient mixed with two colors is infinite. The gradient can be stretched as much as I want. Endless colors in between can be found in the gradient and there are millions of ways to reach from one point to another (Figure1).

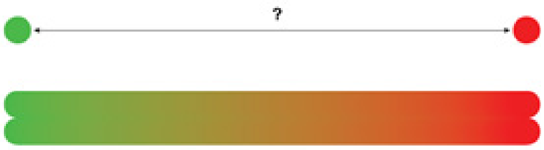

Figure 1. Distance between two elements.

After coming to this answer, I started to realize that my study of the relationship between two elements is just one solution among many others. It could be one great idea, or a group of ideas in the realm of two extremes (Figure 2-A). To explain the relationship of two extremes and how could one move to the next: Try to think about a movement of a ball, it rolls from one extreme to another; it could also bounce from one point to another (Figure 2-B). Visualize it in color, it can go from a red dot to a green dot directly, but it can also reach a green dot generally by reaching through another middle color. Interestingly enough, this matches exactly with color theory and explains the relationship of all the words that I am studying (Figure 2-C).

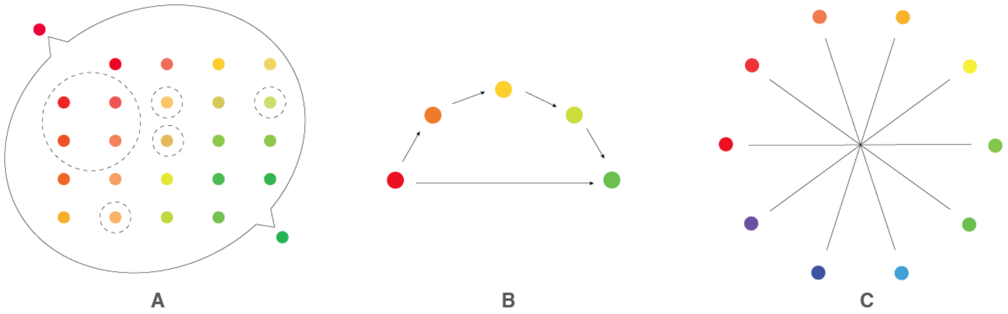

Figure 2. Paths between two elements.

3.2 Analogous Colour that Forms a System

Finished with modeling a pair of contrary words, I started to connect all the different pairs of words and see what could happen among them. The next level of problems becomes, if the study of “big and small (red and green dot)” is about in *between*, where are they lying *within* a context (Figure 3-A)? Remaining on color theory, I started to choose words that have analogous relationships with each other. Physically speaking, those words do connect with each other and can always lead to others that have an analogous relationship with them (Figure 3-B). Now, while my research is about in “between” two extremes, it actually also stays “within” a whole system and circulation. I can put the creation of ideas from one certain problem into a system of looking at the elements that have various connections with it (Figure3-C).

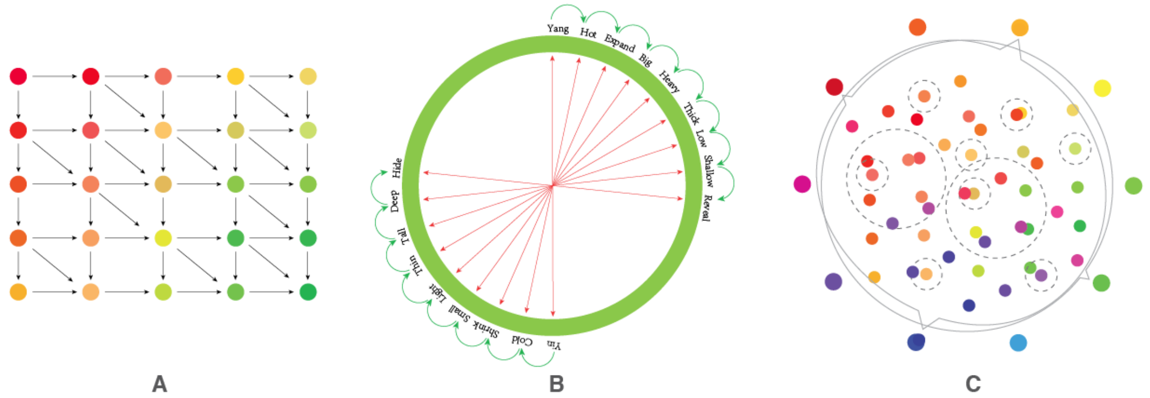

Figure 3: Mapping elements in a color system.

3.3 Saturation and Value Add Another Dimension

To visualize a thinking process by using the model, I analyzed a poem and see how it jumps around *nouns, verbs, adjectives* and *adverbs* (Figure 4-A). When considering the color theory that applies perfectly for the model, I start to think about the “hue”, “saturation” and “value” attributes in the color model, which brings another dimension to the model. In the end, the next level of the model is built upon a gap of time and the next level of a design process. One example to which I applied the model into is a novel story. The model is showing all the overlapped relationships one character has with another at the beginning of the story, and how they developed into different relationships in the end. The main part of the story lies in between of these two levels (Figure 4-B). By adding the time elements in the color diagram, all kinds of possibilities can happen between the beginning and the end.

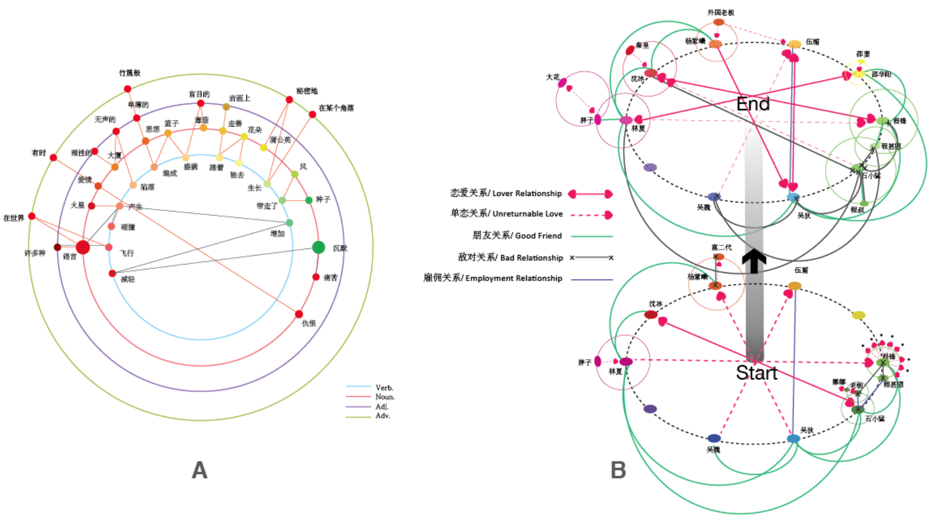

Figure 4: Color diagram applied in contexts.

4. RESULTS & CONCLUSIONS

Designers tackle a problem by anticipating and mind mapping new results. Because of the potential of idea generation in the thinking process, I value the design process as equally vital to the result. “Rarely in design does one know or not know the terminal point but rather one has some information about it; it is a matter of degree. In some kinds of design one knows exactly where one will end up, in others one has very little idea” (Lawson103). Since inspirations and ideas are unpredictable and changeable, there are thus no absolute correct solutions to design problems but rather a whole range of acceptable solutions. The smart way to arrive at a relatively perfect solution is to generate many ideas and compare those ideas to make choices. The color theory based diagram is one way of documenting and visualizing the design thinking process. While stopping at a point where I created a thinking model that might just represent my own voice, I hope to raise a resonance with audiences. It is like putting myself in the diagram, by building a relationship with my thinking process, I wish to share many connections with other designers and methods in the design cosmos.

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Effect of Publications Design Learning from Virtual Classroom upon Metacognition and Learning Potential for Undergraduates

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ABSTRACT

This research aimed to develop a virtual classroom model using connectivism learning upon meta cognition and learning potential in design publication. There were 3 phases of this research and development: to design virtual classroom model, to study the results of using the virtual classroom model upon meta cognition and learning potential, and to propose the virtual classroom model using connectivism learning. The samples consisted of 30 undergraduate students from Rajamangala University of Technology Thanyaburi. The first step was to indentify the factors that influence virtual classroom, Then colour alphabet, background and technique. The second and third steps weren't developed because of limited time. The virtual classroom evaluated by undergraduate students had a quality of 5.00 on average. The research results from the first step revealed that a white alphabet on solid background can be seen more than a coloured alphabet on a coloured background on a computer monitor. They highly agreed, with an average score of 3.63. The best quality was for the virtual classroom through internet network linked to other appropriate learning resources (3.75). Learners can learn in virtual classrooms by themselves (3.73). Images and Texts are in a suitable and neat Layout. The lessons have suitable and neat images and Texts. (3.70).

1. INTRODUCTION

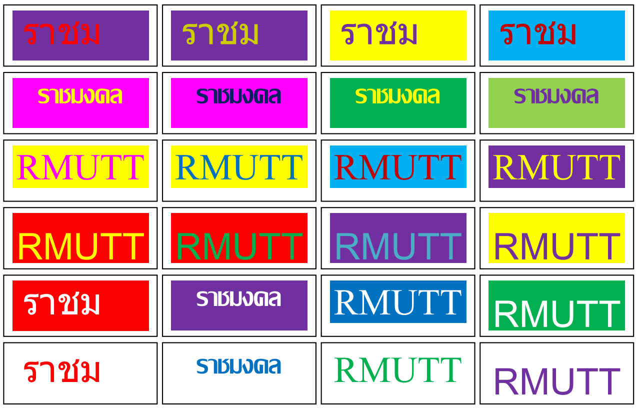
The community news and information services in the 21st century, an era of change along with the changes in the structure of society. And implementation of information technology applications in education. Which the flow of knowledge. Learning theory in the original. Not able to respond to the digital learning. The development of various technologies. Used in communication. And knowledge with the development of the new discoveries occur rapidly connectivism is a learning theory for the digital age. The view that knowledge is a node that can connect anywhere at any time. And can be used for distance learning and opportunities (George Seimens 2006).

According to the importance of information technology and electronic communication which is useful for e- Education, e-Learning, e-Commercial, e-Government and today 's ICT Technology allows both asynchronous and anywhere connections. Therefore, learning is being liberated from location and time-specific from age, life style, traditional institutions and means.

The proliferation of online education gives people time flexibility and also allows them to receive high quality education from anywhere in the world, particularly in emerging countries without developing traditional education infrastructure.

Furthermore, the development of online education methodology is becoming a solid sector in its own right, with dedicated research, innovation and industry-wide effort to find easier ways of promotion, growth, and development in online education field, Education transformation is further accelerated by the availability of new pedagogical forms and mechanisms to deliver content enabled by emerging technologies such as mobile technologies, Smartphone, social networking, using media content and immersive environments (gaming, augmented reality and virtual worlds).

Synchronous, virtual classroom system can provide high levels of interaction for distance learning initiatives. With the rapid evolution of technology, continuous product evaluation is necessary to ensure optimal methods and resources for connecting student, instructors, and educational content in rich, online learning communities. This article presents the analysis of two online, Synchronous learning solution (Elluminate Live and Breeze), focusing on their abilities to meet both technical and pedagogical needs in higher education. To make a solid comparison, the systems were examined in online classrooms with instructors, guest speakers, and student, Pros and cons relative to usability, instructional needs, technical aspects, and compatibility are outlined for both systems (Shauna et.al. 2007) the above-mentioned procedure and rational is about learning through electronic technology, in other words, digital world in order to satisfy the needs to learn without boundary and limitations in time and space. This kind of learning corresponds to the need of an individual in the educational system.



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2. METHOD

This research was aimed to develop virtual classrooms using effective virtual image creation technique. They are suitable for digital world at the present time and the future. The objectives were as follows:

1. To find colours alphabet and background for designing virtual classroom are in suitable and neat layout using on computer, Smartphone, tablet.
2. To find out the learning achievement of learners who entered virtual classroom. (next)
3. To find out the satisfaction of learners towards the virtual classroom. (next)

Step 1 Experimental color vision in a computer monitor

Step 2 Design virtual classroom

Design web for virtual classroom by Responsive web design is the technique used to accommodate the screen size for all kinds of devices, from computers with a screen size up to the standards of the Tablet screen sizes vary. Mobile Phone and Smart Phone the site typically to solve the problem by doing two versions of the site for mobile viewing and for viewing on a computer monitor. Responsive but currently have to help in making the site once. Tablet computers can be viewed either on the phone, but now they have both mobile and Tablet screen sizes.

Table 1: summary of the quality evaluation results of virtual classroom for publication design subject.

Evaluated Items	Mean	Quality Level
1. Images and Texts are in a suitable and neat Layout.	3.70	The best quality
2. The lessons have suitable and neat images and Texts.	3.70	The best quality
3. Colours used in virtual classroom are in suitable.	3.60	The best quality
4. Text colours used in virtual classroom are in suitable and legible	3.60	The best quality
5. Background colours used in virtual classroom are a suitable and effect texts to read.	3.35	Quod quality
6. Graphics used in virtual classroom are suitable	3.35	Quod quality
7. The virtual classroom through internet network can link to other appropriate learning resources.	3.75	The best Quality
8. The virtual classroom through internet network is	3.65	The best Quality
9. The virtual classroom through internet network help learners understand the contents and example design better than in classrooms	3.80	The best Quality
10. Learners can learn in virtual classrooms by themselves	3.73	The best Quality
11. Learners can practice in virtual classroom by themselves	3.65	The best Quality

3. RESULTS AND DISCUSSION

The results showed that Font, a passion for language, tone, style and a head like in English without the top and bottom. The relationship between the colour of the text can be seen in the color divide between cold and warm tones cannot share the vision with all different but with the colours that can be seen easily, the pair have more than two colours, and the use of white letters on a blue background, both warm and cold no different, depending on the percentage saturation is 100 percent (Solid), it makes reading easy part.

4. CONCLUSIONS

Colour and Typography Print-based designs making the switch to web design must be aware of various differences and limitations involved in Visibility. Increased interactivity for the use would further support the simulation design. A reduction in text and increase in graphics may support users in becoming further immersed in the simulated classroom environment. The development of some animation would enhance the authenticity of the 'virtual' classroom. The contrast of the design during system startup lettering with the background will makes increase the readability more easily. Definition Advantages Limitation Case study Features - Virtual classrooms provide the community and control some learners need. - Flexible time: students may participate at any time of the day.(Learning is flexible). - Efficient learning - Location: students are not limited to courses offered in their geographic locality. (Overcome distances) - More active learning: the computer forces response and attention.

ACKNOWLEDGMENT

The virtual classrooms applied the information technology in instructional management in the age of electronics media. This innovation or e-Learning and technique in designing the virtual classrooms based on computer graphic help the virtual classrooms gain quality and effectiveness. Moreover, virtual classrooms were easy to learn and they not boring. Learners could watch video clips or attend online live lecture. And connect to link anywhere in other websites.

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Basic Colour Terms (BCTs) and Basic Colour Categories (BCCs) in Three Different Versions of the Spanish Language: Similarities and Differences

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ABSTRACT

Two experiments were performed to identify and compare the Basic Colour Terms (BCTs) and the Basic Colour Categories (BCCs) of three versions of the Spanish language used in Spain (Castilian), Mexico (Mexican) and Uruguay (Uruguayan). Results are commented in the universalism-relativism debate framework. First experiment recorded a list of monolexemic colour terms for each participant. Frequency (number of lists including it) and list relative position, were computed for each term. Main results were: (a) the three versions of Spanish shared nine BCTs; (b) several BCTs didn't appear in all three Spanish versions but rather in two or one and (c) primary BCTs appeared more frequently than derived BCTs, with the exception of white for the Mexican version. In the second experiment 34 between-colour categories transitions were used. Participants named the colours presented at the two transition's extremes. The results indicated that (a) the nine BCTs shared by the three versions of Spanish in Experiment 1 labelled similar BCCs; (b) two BCCs were named using different BCTs in different Spanish versions and (c) the BCT sky-blue (*celeste*) was used by Uruguayan speakers to name a BCC that does not exist in Castilian or Mexican.

1. INTRODUCTION

Normal people see the rainbow when a monochromatic stimulus changes its wavelength between the ends of the visible spectrum. The rainbow is a discontinuous perceptual variation (stripes of different colour categories) experienced in response to a continuous physical change (wavelength variation). In a similar way, although standard colour spaces (i.e. CIELAB) make it possible to specify continuous changes (ΔE), such spaces are perceptually segmented into subsets of BCCs reflecting some cognitive discontinuities. For example, as showed by the "categorical perception effect", the same CIE distance (ΔE) produces changes easier to appreciate when involving an inter-categorical variation (i.e. from green to blue) than an intra-categorical one.

During the last fifty years there were many experimental works performed to study the origin of BCCs (and how they are related to BCTs) (Berlin and Kay 1969, Kaiser and Boynton 1996, Schirillo 2001). The theoretical position finally reached is named "Interactionism" (Kay et al. 2009) because it assumes that, in every language, BCCs arise from the interaction of some "universal" factors (similar for most humans) and other "relativistic" ones (cultural differences mediated by the language). From an Interactionism position it is very simple to explain why, on a hand, languages differ in the number of their BCCs (from 2 to 12) and, in the other hand, some colours are frequently the best BCCs' representatives in many different languages (or the best examples of a between categories transition).

The two experiments described here initiate a research where three versions of the Spanish Language will be systematically compared. Such versions are spoken in three different countries (Spain, Mexico and Uruguay). This new research complements a previous one (Lillo et al. 2007) where only the Spanish spoke in Spain (thereafter, "Castilian") was considered. In our actual research the three versions will be compared to study universalistic and relativistic factors in CBCs use.

Experiment 1 (elicited lists) required each participant to write (with their eyes closed) all the one-word colour names they could remember during two minutes. Experiment 2 (naming ends and boundary selection) presented 34 between-colour categories transitions (see Figure 1 for an example) for performing two tasks. The first one (naming ends) required participants to name the colours located at each end (i.e. purple for the left and brown for the right). The second task (boundary selection) required participants to select the place of the transition corresponding to the colour that could be named using similarly the two categories located at each end of the transition.

Figure 1: Example of BCCs transition used in Experiment 2.

2. METHOD

2.1. Experiment 1

201 participants took part in Experiment 1. They were students of the following universities: Complutense University of Madrid, Spain (47 participants, 35 females and 12 males). University of Guadalajara, Mexico (97, 57 and 40). University of la Republica, Montevideo, Uruguay (57, 43 and 14). Each participant was evaluated in his/her university.

After writing their name and identification data in a white sheet of paper located opposite to them, they were asked to write (from top to bottom) all the monolexemic (one-word) colour names they could remember during two minutes. Participants wrote the elicited lists with their eyes closed (to avoid the influence of the surroundings).

2.2 Experiment 2

90 participants took part in Experiment 2. Each country group (Castilians, Mexicans or Uruguayans) included 30 people (15 females, 15 males). Although three different monitors were used (one in each country), they were selected and calibrated to be similar in their chromatic coordinates (x, y) for each primary (R: 0.63, 0.33; G: 0.29, 0.60; B: 0.16, 0.07) and for the gamma value (2.27).

The BCCs used in the ends of the transitions presented to the observers were (English equivalence after the Spanish BCTs): rojo (red), verde (green), amarillo (yellow), azul (blue), blanco (white), negro (black), naranja (orange), morado/violeta (purple), rosa (pink), marrón/café (brown), gris (gray) and celeste (sky). Only the 34 transitions that pass through no other category were used (i.e: white-black transition was not used because it passes trhough gray).

3. RESULTS AND DISCUSSION

3.1 Experiment 1

Frequency (number of lists including a term) and relative position in each list were computed for each term. For each version of Spanish language, a colour term was considered a BCT if it appeared in at least 50% of its speakers' lists. Figure 2 shows the English equivalents for the BCTs in the three versions of the Spanish.

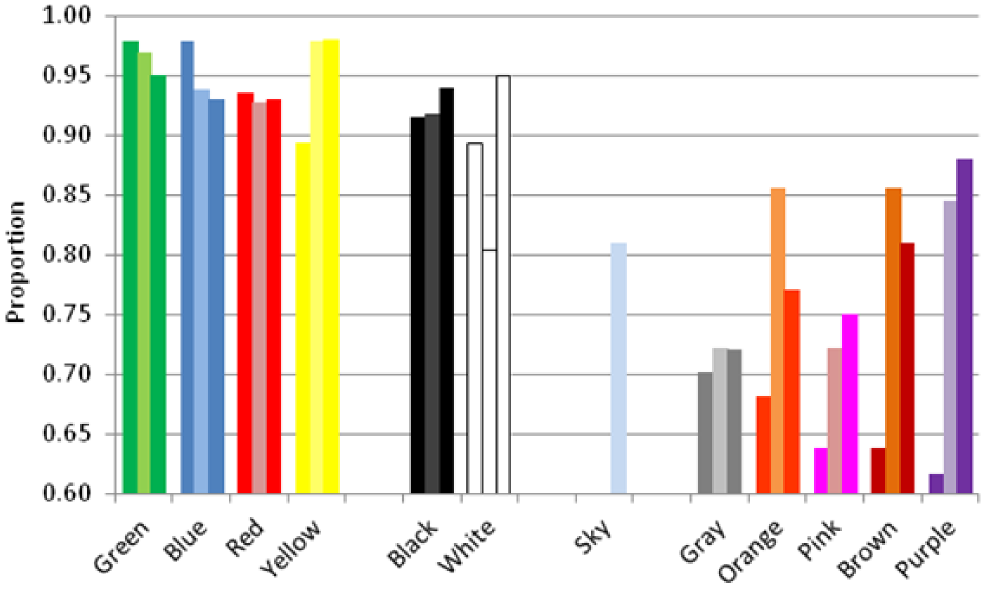

Figure 2. BCTs' frequency for the three versions of the Spanish (Castilian, left; Mexican, center; Uruguayan, right).

Experiment 1 main results were: (a) no significant sex differences were found; (b) the three versions of Spanish (Castilian, Mexican and Uruguayan) shared nine BCTs (red-*rojo*, green-*verde*, yellow-*amarillo*, blue-*azul*, white-*blanco*, black-*negro*, gray-*gris*, orange-*naranja* and pink-*rosa*); (c) several BCTs didn't appear in all three Spanish versions but rather in two (purple-*morado* and brown-*marrón*) or one (purple-*violeta*, brown-*café* and sky-blue-*celeste*); and (d) primary BCTs (red-*rojo*, green-*verde*, yellow-*amarillo*, blue-*azul*, white-*blanco* and black-*negro*) appeared more frequently than derived BCTs, with the exception of white for the Mexican version.

3.2 Experiment 2

Experiment 2 main results were:

1) Naming ends task: (a) no significant sex differences were found; (b) the nine BCTs shared by the three versions of Spanish in Experiment 1 also labelled similar BCCs in the three Spanish versions in the naming ends task of Experiment 2, suggesting that each

BCT was used for naming colorimetrically similar stimuli in Castilian, Mexican and Uruguayan; (c) two BCCs were named using different BCTs in different Spanish versions (brown was named *marrón* or *café*; purple was named *morado* or *violeta*); and (d) the BCT sky-blue (*celeste*) was used by Uruguayan speakers to name a BCC that does not exist in Castilian or Mexican.

2) Boundary selection task: (a) Some sex differences in the mean boundary selection (mainly related to purple) were found; (b) males selections were more variable; and (c) Uruguayan speakers showed less variability than the other two groups of Spanish speakers related to blue-sky (*celeste*) boundary selection.

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Colourful Language: Searching for the Rainbow

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ABSTRACT

The aim of the project was to produce a visual investigation into the relationship between colour and language. The methodology for the project involved a generative approach, where the eleven basic colour terms were inputted into Google Image Search. The first thirty images from the search results were used as a foundation to analyse using digital manipulation. The results of the project present a visual representation of each colour term, showing not only the variety of responses to the names of colours but also the degree of consensus across the range of images.

1. INTRODUCTION

The philosopher Wittgenstein famously asked ‘How do I know that this color is red? —It would be an answer to say: I have learnt English’ (Batchelor, 2000 pp.91). But how do we know what is red? In our today’s digital age perhaps a more pertinent response would be: ‘Google it’.

In many cases the Internet has become our primary source of information, the foundation of our knowledge economy. Largely inclusive and participatory, as an entity it represents the culmination of everything that has been written, posted and uploaded, with each new contribution slightly altering the shape of the whole. But how does Google know what is red? Tags, SEO and complex algorithms now create the precedence for the information we receive when we search online. Search engines are able to dictate the type of information we consume, influencing our perception of what is important with the ranking of their search results.

The use of Google Image Search as a tool to provide a visual interpretation of colour terms began as no more than an exercise in understanding. It proved to be an effective process and it became apparent that the search results were generating a fascinating body of images, providing an insight into both the fluid nature of the Internet and the relationship between the search terms and the colours in the images retrieved by Google.

2. METHODOLOGY

When it became clear that Google Image Search had potential be a valuable tool for a visual investigation into colour and language, I felt it was important to devise a structured methodology while remaining appropriate to the scope of my design-based course. In this instance a generative approach was highly applicable as Google Image Search could be used as an input/output system.

English was chosen as the language for the project as I am a native speaker, was using a UK based IP address and ISP with Google UK as a default and because English is still the dominant language on the Internet both in terms of content generate and the native language of users (Anon, 2013).

To create my initial set of colour terms to use for the process I employed the eleven basic colour terms in English as defined by Berlin & Kay (1969). They offered a clearly defined set of widely used colour terms, representing a range of both spectral, non-spectral colours. While there have been criticisms of bias in the methodology used by Berlin & Kay, these arguments were deemed not relevant to the methodology of the project.

Before beginning the process I cleared my browser history and deleted any cookies, so that the results would not be influenced by my Internet history. This was followed by inputting each of the eleven basic colour terms into Google Image Search with the addition of the word 'colour'. The inclusion of the word colour in the search terms was an undesirable but an unfortunate consequence of a number of high profile celebrities who feature colour terms as part of their names. This created significant distortions in the image results for a small number of the colour terms in the initial trials of the process, without adding anything of value to the comparison. It should also be noted that for consistency I used the English spellings of the words 'grey' and 'colour' throughout, rather than the American English spellings 'gray' and 'color'.

Once each search had been completed I took, without exception, the first thirty images from the search results. When developing the methodology for the project thirty was considered to be a suitable number for the study, as it would generate a reasonable quantity of images without creating an excessive time burden for analysis.

Based on a series of earlier trials, a sequence of digital manipulation techniques were used to visually analyse the colour content of the image results. Each process was applied to the images in isolation rather than cumulatively. The original images were first converted to jpegs and were given the Adobe 1998 ICC colour profile. They were then converted to gifs so that they could be indexed using Colourphon (www.colourphon.co.uk), resulting in a 9 × 9 grid of dominant colours. The jpegs were blurred with a specific and constant amount of Gaussian blur (a radius of 80 pixels) in Photoshop and finally, also using Photoshop the RGB values for the pixels in each image were averaged to give a solid block of colour.

3. RESULTS & DISCUSSION

The methodology for the project resulted in a combined total of 1320 images, 120 for each of the basic colour terms. As a visual investigation, creating a body of images rather than generating numerical data or observations, the results were originally presented in book form.

The contents were arranged by colour term, then grouped by process, beginning with the original results, and were presented in the sequence they ranked in the Google Image Search results. This meant the images could be compared both by hue and process, allowing the reader to appreciate how the colours and images transformed and mutated with each of the different processes applied, as they are transformed from clear shapes into a solid, uniform block of colour. The complete set of results is available to view online: http://issuu.com/Eleanorbydesign/docs/searching_for_the_rainbow/79.

As this study was produced as a visual research project, using design methodologies to investigate the relationship between colour and language, there was no formal data analysis conducted on the results. However there is much scope for further extension of the project, particularly the potential for analysis of RGB values for the images. While this would clearly add more weight and academic rigour to the results of the project, at the time it was beyond the scope of my course. To have numerical data measured against accepted colour standards, supporting the visual output of the project may also benefit other researchers and make a more valid contribution to the field of colour naming.

However, one of the key aims at the outset of my main investigation was to differentiate this project from other studies in the same field through the creation of a strong visual component to the outputs of the research. The project provides a bridge between purely artistic studies of colour and scientific investigations in the field, striking a balance between aesthetic experiments and objective data. While there are always areas for improvement in this respect I view this aspect of the outcome as successful.

3.1 Extensions – further image manipulation

As the use of Google Image Search proved fruitful I extended this line of enquiry. Working with the 1320 images already generated I considered methods which might produce further visual insight into the distribution of colours within the image results.

All of the images for each process and within each colour term were layered with 30% transparency to demonstrate the combined effect of the colours in each image. It allowed the areas saturated with the colour used as the search term to be seen more clearly and to see how that particular colour is distributed throughout the images.

A sample of the centre area of the averaged images was taken and enlarged. This produced a value for the culmination of the averages in the sample. It acted as a collective representation of that particular colour term, mediated both by Google and Photoshop.

In addition to this, images were created for each of the colour terms by taking a vertical, one pixel wide section through the layered images and stretching it across a wider area. This allowed a greater visual impression of the layering and presented the colour composition of the image in an alternative way. The full results for this part of the project are hosted by Issuu and are available to view online at:

http://issuu.com/Eleanorbydesign/docs/transforming_the_rainbow/11

Collectively, these further visual experiments represented a conclusion to this particular line of investigation. While having created some striking and appealing imagery, the method of applying additional digital processes to the images presented a limited opportunity for further insight. However it is clear that the use of Google Image Search, and other search engines, as research tools has great potential to generate insights, certainly in colour naming, if not beyond.

3.2 Extensions – widening the search

Also building on the methods outlined in section 3, I extended the process by expanded the search to commonly known, but less widely used colour terms. Although this criteria is not as clearly defined as the eleven basic colour terms and therefore subject to the influence of personal bias, it was useful to extend the process to include a greater variety of colour terms. The terms were all monolexemic, but many were descriptive, such as ‘cream’ and ‘peach’.

As before, the colour names were used as search terms in Google and the first thirty images from the ranking were extracted in the order they appeared in the results. The images were presented in book form with the colour terms ordered sequentially by hue, so it was possible to compare the results of different searches or similarly coloured images. The images were not subjected to any additional digital processes as this aspect study was specifically concerned with the comparison of Google Image Search results.

This method allowed for subtle distinctions to be observed between colour terms that are often regarded as interchangeable, for example wine, claret, maroon and burgundy. It also allowed for similarities to be seen between colours that are generally thought of as more disparate. The complete set of image results can be viewed online at:

http://issuu.com/Eleanorbydesign/docs/looking_for_hue/21

The outcome of a Google Image Search may not provide a conclusive answer for the visual interpretation of colour terms, but as the results show, colour is rarely, if ever, definitive. Everyone's idea of what a particular colour is, may equate to many subtly different shades. However, in all but a few cases, notably puce, there is a degree of consistency across the search results. While it is widely understood that both colour perception and colour naming are subjective, this methodology has produced a body of images defined by the process of colour naming but created in a real-world, non-experimental context. The degree of variation seen within the colour range of the images is a reflection of how each colour term is used in the vernacular.

4. CONCLUSION

As a body of work this project presents a visual representation of each of the eleven basic colour terms, mediated by Google, and functions as a snapshot of colour on the Internet that due to its constantly shifting nature, can never be replicated exactly. It has allowed me to capture an interpretation of colour terms across a medium, which is still relatively democratic and where content is currently less regulated.

The results of each search add to the collective understanding of what a colour term represents, and it is possible for anyone, through their own contributions to the Internet, to influence that understanding to a degree. Although they are translated through Google's algorithms, collectively, the images retrieved from internet searches represent the particular level of understanding of colour and colour terms by those posting them, tagging them or writing the accompanying text. This method is but one of the many possible ways of exploring the relationship between colour and language but it one that is truly a reflection of our digital age.

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How Are Custom Color Names Valuable? Tendency in Color Naming in Custom Color Names of JIS Z 8102

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Evolutional Blue (Independent Designer in Japan)

ABSTRACT

Color strategy for industrial product design and some information media make new color and its name increase. In this situation, how are Japanese custom color names in Japan Industrial Standard (JIS Z 8102) used ?

This paper aims to examine the usage of custom color names in JIS Z 8102 "Names of non-luminous objective colors" from color naming task with PCCS color cards. At the "Blue" (hue number : 18) in PCCS color system, color naming "Ao" ("Blue" in Japanese name) as a basic color name appears in high and part of middle range. In terms of usage condition of JIS custom color names, only 14.1% JIS custom color names appear in "GB", "B", "PB" and "P" in Munsell hue area, and only 13.4% appear in "GB", "B" and "PB". That result imply to room for the consideration to usage or existence of JIS Z 8102 custom color names.

1. INTRODUCTION

Various words are used for expression of color in daily life. Existent color names may be included in. In Japan, a number of color name keeps on increasing because of color design strategy for industrial products, for example, automobiles, cell phone and so on. A new color name from color lineup of an industrial item may be in fashion.

By the way, 269 custom color names by JIS (Japan Industrial Standard) exist (cf. JIS Z 8102 "Names of Non-luminous Object Colors"). Origins of each name are from plant, material, animal and so on.

In this situation, each color name by JIS may be "a) used frequently and correctly", "b) seldom used" or "c) used with misconception". To confirm this hypothesis, we examined how custom color names are recognized with three indices (i.e., the distance in CIE L*a*b* color space between a given standard color of JIS Z 8102 and subjects' choice for it, the familiarity of color names, and the imaginableness of color names). And principal component analysis revealed that two components "Recognition" and "Distance in color space" have 95.8% explain-ability of the familiarity of color names (2009 Yoshizawa).

This research is to grasp tendencies of color naming in each color (hue and tone). Especially, to grasp color space ranges in each color and how many colors named in each color. To reveal on these aspects, the value of each color name will be estimated.

(In this paper, only hue number 18:B in PCCS System is limited. Another hues will be on the poster.)

2. METHOD

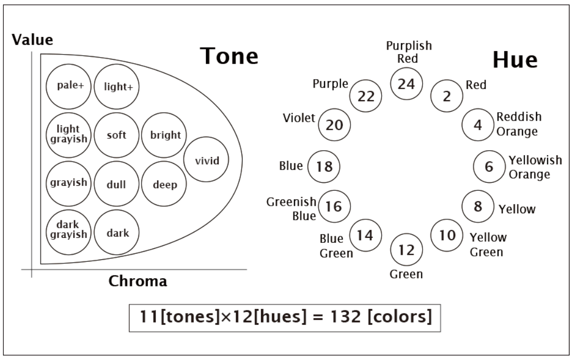
2.1 Subject

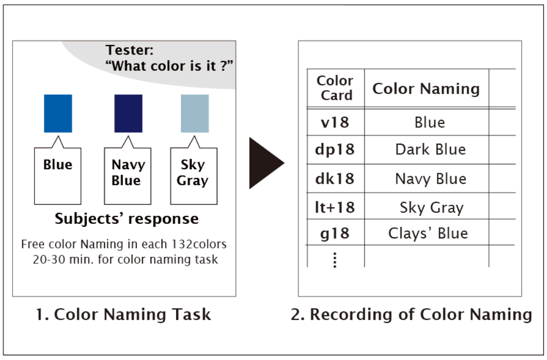
28 people participated in the test (15 men and 13 women, age: 20-27). 20 of all had studied design or color. All subjects did not have color deficiency.

2.2 Procedure

In this test, PCCS color system was used and especially, 11 tones and 12 hues were picked up and 132 colors were used (Figure 1; PCCS Color Harmonic Color 201-L, Japan Color Enterprise Co., Ltd.).

Subjects answered a name in each color card after tester showed. And color naming by each subject were recorded (Figure 2). Lighting condition was 600lx with natural white florescent lamp (6500K).





Color Card	Color Naming
v18	Blue
dp18	Dark Blue
dk18	Navy Blue
lt+18	Sky Gray
g18	Clays' Blue
⋮	

Figure 1: PCCS system as color stimulus. *Figure 2: Procedure in the test.*

3. RESULTS

3.1 Tendency in JIS Custom Color Name

Table 1 shows color naming in each tone in "18:Blue". Color name "Ao" (blue in English) appears on 6 tones of 11(vivid, bright, deep, light+, dull).

"Ao" is one of the Japanese basic color names, so 82.1% subjects answer "Ao" in v18 (vivid), 28.6% in bright and 32.1% in deep. Another JIS custom color names appear on high saturation area ("Blue": 3.6% in vivid, "Sora-iro": 10.7% and "Blue": 3.6% in bright, "kon-iro" and "Ao-Murasaki":3.6% in deep).

In middle saturation area (light+, soft, dull and dark), "Ao" appears on 3 tones (light+, soft and dull), but percentage of appearance on middle saturation area is lower than high saturation area. "Mizu-iro" is the highest appearance in light+ (17.9%), and "kon-iro" in dark (21.4%)

In low saturation area (pale+, light grayish, grayish, dark grayish), "Ao" does not appear on any tones. Instead of "Ao", neutral color appears on some tones ("Nezumi-iro"): 17.9% in light grayish and 10.7% in grayish, and "Kuro":35.7% in dark grayish).

Table 1: Color Naming in 18: Blue in PCCS

Tone		v18 (vivid)		b18 (bright)		dp18 (deep)		lt18+ (light)		sf18 (soft)	
Munsell Notation		**3PB 3.5 / 11.5**		**3PB 5 / 10**		**3PB 2.5 / 9.5**		**3PB 6 / 7**		**3PB 5 / 5.5**	
Color Naming	**[%]**	**Color Naming**	**[%]**	**Color Naming**	**[%]**	**Color Naming**	**[%]**	**Color Naming**	**[%]**	**Color Naming**	**[%]**
(Color Naming)*1 (Munsell/English) *2		*Ao (Blue)* *10B 4/14*	82.1	*Ao (Blue)* *10B 4/14*	28.6	*Ao (Blue)* *10B 4/14*	32.1	*Mizu-iro* *6B 8/4*	17.9	*Ao（Blue）* *10B 4/14*	14.3
		Blue *2.5PB 4.5/10*	3.6	*Usui Ao* *pale blue*	10.7	*Koi Ao* *deep blue*	25.0	*Usui Ao* *pale blue*	14.3	*Kusunda Ao* *dull blue*	10.7
		others	14.3	*Sora-iro (Sky)* *9B 7.5/5.5*	10.7	*Kurai Ao* *dark blue*	7.1	*Ao (Blue)* *10B 4/14*	14.3	*Kusunda Muzu-iro* *dull Mizu-iro*	7.1
				Blue *2.5PB 4.5/10*	3.6	*Kon-iro* *6PB 2.5/4*	3.6	*Sora-iro* *9B 7.5/5.5*	7.1	Navy Blue 6PB 2.5/4	3.6
				others	46.4	*Ao-Murasaki* *2.5P 4/14*	3.6	others	46.4	*Nezumi-iro* *N5.5*	3.6
						others	28.6			others	60.7

d18 (dull)		dk18 (dark)		p18+ (pale)		ltg18 (light grayish)		g18 (grayish)		dkg18 (dark grayish)	
3PB 3.5 / 5.5		**3PB 2 / 5**		**3PB 7.5 / 3**		**3PB 6.5 / 2**		**3PB 3.5 / 2**		**3PB 1.5 / 1.5**	
Color Naming	**[%]**	**Color Naming**	**[%]**	**Color Naming**	**[%]**	**Color Naming**	**[%]**	**Color Naming**	**[%]**	**Color Naming**	**[%]**
Gunjo-iro *7.5PB 3.5/11*	10.7	*Kon-iro* *6PB 2.5/4*	21.4	*Mizu-iro* *6B 8/4*	10.7	*Nezumi-iro* *N5.5*	17.9	*Nezumi-iro* *N5.5*	10.7	*Kuro (Black)* *N1.5*	35.7
Ai-iro *2PB 3/5*	7.1	*Ai-iro* *2PB 3/5*	14.3	*Usui Mizu-iro* *pale Mizu-iro*	10.7	Gray N5	14.3	*Hai-iro* *N5*	10.7	*Kuro ni chikai Ao* *Blue near Black*	7.1
Ao (Blue) *10B 4/14*	7.1	*Koi Gunjo-iro* *deep Gunjo-iro*	7.1	*Usui* Blue *pale* blue	10.7	*Hai-iro* *N5*	10.7	*Gray* *N5*	10.7	Gray N5	3.6
Kurai Ao *dark blue*	7.1	*Koi Kon-iro* *deep Kon-iro*	7.1	*Usui Ao* *pale blue*	7.1	*Mizu-iro* *6B 8/4*	3.6	*Koime no* Gray *deep* Gray	7.1	*Kon-iro* *6PB 2.5/4*	3.6
Sumire-iro *2.5P 4/11*	3.6	*Koi Ai-iro* *deep Ai-iro*	7.1	*Murasaki (Purple)* *7.5P 5/12*	3.6	others	53.6	others	60.7	*Nou-Kon* *deep Kon-iro*	3.6
Nezumi-iro *N5.5*	3.6	*Gunjo-iro* *7.5PB 3.5/11*	3.6	*Hai-iro (Gray)* *N5*	3.6					*Ai-iro* *2PB 3/5*	3.6
others	57.1	others	35.7	others	53.8					others	42.9

▣ : Color Naming "Ao" (as a basic color , "Blue" in English)

▨ : Color Naming in Custom Color Name of JIS Z 8102

*1 : *Italic - Color Naming in Japanese* , Non-italic - in English

*2 : Representative Munsell Notation in case of using custom color naming in JIS Z 8102 / Color Naming in English in case of not using.

Table 2: Usage Condition of JIS Custom Color Names in the hue "18:B"

		GB	B	PB	P
Japanese Custom Color Name in JIS Z 8102	Percantage of Appearance	**0%**	**20.0%**	**17.6%**	**27.3%**
	(A/B) *3	0/4	2/10	3/17	3/11
Foreign Custom Color Name in JIS Z 8102	Percantage of Appearance	**0%**	**0%**	**18.2%**	**0%**
	(A/B) *3	0/3	0/7	2/11	0/8
Total	Percantage of Appearance	**0%**	**12.3%**	**17.9%**	**15.8%**
	(A/B) *3	0/7	2/17	5/28	3/19
Total (GB+B+PB+P)	Percantage of Appearance	**14.1%**			
	(A/B) *3	10/71			
Total (GB+B+PB)	Percantage of Appearance	**13.4%**			
	(A/B) *3	7/52			

*3 : A : Number of JIS Custom Color Names **Appearance in this test.**
B : Number of **total** JIS Custom Color Names.

3.2 Usage Condition of JIS Custom Color Names

Table 2 shows usage condition of JIS custom color names in the hue “18:B”of PCCS. To grasp usage condition, number of color names appearance of JIS custom color names is counted in each “GB”,”B”,”PB” and “P” of Munsell hue area.

In “GB”, ”B”, ”PB” and “P” in Munsell hue area, total number of JIS custom color names is 71. But only 10 names appear in this test (14.1%). And limited to “GB”, “B” and “PB”, total number is 52, but only 7 colors appear (13.4%).

4. DISCUSSION AND CONCLUSION

This paper indicates to examine how JIS custom color name appears in the hue “18:B” in PCCS System by color naming test.

In each tone, number of color naming, ration of appearance in JIS custom color name and share of appearance in each color naming as a characteristics are different.

And in Table 2, 14.1% of total JIS custom color name appear in “GB”, “B”, “PB”, “P” of Munsell hue area, and it implies rest of 85.9% does not appear. That result has room for the consideration to usage or existence of JIS Z 8102 custom color names.

28 subjects from 20 to 27 years old participated in this test. If changing generation of subjects or increase of subject, results of color naming may be different.

(In this paper, only hue number 18:B in PCCS System is limited. Another hues will be on the poster.)

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Colour Naming Ability of Chinese College Students

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School of Optoelectronics, Beijing Institute of Technology

ABSTRACT

The purpose of this investigation was trying to explore the colour naming ability of Chinese college students, meanwhile, the relationship between colour terms and colour cognition of Chinese college students was also discussed. Most former researches focused on colour naming ability of children. There were 144 Chinese college students with normal colour vision and normal or corrected-to-normal spatial vision and matured colour cognition in the experiments, and they were asked to name, in Chinese, all colours in four series (i.e. pink, blue, orange, and cyan series). To determine whether the colour naming abilities are different for Chinese college students from different regions (southern and northern) and in different genders (female and male), t-tests were conducted. The results indicated that: (1) the total mean percentages of successful colour naming of Chinese college students in the four series from high to low were as follows: b (blue) series; p (pink) series; o (orange) series; c (cyan) series; (2) further t-tests showed that in the four series colour naming abilities of Chinese college students from different regions and in different genders were not significantly different. (3) females used more elaborate colour names than males did.

1. INTRODUCTION

Colour naming is the description of colour cognition by languages. In general, colour naming often relates to the colours in the nature worlds, such as plants, animals, and minerals etc. Colour naming may be defined as “the description of a colour with a verbal expression.” People could use colour names to distinguish and to classify colour which they perceived with their eyes, to convey information about colour and to communicate with others.

Currently there are three views on the relation between colour terms and cognition: 1) colour naming universality which means that colour terms and cognition are mutually independent 2) linguistic relativity hypothesis which believes that colour terms affect colour cognition and 3) a combination of 1 and 2.

Most researches have focused on children (see Preyer 1905, Winch 1910, Lin et al. 2001 and Liu et al. 2004), whereas we worked with college students whose colour cognition had already matured. Zhang et al. (Zhang 2007) worked with undergraduates from Yi, Bai and Naxi nationalities. We also differed from other work by using four colour series, i.e. pink, blue, orange, and cyan rather than the colours more commonly used. Each colour was chosen from RGB to Color Name Reference (Walsh) and had a known English name. There is no such reference in China. Previous researches have also mainly been concerned with correct percentages of colour naming of the children; our work attempted to explore the colour naming ability of Chinese college students, meanwhile, the relationship between colour terms and colour cognition of Chinese college students was also discussed.

2. METHOD

144 participants, whose ages varied from 18 to 23 years old, 88 were northerners and 56 southerners (i.e. different regions); 50 were females and 94 males (i.e. different genders) participate in the experiments. All participants had normal colour vision and normal or corrected-to-normal spatial vision.

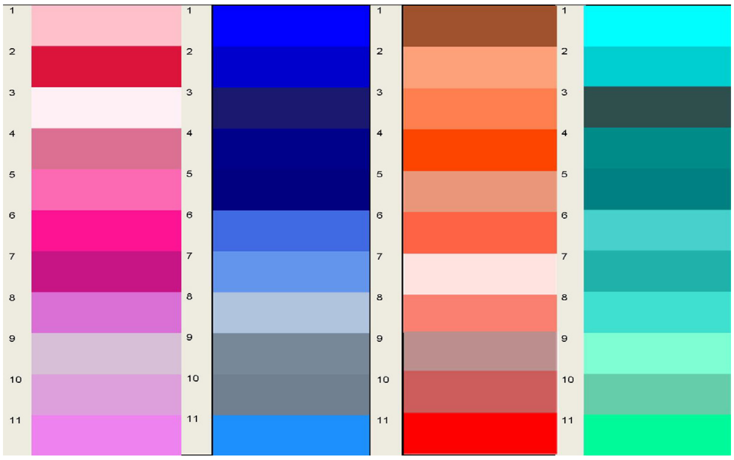

Figure 1: The 44 colours used from four of the colour series (p:pink b:blue o:orange c:cyan).

As Figure 1 showed, the 44 colours, which are roughly scattered in four hues, were presented on a large screen by a projector. The subjects viewed the 44 colours together in a room well-lit by natural daylight. They were required to name the 44 colours.

3. RESULTS AND DISCUSSION

To explore which colour series is easy or difficult to name, the participants were asked to attempt to name each colour. The percentages of successfully named colours in the four series (i.e. pink, blue, orange, cyan) were analysed.

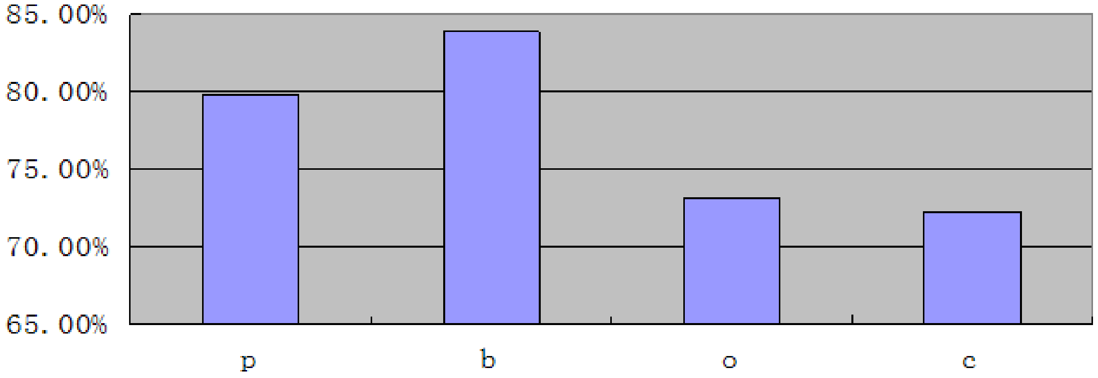

Figure 2: Mean percentages of colour naming in four series.

The total mean percentages of successful colour naming of Chinese college students in the four series from high to low were as follows: b (i.e. blue) series, 83.90%; p (i.e. pink) series, 79.92%; o (i.e. orange) series, 73.23%; c (i.e. cyan) series, 72.29%, see Figure 2. Figure 2 shows that colour naming abilities of Chinese college students in four series are different, which indicates that the colour naming ability of Chinese college students in b series is the strongest, while c series the weakest.

To determine if the colour naming abilities in four series exhibited significant differences, χ^2 (chi-squared tests) were conducted. Results indicated that both p series (χ^2=17.003, p=0.074) and b series (χ^2=10.525, p=0.396) did not show significant differences. On the contrary, o series (χ^2=51.878, $p<0.05$) and c series (χ^2=33.057, $p<0.05$) demonstrated significant differences.

According to the research of Lin, there was no significant difference about colour naming ability of children between Beijing and HongKong. Furthermore, we focused on Chinese college students whose colour cognition had already matured. T-tests were performed to determine whether colour naming abilities from different regions (southern and northern) and in different genders (female and male) showed significant differences. With a significance level (α) of 0.05, the P-values from different regions in four series were 0.223, 0.219, 0.904, 0.708. These P-values are bigger than α, which reflected that the colour naming abilities of Chinese college students in four series were not different from different regions. The P-values which were also bigger than α in different genders in four series were 0.421, 0.493, 0.467, 0.120 which showed that the colour naming abilities of Chinese college students in different genders had no significant difference.

Owing to the difference of environment and culture backgrounds, the basic colour terms from different regions are not the same. In Berlin's opinion, colour terms of various languages have something in common, moreover, colour terms and colour cognition are mutually independent. The average number of elaborate colour names in different genders were 8.79 (males) and 11.08 (females) respectively. The statistical results of elaborate colour names showed that females used more elaborate colour names than males did in our experiments, however, there was no significant difference in colour naming ability in different genders. In conclusion, the colour terms used by different genders were different, while they had almost the same colour cognition, which proved the colour naming universality (Berlin 1969).

4. CONCLUSIONS

We explored the colour naming ability of Chinese college students, meanwhile, the relationship between colour terms and colour cognition of Chinese college students was also discussed.

Based on the data, we could conclude that: (1) the total mean percentages of successful colour naming of Chinese college students in the four series from high to low were as follows: b (i.e. blue) series, 83.90%; p (i.e. pink) series, 79.92%; o (i.e. orange) series, 73.23%; c (i.e. cyan) series, 72.29%, these data showed that the students could name colours in b series easier, while those in c series more difficult. What's more, p series and b series did not show significant differences, while o series and c series did; (2) further t-tests showed that in the four series colour naming abilities of Chinese college students from different regions and in different genders were not different significantly. It could be concluded that, unlike children, the colour naming ability of the adults did not depend on where they came from or which gender they had. (3) females used more elaborate colour names than males did, however, there was no difference in colour naming ability in different genders, which proved the colour naming universality.

Our data drew preliminary expected conclusions, and our research which laid a foundation for further study was in a creative open-source way.

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‘Grapheme Synaesthesia – A Coloured Alphabet’

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ABSTRACT

The condition called synaesthesia occurs when information that is normally processed separately in the brain is manifested simultaneously, producing visual and haptic sensations concurrently (Robertson & Sagiv 2005; Dann 1998; Cytowic 1993; Cytowic & Eagleman 2009). Some synaesthetes experience particular colours when presented with the alphabet or text and it is this category of synaesthesia called grapheme synaesthesia (Robertson & Sagiv 2005; Dann 1998; Cytowic & Eagleman 2009; Ward 2008),that I have chosen to focus on.

This paper presents an investigation into the possibilities of translation of previously private internal colour perceptions of a small group of synaesthetes into a collection of external analogue letter/colours of the alphabet. I will order and re-order the letter/colours, make comparisons with other letter/colours and begin a systematic series of configurations and re-configurations, to induce different colour experiences. Taking colour through into a different ‘vocabulary’ in the communication of a perceptual experience to externalise a previously personal, unique and private experience, and contribute to the discussion of colour and perception. At each stage the collaborative nature of the project will be identified and articulated and the individual input to this study will be acknowledged, ensuring a continuous symbiotic association and dialogue.

1. INTRODUCTION

My first experience of synaesthesia was during a teaching session at UCA, Farnham, where I was demonstrating the range of colours one could obtain, using Cyan, Magenta and Yellow. A student fled the studio obviously in extreme distress. It later transpired that she had become overwhelmed by the quantity of colours on display and this had induced sensations of panic and nausea. She explained that she was a grapheme synaesthete and that words and texts induced involuntary colours in her ‘mind’s eye’. For example:

> ‘A, pure white, and like china texture.
> E, red, not transparent; vermilion, with china-white would represent it.
> I, light bright yellow; gamboge.
> O, black, but transparent; the colour of deep water seen through thick clear ice.
> U, purple.
> Y, a dingier colour than I’. (Baron-Cohen and Harrison 1997:46, Galton, F.: Mrs H).

Since then we have worked together to transpose her colour perceptions from her ‘mind’s eye’ into analogue form through my skills as a dyer. I completed my first two alphabets last summer and these were confirmed by my case studies this autumn. I am working with a further three subjects and anticipate keeping the number of participants relatively small for this study. To date, I have interviewed five case studies of which three have volunteered to participate in this study. Out of the three going forward, two were aware of their synaesthesia for as long as they could remember. However, the third discovered her synaesthesia fairly late, while in her early to mid twenties. One of the participants HW, has a mother with synaesthesia but synaesthesia was not passed down to her brother. The remaining two participants are not aware of anyone else in their family having synaesthesia. I was introduced to a woman who has grapheme synaesthesia as do her two daughters. She has a brother and a male cousin who have it and he has a son also with synaesthesia, but they were unable to take part in this study as they are dispersed throughout this country and abroad so regular meetings would be too difficult to sustain. At present all my participants are female.

My background is in textiles. I trained at UCA, Farnham, and part of my training was to work with a resident dye chemist from ICI to achieve the exact colours identified for my textile work. This constant dyeing and matching process gave me the skills to become a colour matcher for the textile industry alongside conservation and restoration work. I have tested dyestuffs retrieved from an East India Company shipwreck found off the Hebrides, that was travelling from the Coromandel coast with dyewoods destined for Sweden. I have studied eighteenth century dye-receipt books from an archive in Trowbridge, and written a book on natural dyes for the British Museum Press.

My personal textile work has always been centred round colour. I have used artists such as Barnett Newman, Ellsworth Kelly, Brice Marden, Ad Reinhardt, Malevich, Mark Rothko, Robert Ryman, Joseph Albers, Sol LeWitt, Agnes Martin, Bridget Riley, Edwina Leapman, and many others as sources of reference. More recently I have integrated ideas of text through Morse Code and Braille with my interest in systems, repetition, chance and order.

2. METHOD

I am interested in the internal and external representations of the sensation of colour and will be working to map the colours that are presented in the ‘mind’s eye’ of a number of synaesthetes, as physical analogue sensations. There seem to be two ways that grapheme synaesthetes experience coloured text, the “projective” experience, when the synaesthetic colours appear as overlays onto the text, and the “associative” experience, where the colours appear in the mind’s eye. (Blake, Palmeri, Marois & Kim, 2005, also Smilek, Dixon, Cudahy & Merikle, 2002).

As a colourist and dyer with extensive industrial and academic experience, I will focus on how ideas of colour may be instantiated in individual textile pieces; the source of material for this work will be grapheme synaesthesia. My first two participants are “associative”. I hope that by externalising the synaesthete’s internal experiences of colour I will be able to contribute to the ongoing dialogue of what a grapheme synaesthete experiences. Each of the case studies I have been working with manifests their own unique perception of colour sensation for each letter of their alphabet. From my initial studies so far, this would appear to be a common phenomenon amongst the synaesthetes I have met.

An interesting characteristic of the grapheme synaesthetes that I have encountered is that they seem to be exceptionally sensitive to nuances of colour and to the language used to name colours. By working with them, I will create works that are responses to this sensitivity. While this work lies principally in the domain of art and design, I believe it may provide insights into the colour world of synaesthetes that is of wider application and reference.

I have adopted a grid system to facilitate the arrangement of the letter colours in different configurations allowing colours to be built up in clusters or blocks according to organisation of words and letter colours.

The alphabets I have been working on have been photographically recorded in arrangements of ABCDE, FGHIJ, KLMNO, *Figs 1,2,3.*

Figure 1

Figure 2

Figure 3

All the colours produced have dye recipes as part of the notation process. I am working on a series of artist's books. Each page begins with the letter of the alphabet, followed by the verbal description of the colour perception, the Munsell reference and finally the colour swatch. These sets will be folded and arranged in order, but can be re-arranged for comparisons as seen in Figs 1, 2, 3, 4.

By using various ratios of 1:1, 2:1, 3:1, it will be possible to vary the proportion of each letter colour 1:1 with A:B, 2:1 with AA:B implementing a standard 'colour & weave' procedure, thus introducing the next letter to the first and shifting the emphasis of one letter to the next, stretching it through the addition of another letter colour in an ordered system of partitive mixing following the ratio system. The initial colour may be accentuated or blurred by the addition of another letter colour until it morphs into the next letter and so on through the alphabet. By varying the proportion of a personal alphabet colour in relation to another letter colour, it should be possible to record when/if the letter colour shifts for the synaesthete, or if the original perception remains intact. By introducing a number of simple progressive exercises, and exploring issues of scale, proportion, repetition, reactions to results will be recorded. The grid system will be rectangular, to suit the idea of text as a linear arrangement of letters to form words and blocks. This is also an aesthetic decision, as the rectangle will be only slightly 'off square'.

The initial work on compositional layouts will be conducted through paint on paper and card windings as these methods will give relatively quick feedback before further developments of scale take place in a textile format.

My prior experience as a colour matcher has given me many years of working towards seamless colour matching. By constantly referring back to my case studies I hope to ensure accuracy of interpretation and translation. I am interested in using colour to explore its potential to convey an idea. My intention is that the projected outcomes from this study, whilst being conclusive in themselves, may prove to be a platform from which further working developments may be anticipated.

I would like to extend my knowledge of colour and take control of the use and application of these new and untested colours in my work to convey thought provoking, challenging work that has the capacity to push the boundaries of engagement and exploration of the chemistry/alchemy of beauty.

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Colourful Language: Survey of Colour Naming

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ABSTRACT

This paper presents the results of a survey examining the relationship between colour and language, investigating the way we use our vocabulary of colour terms to communicate the colours we see. The survey was conducted over a period of approximately ten weeks, using a number of online channels to solicit responses from a random sample of the general public. The analysis of results included completed surveys from 194 participants and demonstrates a substantial breath and depth to colour naming, alongside a breakdown in understanding as colour terms become more obscure.

1. INTRODUCTION

Is my understanding of colour names the same as your understanding? Would we identify different hues with the same name or give different labels to the same colour? I have sought to explore these ideas through my MA Graphic Design Major Project, Colourful Language. This survey forms a significant part of a wider investigation in to the relationship between colour and language and was created to gain further understanding of a number of aspects of colour naming among the wider population. This included assessing general attitudes to colour naming and examining any changes in response as colour terms became more sophisticated.

2. METHODOLOGY

Prior to issuing, a pilot study was carried out on a small group of volunteers, in order to test survey functionality and the wording of the questions. Feedback allowed for refining the presentation and content of the survey. The survey was constructed and hosted by SurveyMonkey and was accessed via a weblink, which was issued potential respondents. It was conducted over a period of approximately ten weeks and a number of channels were used to invite responses including email, social media, public forums and blogs.

To begin the survey participants were asked a series of basic questions, in order to establish the demographics of the sample. These included gender, age group, nationality, native language, visual colour deficiency and involvement in art and design. These categories were established as factors that may influence the perception and labelling of colours, and therefore needed be acknowledged. As sources and quantity of ambient light, type of computer and screen can affect how we perceive colours in the digital realm; participants were all asked a series of questions about how they viewed the survey in order to accommodate these variables.

To introduce the idea of colour naming participants were asked about their colour vocabulary, how they felt about describing colours and whether describing colours had led to disagreements. To explore how participants translated sophisticated colour names in more basic terms, respondents were asked to explain a number of colour names using simple words like red, blue and light, dark. The stimulus terms were grouped into two categories, sophisticated colour terms and obscure colour terms. The sophisticated colour terms were: maroon, coral, nude, puce, mauve, teal, pistachio, khaki, fawn, tawny and taupe. These colour names were chosen because they are less widely used than basic colour terms, but are still well known and can be open to interpretation. The obscure colour terms were selected because they were particularly complex, in order to test the respondent's awareness and understanding. This group of terms comprised of: alizarin, cinnabar, citrine, gamboge, chartreuse, celadon, cerulean, periwinkle, ianthine, porphyry and greige.

To study colour naming, participants were asked to name a total of thirty-three colours, three groups of eleven swatches. The swatches were presented as a row of numbered, coloured squares. All of the colours were selected from Pantone's Europe Coated colour book. The colours were grouped based on three levels of complexity. The first group featured swatches that could easily be described as matching the eleven basic colour terms in English (Berlin & Kay 1969). The second group was comprised of colours that would not be strongly associated with a basic colour term. They varied more in saturation and brightness and were closer to the boundaries between basic colour categories. The third group of colours were selected to be more difficult to name as they varied to an even greater degree of saturation and brightness and were more difficult to categorise.

In a reversal of the colour naming exercise, participants were asked to pick colours from a table of swatches, also adapted from Pantone's Europe Coated colour book, which they thought was the best visual representation of a given colour term. The colour terms acting as the stimulus for the task were presented in three groups. The first group comprised of the eleven basic colour terms in English, as defined by Berlin & Kay (1969). The second and thirds sets included the same groups of sophisticated and obscure colour terms featured in previous sections of the survey.

The analysis of the raw data was conducted with the aid of Microsoft Excel, with the addition of some manual processing. The contributions from 194 participants have been included in the results. Although this does not represent the total number of responses, instances where the survey was not completed have been discounted from the final analysis.

3. RESULTS & DISCUSSION

3.1 Demographics

Approximately two-thirds of participants were female. As this is a significant gender bias, the high proportion of female responses affects how the results of this survey should be viewed. There is also a bias among the age groups represented in this survey. Nearly two thirds of respondents were aged between 20 and 39, with the second largest group of participants being those aged 40-59. Just one person in the survey was over sixty, equivalent to 0.5% of the total and just over ten percent were aged under twenty. However, of those who took part, none of the respondents reported having any colour deficiency in their vision.

More than three-quarters of respondents spoke English as a first language. Of those who didn't, a range of twenty-six different languages were spoken by participants, including French, German, Portuguese, Arabic, Cantonese and Japanese.

3.2 Viewing Conditions

Just over half the respondents reported viewing the survey in artificial light, with an almost equal number split between fluorescent and incandescent sources. The remaining participants viewed the survey in natural daylight, with just under two thirds reporting the light as having medium brightness. 19% of participants said that they had taken the survey in dim light, while 17% said described their light source as bright.

3.3 Talking about Colour

Well over half of participants reported having difficulty describing colours at least some of the time. A similar amount also had trouble understanding what colours other people were describing. Just over half thought that it was important to describe colours accurately; however, a significant proportion felt that it depended on the situation. Many of the participants reported disagreeing about colours that were similar or lie close to the boundaries between basic colour categories such as blue/green, blue/purple, purple/pink and green/brown. Others described disagreements that centred on a difference in colour term labelling, such as teal/turquoise, teal/aqua, pink/fuchsia.

3.4 Colour Vocabulary

In order to appreciate the size of participants' colour vocabulary, respondents were asked name as many colours as they could think of. The amount of colour terms listed varied considerably, ranging from 7 to 100. Overall, the average number of colours named was 26, representing a colour vocabulary of just over twice the number of basic colour terms in English. In comparison, a combined total of 542 unique colour terms were listed by respondents, creating an incredibly rich and diverse vocabulary of colour names.

3.5 Describing Colour Terms

Participants produced a wide variety of responses to the eleven sophisticated colour terms. Often the participants were in agreement about the colour term translation, but explained it in different ways, creating a rich body of colour expressions. As expected, the majority of respondents were unfamiliar with a significant number of the obscure colour terms. Of the list citrine, periwinkle and chartreuse were the terms that participants were most acquainted with, while gamboge and ianthine were the least known.

3.6 Naming Colours

The first set of coloured swatches were named with the most consistency. The responses were dominated by the eleven basic colour terms, with the vast majority of participants using a basic term to name every swatch. The swatch that produced the greatest variety of names could best be described as pink, while the 'white' swatch was the most consistent named. The responses to the second and third groups of colour swatches were far more diverse. There was also some overlap in the colour naming, with respondents giving the same name to different colours. Some of the more interesting responses included; "70s yellow, Industrial green, Blue Pyjamas, Barbie purple, Donkey, Mouldy Green, Red Wine Sauce..." showing a considerable degree of imagination and creativity.

3.7 Interpreting Colour Terms

The interpretation of the basic colour terms was by far the most consistent. However some colour terms produced a wider range of responses than others. Yellow received a very narrow range of interpretations, whereas the responses to purple varied from red toned shades to the more bluish end of the spectrum. The responses to pink, orange, green and blue varied more in their lightness and darkness than hue.

There was a far greater diversity in the responses to the more sophisticated colour terms, notably coral, which some participants identified as blue. Although referring to different hues there was some similarity in the interpretations of tawny, fawn and taupe. Of the sophisticated colours, it was puce that caused the greatest confusion.

The understanding of colour names broke down further in response to the obscure colour terms. Alizarin, ianthine and gamboge were the colour terms least familiar to participants, whereas cerulean and periwinkle were most likely to be identified correctly. Some colour terms were interpreted more consistently than others, including citrine, cerulean, greige and cinnabar, although very few participants identified hues close to the true colour of cinnabar or citrine. In contrast, there was very little agreement among the responses to alizarin, ianthine, cerulean and porphyry.

The full results of the survey and a more detailed discussion can be found at: http://issuu.com/Eleanorbydesign/docs/survey_report

4. CONCLUSIONS

From the results of the project, it is clear that there is considerable diversity in the way we describe and name colours. The assortment of terms given as responses to the survey was far beyond the original expectations of the project. However, the paradox with colour naming is that although a great variety of colour names were given in response to the questions, the eleven basic colour terms still dominate the way we communicate colour.

How we describe colours is a fascinating subject, almost guaranteed to generate discussion and debate. Although this research project captures only a fraction of our interpretations and understanding of colour terms it is hoped that it can, in some way, contribute to the body of research that already exists on colour naming. It is clear that there is great potential to further extend the project, including improving the methodology, obtaining a larger sample and conducting statistical analysis on the data produced by the survey.

Our use of language in the description of colour is fraught with the difficulties of consistency, accuracy and mutual understanding. However, rather than trying to impose rules or design a system to address the issues, this project has become a celebration of our descriptions and interpretations, as it reveals not only the personal nature of our experience of colour, but the versatility and fascinating complexity of our language.

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Shades of Gray: an Experiment in the Context of Illuminant Spectrum Recovery

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ABSTRACT

Much research has been done in the field of colour constancy. Even though recent algorithms achieve reasonable good estimation, it is yet not clear how relevant computational algorithms are in the context of human vision. Research has been made to determine this relationship, for instance, the organisers of the OSA 2011 Fall Vision Meeting launched a contest which main goal was to recover the illuminant spectrum of 10 cone-based generated images by means of computational algorithms. In this paper, we investigate how computational illuminant estimation can be adapted to this human vision experiment. Specifically, how Shades of Gray, a recent algorithm based on a Minkowski norm estimator, performs in this context of illuminant spectrum recovery. We also describe the principles of *Spectral Sharpening* and show why it is crucial to include it to ensure more accurate estimation. Results show that Shades of Gray and its constrained version, not only deliver good performance for the task at hand but also outperforms other approaches.

1. INTRODUCTION

Colour constancy is the ability to determine colour descriptors independent of the illumination in a scene. Typically, colour constancy is divided in two steps: first, the scene's illuminant is estimated from a digital image, and then illuminant-invariant colour descriptors can be extracted. In tasks such as object recognition, colour could be used to describe objects of interests if its invariability (to illumination) could be ensured.

In a recent experiment, the Optical Society of America ran a competition where computational algorithms were – in a blind fashion – evaluated on a set of images (typical of the type used in psychophysical experiments). In our recent work we showed that a simple grey-world type approach (Buchsbaum 1980) could deliver surprisingly good constancy results. However, rather than using the mean RGB in the scene as the estimator, we used a Minkowski p-norm algorithm (Finlayson and Trezzi 2004).

In the Minkowski approach the *p*th root of the sum of the pixel values raised to the power *p* is taken as the illuminant estimate. While the method sound complex, it is effectively weighting bright pixels more in the illuminant estimate. In line with previous work in the algorithm we call this approach *Shades of Gray* or SoG. The method was recently extended to incorporate a constraint of the illuminant, which is called SoGC.

The SoGC approach – though, conceptually simple – is the leading simple algorithm for colour constancy. We were curious to evaluate how well it worked when applied to the OSA experiment (Brainard and Wade 2011).

A key assumption underlying the method is that as the illumination changes the image colours (R, G and B channels) are modulated by a single scaling factor (the so-called von Kries or diagonal model of illumination change). Because the OSA images were in cone space, this model did not apply and so to apply the SoG approach we needed first to transform to the *sharp* sensor basis. Sharp sensors which are linear combination from the cones look more like those found in typical cameras and are explicitly designed so that the diagonal model holds. SoG and SoGC working on sharp sensors both support excellent colour constancy when evaluated on the OSA data set.

2. COMPUTATIONAL ILLUMINANT ESTIMATION IN THE CONTEXT OF SPECTRUM RECOVERY

2.1 SPECTRUM RECOVERY: THE 2011 OSA CONTEST

The OSA's Fall Vision Meeting is an annual meeting designed to motivate scientific discussion among researchers on key aspects in vision science, such as, the visual system, colour vision, perception, application areas and clinical vision. On the 2011 meeting, they presented the Spectrum Recovery Competition 2011. The aim of the competition was to estimate (using computational algorithms) the illuminant spectra for a set of ten cone-response images. That is, an algorithm would have the set of ten images as input, compute a series of operation and finally provide ten illuminant spectra (one for each image). The contest closed on July 2010 but all data details about it (instructions, rules, data, final participant's scores, answers) were made available on line for further reference (Brainard and Wade 2011). This provides an excellent opportunity to test future algorithms in the context of illuminant spectrum recovery for cone response images.

2.2 Spectral Sharpening

Many colour constancy algorithms –including SoG and SoGC– assume that as the illumination changes the pixel's values in each sensor channel scale by the same scaling factor. We model a "redder light" by multiplying all the red responses by a scalar greater than 1. This model is sometimes call the "diagonal model" as we can write illuminant change as a diagonal matrix pre-multiplying an RGB response. Let us denote the sensor response to some surface viewed under an arbitrary light as $[R \quad G \quad B]^T$. If we then denote the sensor response to the same surface but viewed under a second light by $[R' \quad G' \quad B']^T$, then the diagonal model determines that two sets of sensor responses are related by:

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} \alpha & 0 & 0 \\ 0 & \beta & 0 \\ 0 & 0 & \gamma \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

where α, β and γ are three scaling factors depending only on the pair of illuminants. A disadvantage of the diagonal model is that the cone sensitivities have broad functions and the model does not perform well in these cases. However, it has been shown that by using spectral sharpening and working with narrower-band cone sensitivities improves the accuracy of illuminant estimation (see Finlayson 1994, Finlayson and Süsstrunk 2000a and 2000b).

Narrow-band sensors are those that are sensitive to just one wavelength and with respect to these sensors the diagonal model holds (exactly). Sensor-based spectral sharpening finds linear combinations of broad sensors that are maximally sensitive in a given wavelength interval and which are narrower. Using sharp sensors helps algorithms (based on the diagonal model of illumination change) to achieve better estimation than using broad sensors (Finlayson 1994).

It has been shown that a Sharp Adaptation Transformation, which was derived by using a sensor-based spectral sharpening method, is a good spectral sharpening transformation, i.e. the diagonal model is an accurate model of light change with respect to these sharp sensors. Not only does it provide narrower sensors, it also can be used to model psychophysical corresponding colour data (Finlayson and Süsstrunk 2000a, 2000b).

In this work, we incorporate the Sharp Adaptation Transform to derive sharp cones for our experiments. Numerically, this transforms is represented by:

$$Msharp = \begin{bmatrix} 1.2694 & -0.0988 & -0.1706 \\ -0.8364 & 1.8006 & 0.0357 \\ 0.0297 & -0.0315 & 1.0018 \end{bmatrix}$$

3. RESULTS AND DISCUSSION

All the computational algorithms return an RGB estimate of the light. As part of the available data provided by the organisers of the contest, a standard method for mapping this RGB to spectral power distribution is supplied as a Matlab function. Thus, we use the same contest code to turn our RGB estimates into spectra.

An illuminant set needs to be defined prior running SoGC (remember this approach is finding the p-norm central moment subject to the constraint that the estimate is drawn from a set of known possible illuminants). In our experiment we use two different illuminant data sets. We use the 99 Granada University's measurements of day light (Hernandez Andres 2001). Results using this dataset are labelled as v99. For a second set we also add the actual correct answers published with the results of the competition. When using the real answers the algorithm is labelled as v99+10.

Participants in the 2011 OSA contest submitted their spectrum estimations and a score for these submissions was provided. The score was computed as the sum of the squared differences between the relative illuminant spectrum estimations and the actual illuminant spectra, providing a measurement to compare algorithm's performance.

In this work we first test SoG using the cone fundamentals and secondly using sharp cone sensitivities. We then compare their respective performances. The result for this test is presented in Figure 1, where the score for SoG is presented (for norms one to thirty-two). The blue continuous line represents the SoG's performance over cone sensitivities and the star magenta line represents the performance when using sharp cone sensitivities. We can observe from the figure that a remarkable improvement is achieved when using sharp cone sensitivities from norm two and onwards. Furthermore, large norms, from fifteen and onwards, the score remains constant, much more constant than the performance of the cone sensitivities.

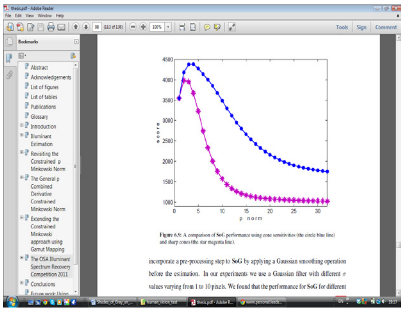

Figure 6.9: A comparison of **SoG** performance using cone sensitivities (the circle blue line) and sharp cones (the star magenta line).

incorporate a pre-processing step to **SoG** by applying a Gaussian smoothing operation before the estimation. In our experiments we use a Gaussian filter with different σ values varying from 1 to 10 pixels. We found that the performance for SoG for different

Figure 1: A comparison of SoG performance using cone sensitivities (circle blue line) and sharp cones (star magenta line)

Next, we want to investigate if including an illuminant constraint helps for the estimation. We compare the results for SoG and SoGC using sharp cones sensitivities for norms form one to thirty-two for the second illuminant set, using the Granada daylights, v99. In Figure 2 we summarise the results. Immediately, we can conclude that a constraint on an illuminant is powerful. Yet, SoGC's best result is surprisingly slightly better than the unconstrained version. An explanation for this counterintuitive result could be that the Granada daylights did not well represent the actual lights used in the experiments.

For this reason, we carried out an experiment where we added the ten actual lights to the Granada Lights, v99+10. The results are summarised in Figure 3. The best result achieved on this experiment are 1023.6 for SoG and 297 for SoGC. We can observe that adding a constraint on the illuminant does make a significant difference. From this experiment, we can conclude that when care is taken to select a representative and relevant illuminant set, the constrained version of SoG is a powerful estimator.

Finally, the best scores for the algorithms participating in the competition were: the leopards (1st place), 597.92, ales (2nd place), 1224.95, abe (3rd place), 1299.71, pinkStinks (4th place), 1331.71, Grey World (13th place), 3544.88. Furthermore, the best scores for the algorithms tested in this experiment are: for SoG, the best score was 1033 for *p=32*, while for SoGC v99, the best score is 1078.8 for *p=1*, and for SoGC v99+10, the best score is 297 for *p=11*. Again, we can see how the constraint helps to improve the illuminant spectrum estimation. Moreover, for SoGC the results are comparable with those of the algorithms participating in the contest, even the results of the winning algorithm.

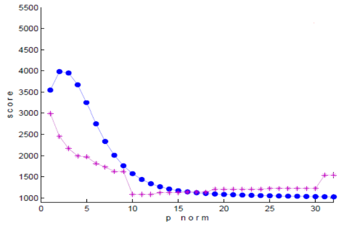

Figure 6.12: The results for sharp cone sensitivities using the Granada Daylights for SoG (circle blue line), SoGC (star magenta line), CD (triangle red line) and CDC (square green line).

Figure 2: The results for sharp cone sensitivities using the Granada Daylights, v99, for SoG (cirlce blue line) and SoGC (star magenta line)

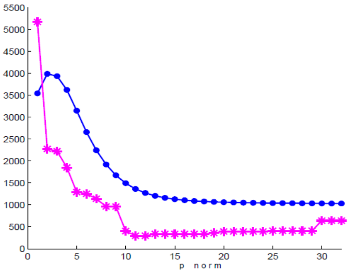

Figure 3: The results for sharp cone sensitivities using the Granada Daylights plus the real lights, v99+10, for SoG (circle blue line) and SoGC (star magenta line)

4. CONCLUSIONS

We wanted to investigate if the computational illuminant algorithm Shades of Gray could be applied more generally in the context of human vision. We carried out experiments for the OSA Illuminant Spectrum Recovery Competition and showed that the algorithm achieves good estimation. Furthermore, by using the constrained approach on spectral sharpened cone sensitivities we achieve remarkable good illuminant spectrum recovery in terms of this human vision test. The results for SoGC outperform its unconstrained counterpart and other computational algorithms (if our algorithm had entered the competition it would have been in first place, out of 32 entries).

ACKNOWLEDGEMENTS

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Rod, Cone and Melanopsin Interactions in Color Perception

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ABSTRACT

The recent discovery of intrinsically photoreceptive retinal ganglion cells (ipRGCs) has led to a fundamental reassessment of non-image forming processing, such as circadian photoentrainment and the pupillary light reflex as well as visual perception. This study is intended to present an investigation of color perception in human vision in relation to ipRGC, cone and rod stimulations. A four-primary stimulation system that enables independent stimulation of each receptor class was used to control stimulation of the three cone types, rods and ipRGCs in the human eye. We applied these stimuli for backgrounds at intense photopic light level and at dim mesopic light level for cone, rod and ipRGC stimulations. Thresholds for change detection were measured. It was found that there was a weak interaction between ipRGC and M-L cone-opponent signals at the photopic light level where both cones and ipRGCs are activated. On the other hand, there was a strong interaction between rod and M-L cone-opponent signals at the mesopic light level where both rods and cones are activated. These results indicated that there is a small contribution of ipRGCs to color perception.

1. INTRODUCTION

The discovery of melanopsin-containing retinal ganglion cells (ipRGCs) has led to a fundamental reassessment of non-image forming processing, such as circadian photoentrainment and pupillary light reflex, suggesting that ipRGCs play an important role in encoding ambient illuminance in the brain function. Signals from ipRGCs contribute to non-image forming processing along with signals from the classical photoreceptors rods and cones.

Growing evidence indicates that ipRGCs contribute not only to non-image forming processing but also to visual perception. For example, a blind human patient lacking functional classical photoreceptors can detect a monochromatic light stimulus (Zaidi et al. 2007), suggesting that ipRGC-mediated signals may support conscious awareness. There is a strong input of ipRGC signals to a large portion of neurons in the lateral geniculate nucleus (Brown et al. 2010); these neurons showed sustained activation to a steady-state light step. Furthermore, the ipRGC-mediated signals influence brightness perception in both mice and humans (Brown et al. 2010; Brown et al. 2012). Although these results support the fact that ipRGCs play an important role in the conventional visual pathway in the brain, their functional role is not yet clear. This study is intended to present an investigation of color perception in human vision in relation to ipRGC, cone and rod activations.

In humans, it is difficult to investigate whether ipRGCs contribute to visual functions. The challenge stems primarily from the need for selective stimulation of ipRGCs avoiding those of other receptors and post-receptoral mechanisms. For example, since the ipRGCs are sensitive to blue-green lights one could use a monochromatic light stimulus having an approximate wavelength of 480 nm to selectively stimulate ipRGCs. In this case, however, the classical photoreceptors are strongly stimulated. As a result, it is difficult to extract ipRGC contribution in luminance and color perception by using such a technique.

In this study, in order to stimulate ipRGCs independently from the other photoreceptors, we used a silent-receptor substitution technique with a four-primary stimulation system.

2. METHOD

2.1 Apparatus

A personal computer controlled the four-primary illumination system. Four different types of light-emitting diode were used. The annular ring test stimulus was superposed on the circular adaptation field using a beam splitter (Figure 1). A detailed description of the illumination system has previously been published (Tsujimura et al, 2010; Tsujimura and Tokuda 2011; Brown et al. 2012).

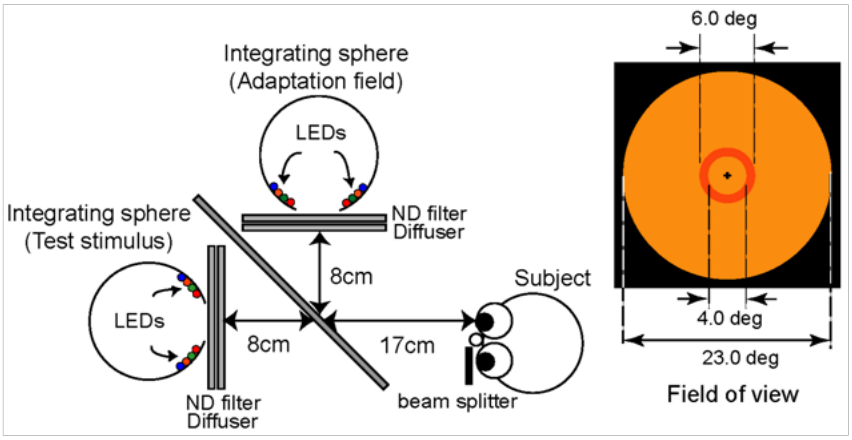

Figure 1: Experimental setup.

2.2 Procedures

Four observers participated in this study. All observers had ocular health and normal color vision according to the Ishihara color blindness test. All observers gave written informed consent; the study was approved by the local research ethics committee.

The 10-deg cone fundamentals were used to calculate the stimulation of three cone types. In addition to these three cone fundamentals, we used a spectral sensitivity curve for ipRGC. We estimated the spectral sensitivity of ipRGC from a pigment template nomogram with a peak wavelength of 480 nm. The resultant spectral sensitivity function of ipRGC in a 10-deg field displayed a peak wavelength of 493 nm.

We used two test stimuli: an M-L stimulus and a metameric stimulus. The M-L stimulus modulates the stimulation of M and L-cones antagonistically with no changes in luminance or stimulation of other receptors. The metameric stimulus modulates the ipRGC and rod stimulations with no modulation of cones (i.e. no change in luminance and color in photopic vision). The metameric stimulus appears indistinguishable to cones despite having different spectral power distributions. We used the metameric stimulus with a neutral density filter for rod stimulation and used the same metameric stimulus without neutral density filter for ipRGC stimulation since the peak of spectral sensitivity curve for ipRGCs is close to that for the rod. The metameric stimuli for rod stimulation was generated by a spectrally neutral decrease in radiance of the metameric stimulus for ipRGC stimulation.

In the first experiment, we chose the intense adaptation field to investigate the cone and ipRGC interaction in photopic vision. In the second expeirment, we chose the dark adaptation field to investigate the rod and cone interaction in mesopic vision. A temporal sinusoidal grating (1 Hz) was used as test stimulus that was modulated on the background. Thresholds for change detection were measured. Test stimuli were a mixture of M-L stimulus and the metameric stimulus in variable ratios. These stimuli were represented on the M-L vs. ipRGC/rod plane. The change detection threshold on the plane illustrates how ipRGC/rod and M-L signals influence each other. The shape of the threshold contours on the planes can provide information on the relative contribution of color and ipRGC/rod signal.

3. RESULTS AND DISCUSSION

The left panel in Fig.2 showed a typical result in photopic condition that represent the threshold contours in the M-L vs. ipRGC plane. The vertical axis represents the metameric stimuli that modulate only ipRGC stimulation at the intense adaptation field. The horizontal axis represents the M-L stimuli modulating only red-green isoluminant color component. The results at the intense adaptation field showed that the threshold contours were almost parallel to the vertical axis on the M-L vs. ipRGC planes for all observers, indicating that these thresholds were determined mostly by signals on the horizontal axes, namely, the M-L cone-opponent signals, although the test stimuli were a mixture of the M-L and ipRGC stimuli in various ratios. These results showed that the axis of the least sensitivity to M-L color-opponent post-receptoral mechanisms corresponds to the ipRGC axis, indicating that there is a small contribution of ipRGCs to color perception.

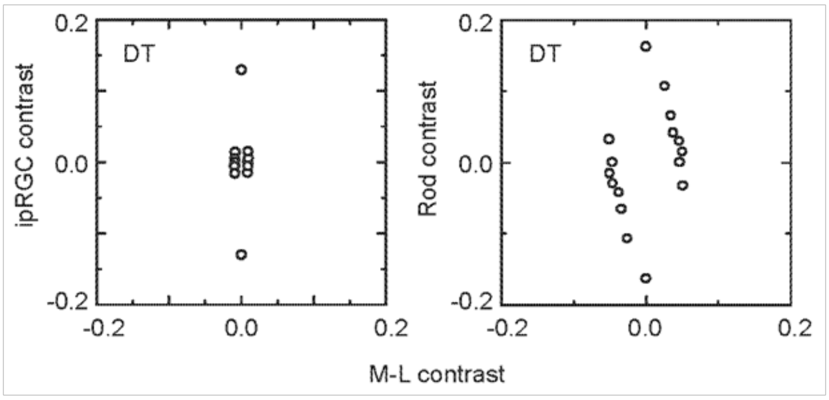

Figure 2: Threshold contours in M-L vs. ipRGC plane (left) and in M-L vs. rod plane (right).

The right panel in Fig.2 showed a typical result in mesopic condition that represents the threshold contours in M-L vs. rod plane. The vertical axis represents the metameric stimuli that modulate only rod stimulation at the dark adaptation field. The horizontal axis represents the M-L stimuli. Note that the shape of spectral distribution of the metameric stimulus used here was generated by a spectrally neutral decrease in radiance of the metameric stimulus for ipRGCs.

The results at the intense adapting field (the left panel) showed that the threshold contours were almost parallel to the M-L axis. The results at the dark adapting field, on the other hand, showed that there is a strong contribution of rod signals to color perception. It was found that the threshold contours had negative slopes on the M-L rod plane for all observers. In other words, as rod signals increase less M-L signals were required, indicating that the M-L and rod signals were positively summed, suggesting that M-L cone-opponent mechanism receives rod signals and *vice versa*. It seems reasonable to conclude from these results that the contribution of ipRGCs to color perception is smaller than the rod contribution to color.

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A Novel Colour Discrimination Test Suitable for Low Vision Observers

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ABSTRACT

Normal colour vision relies on the absorption of light by the short-, medium-, and long-wavelength-sensitive cones. If one or more cone types are absent, or their function is compromised (e.g., diabetic retinopathy, macular degeneration, Leber Congenital Amaurosis), colour vision is affected. Most of the available colour vision tests (with some exceptions, e.g. Simunovic et al. 1998; Arden and Wolf 2004; Barbur 2004) can only assess the degree of colour vision in observers with visual acuity better than 1.0 logMAR. To measure the residual colour vision retained by observers with lower visual acuity, we have developed a new test which uses a large 5-degree target. The test is a promising tool for measuring and monitoring changes in colour vision due to the progression of a disease or its improvement after a clinical treatment.

1. INTRODUCTION

This work is inspired by our recent involvement in gene therapy clinical trials which are currently taking place at Moorfields Eye Hospital and the Institute of Ophthalmology, University College London. The participants of these trials are patients affected by severe and progressive cone-rod dystrophies. The gene therapy treatments aim to arrest the progression of the disease and restore normal visual functions. In order to monitor the effect of treatment, it is very important to determine an accurate baseline of the patient's visual performance before the treatment, as well as accurately monitor any sign of improvement or degeneration after treatment. Our team is involved in measuring several aspects of visual performance, but here we concentrate only on the chromatic discrimination assessment.

Chromatic discrimination is the ability to distinguish two test lights uniquely on the basis of their chromatic difference. This ability relies on the absorption of light by the short-, medium-, and long-wavelength-sensitive cones. If one or more cone types are absent, or their function is compromised (e.g., diabetic retinopathy, macular degeneration, or Leber Congenital Amaurosis), colour discrimination is affected. Several studies on chromatic discrimination conducted so far (e.g., Bedford and Wyszecki 1958, MacAdam 1942), have characterised the chromatic discrimination of normal trichromats during their life span (see for example Knoblauch et al. 2001, Paramei 2012). While there has been a growing interest in measuring the spatial and temporal properties of vision in observers affected by visual deficits, the information about their colour discrimination is sometimes incomplete. This is because most conventional colour vision tests (with some exceptions, e.g. Simunovic et al. 1998; Arden and Wolf 2004; Barbur 2004) have been designed to screen for inherited colour vision deficits that are typically stationary, binocular, symmetrical, and usually characterised by a relatively good degree of visual acuity. These tests are generally unable to measure small or gradual changes in colour discrimination and often cannot be used to test observers with low vision.

The aim of our study is to develop a Universal Colour Discrimination Test (UCDT) that is able to:

(i) provide an accurate measurement of colour vision in observers with both progressive and stationary visual deficiencies, including those with low vision

(ii) monitor the progression of the disease and assess the effectiveness of treatments

(iii) make the assessment suitable for observers of any age and any motor or intellectual abilities

2. METHOD

2.1 Observers

Twenty nine adults and fourteen children, labelled as Normal or Affected according to their performance as measured by conventional colour vision tests, were tested.

2.2 Apparatus

A 22” NEC CRT was used to display the stimuli, using ViSaGe (CRS Ltd) connected to a DELL computer. The monitor’s spatial resolution was set to 1024 × 768 pixels at 120 Hz. A response box (Cedrus) was used to collect observers’ responses.

2.3 Stimuli

The stimuli consisted of a 35.1 × 26.6° background made of circles of random luminance with a small sub-set of them delineating a 5° square-target. The target varied in saturation and hue along 20 colour directions (illustrated by the grey dashed lines in Figure 2) which were equally spaced and centred on the white point [CIE (1931) chromaticity coordinates (x,y) equal to (0.333, 0.333)]. The luminance of the circles varied between 6 and 26 cd/m^2.

2.4 Procedure

Using a 2AFC paradigm and a weighted 1 up / 1 down staircase (Δ- / Δ+ = 1/3), observers indicated whether the chromatic square appeared on the left or on the right. On the next trial, the target saturation decreased if the answer was correct or increased if the answer was incorrect. Large, medium and small step sizes (Δ) were used depending on the number of reversals completed. We measured the minimum saturation required (mean of the last 5 reversals) for each observer to discriminate the target from the background along each direction of the CIELUV colour space. We tested adults and children on the UCDT, as well as the Cambridge Colour Test (CCT), the Ishihara plates, the Farnsworth-Munsell 100 Hue Test or the D15, and the Nigel Anomaloscope.

3. RESULTS AND DISCUSSION

We fitted each observer’s chromatic discrimination thresholds with an ellipse and considered the length of the major axis (Figure 1) and the axial ratios (Figure 2) as indices of colour discrimination. Normal observers had the shortest axis and ratios approximately equal to 1. Affected observers had the longest axes and the highest ratios, with no difference between adults and children. The ratios obtained with our test (UCDT) generally agreed with the ones obtained with the CCT.

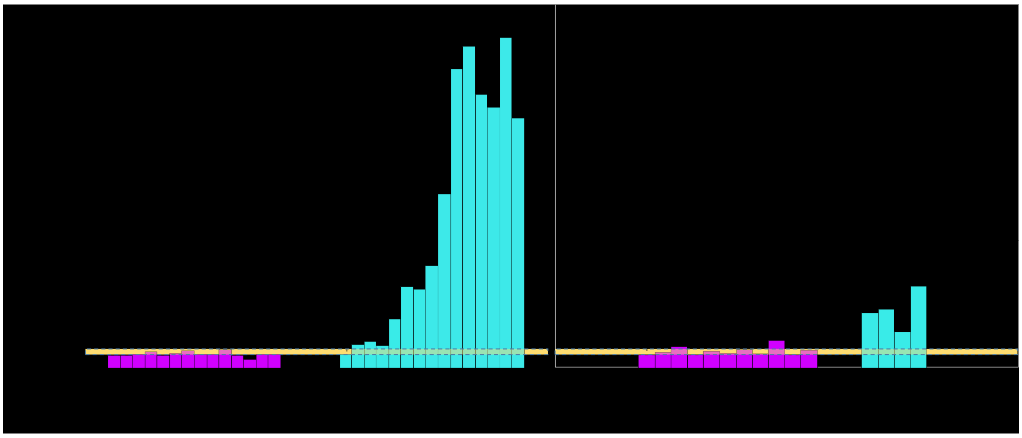

Figure 1: Length of the ellipse's major axis for Normal adults and children (magenta) versus Affected adults and children (cyan). The yellow horizontal bar represents the Normal mean length ±1 stderr. Shorter axis length indicates that less saturation is required to discriminate the target from the background.

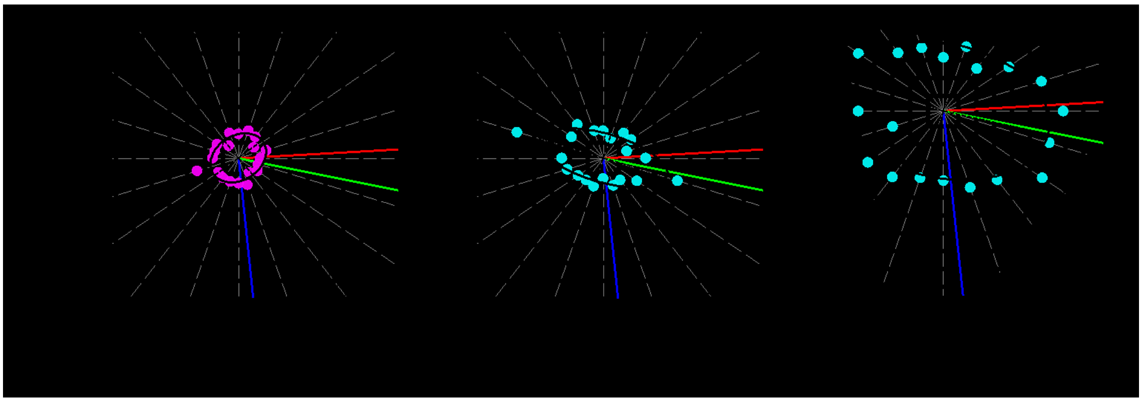

Figure 2: Representative data from one Normal (left) and two Affected observers (Deutan, middle; incomplete Achromat, right) and their respective axial ratios.

Representative chromatic discrimination thresholds from one Normal (left), one Deutan (middle), and one incomplete Achromat (right) are illustrated in Figure 2. The black ellipse represents the thresholds' best fit and the dashed black lines the ellipse's axes. The dashed grey lines illustrate the 20 colour directions probed, and the continuous red, green, and blue lines represent the protan, deutan, and tritan confusion axes, respectively. Note that the u' v' axes of the right panel are scaled differently.

Our test was able to measure colour discrimination in all affected observers, including those who, due to their low visual acuity had been unable to perform the conventional tests, including the CCT.

4. CONCLUSIONS

Chromatic discrimination thresholds measured by our test were generally consistent with those measured by the CCT. Moreover, observers with very low (worse than 0.78 logMAR) visual acuity were not able to perform the CCT, but could successfully complete our test. This result has important clinical implications, as it allows us to determine chromatic discrimination baselines in patients undergoing clinical treatments.

The test is a promising tool for measuring and monitoring changes in colour vision due to the progression of a disease or its improvement after treatment. Our future goals are to validate the test with a larger number of observers and to extend it to younger ages by using gaze-contingent (eye tracking) methods.

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Bezold Effect Produced in the Vision of a Sequence Rectangular Neutral Interleaved in a Monochromatic Grating (red, green or blue)

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ABSTRACT

The Bezold effect produced in the vision of a rectangular sequence embedded in a grating neutral monochrome (red, green or blue) is proportional to the angular frequency of the same. It may represent the relationship between the two variables like a straight line, type "ay = bx + c" where the variable "y" refers to the Bezold effect (eB) and the variable "x" to the angular frequency of the grating (fa).

1. INTRODUCTION

It is well known that, apart the physical magnitudes of a color test (dominant wavelength, purity and the luminance factor) their psychophysical magnitudes (hue, saturation and lightness) may vary depending on the surrounding colors. With certain spatial distributions, interspersed colors (in this case, the colors of a grating) were added to the test studied (in this case a sequence) this phenomenon was described by Bezold (Bezold 1876) and known for assimilation effect (Evans 1948), Bezold effect (Albert 1963), expansion effect or, simply, chromatic assimilation.

In our laboratory[1], from ten years ago (Aguilar 2001) to actuality (Tortajada 2011), we quantified this effect in color vision. In this paper we analyzed the vision of a neutral sequence, against the background of a rectangular monochromatic grating (red, green or blue) causing the Bezold effect in the viewing of the sequence.

2. METHOD

The experimental technique used is based on a test consisting of three neutral parallel sequences of a width equal to the separation (1 cm.), Such sequences having a rectangular bottom with a period of 2 cm. covering a circle of 20 cm. in diameter. This circle is circumscribed by a square. The grating is presented with two orientations, vertical and horizontal stripes, with their sequences always perpendicular to the grating (Figure 1).The test are generated and printed by a computer previously calibrated.

Observers initially were adapted to darkness form 10 min before the observations. From a distance of 4 meters where not seen the central sequence, observers they approach the test in four intermediate distances of 3, 2, 1 and 0.5 meters, giving the value V which in his opinion has the visual perception of the central sequence on a scale ranging from 0 to 10. The observer compares the central sequence with the two lateral sequences. The two side stripes are always given a fixed value of 10. The value 0 means that observers do not perceive the central sequence (disappears). The value 10 means that the central sequence is perceivedequal to the laterals.

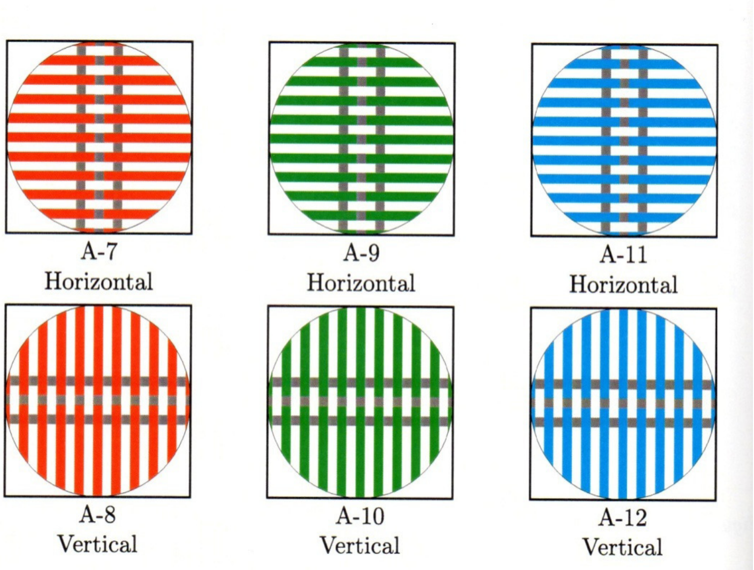

Figure 1: Test used in the experience.

With this value we determine the visual contrast in the distances above, between the central and lateral sequence. With this contrast we quantify the Bezold effect by the expression:

The chromaticity coordinates of colors used are listed in Table 1,and its Y in all cases is the order of 25 cd/m^2.

Table 1. The chromaticity coordinates of the color of the test used on experience.

Color	**x**	**y**
Red	0.58	0.36
Green	0.37	0.48
Blue	0.29	0.36

On the experiences, we have used four observers, all are students, aged between 20 and 25 years and with normal vision.

The experiments have been conducted in a room painted medium grey and completaly dark. The tests have also been placed on a medium gray cardboard.

3. RESULTS AND CONCLUSIONS

The results are presented in Table 2 and Figure 2 attached.

Table 2. Equations relating to each of the three colors of the sequence to study the two variables, Bezold effect (y) and the angular frequency of grating (x)

Color	Equation of lines	
	Horizontal Grating	Vertical Grating
Rojo	y = 0.17 x + 0.05	y = 0.14 x – 0.39
Verde	y = 0.17 x + 0.08	y = 0.14 x + 0.09
azul	y = 0.14 x + 0.10	y= 0.17 x + 0.06

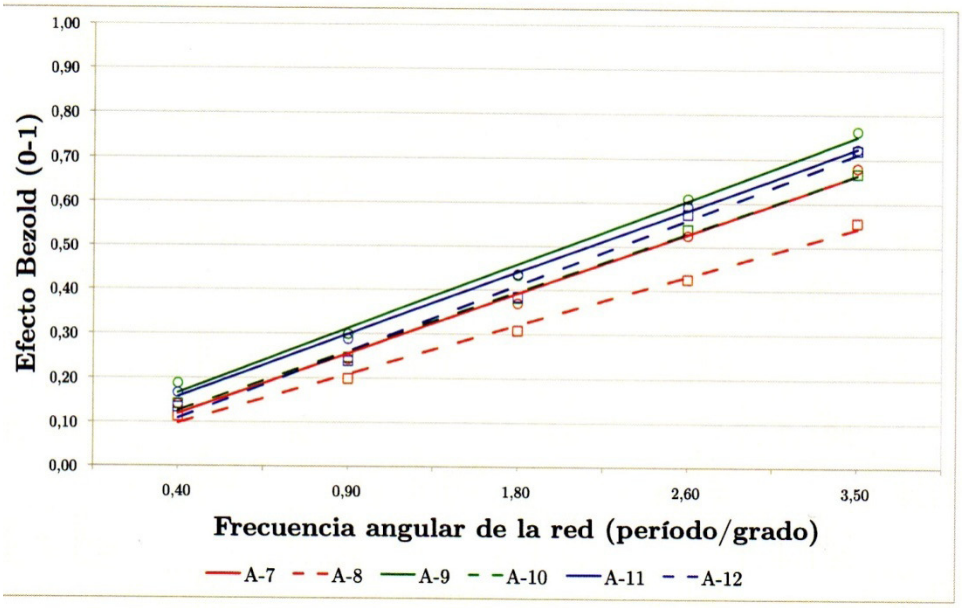

Figure 2. Relationship obtained between Bezold effect and the angular frequency of the network (in period / degree)

The observation of the table and the graph, leads us to obtain within the magnitudes in which we worked, the following conclusions:

1. The action of Bezold effect in the vision of a neutral rectangular sequence interleaved perpendicularly on a grating monochromatic (red, green or blue) oriented horizontally or vertically is proportional to the angular frequency, according to the equation of a line of type “ay = bx + c”.

2. With red and green gratings, the relationship “Bezold effect - angular frequency” is greater with the horizontal orientation of the grating, the opposite happening with the blue.

3. With the red grating, the relationship “Bezold effect - angular frequency” is much higher than green or blue gratings.

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Categorical Colour Constancy during Colour Term Acquisition

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ABSTRACT

To elucidate the relationship between colour constancy and colour categorisation we investigated categorical colour constancy at the stage when toddlers are learning colour terms. In adults there is a robust pattern of categorical constancy across different colour shades. If this pattern has a perceptual origin in colour constancy, category development should follow this pattern. In contrast, if the pattern is the result of categorisation it should emerge when toddlers learn the categorical concepts that correspond to colour terms. For this purpose, we focused on toddlers who are just developing linguistic colour categories (39-42 months). We asked them to categorise 160 Munsell chips under different illuminations. For each toddler, we determined how consitently each chip was categorised across illuminations, resulting in a consistency map. The consistency map of toddlers was positively correlated to the typical consistency map of adults, indicating that the pattern of consistencies across colours was highly similar between toddlers and adults. These results show that category development follows the pattern of categorical colour constancy found in adults. These findings support the idea that categories develop around colours that are perceived as particularly constant.

1. INTRODUCTION

Colour categories and colour constancy serve the purpose of reliably identifying surface colours across illuminations and across observers. This is shown by the categorical colour constancy of adult observers. Categorical colour constancy is the consistency of category membership across changes in illumination and across observers. In fact, the categories that correspond to basic colour terms are highly stable even across dramatic changes in illumination (Olkkonen, Witzel, Hansen, and Gegenfurtner, 2010). As a result, the identification of colours through colour terms is highly reliable across illuminations and across observers.

The question arises whether the development of colour constancy and colour categorisation involve common processes of adaptation to and coordination with the visual environment so as to achieve a high level of categorical colour constancy. This idea is supported by the finding that the stability of categories across illuminants is linked to the stability across individuals. In fact, there is a robust pattern of categorical constancy across different colour shades in adults (Olkkonen, Hansen, and Gegenfurtner, 2009; Olkkonen, et al., 2010).

Moreover, Philipona and O'Regan observed that the light reflected by prototypes of the basic categories is particularly stable across changes in the illumination (Philipona & O'Regan, 2006). As a result, these stable colours might be used as points of reference in communication, resulting in the development of categories around these points of reference. This would also explain why these typical colours are particularly stable across languages (Regier, Kay, and Cook, 2005).

To elucidate the relationship between colour constancy and colour categorisation we investigated categorical colour constancy at the stage when toddlers are learning colour terms. The first colour naming skills appear around 2 years of age, and stabilise around 3 years

(Pitchford and Mullen, 2002). In contrast, perceptual colour constancy develops much earlier. In fact, there is evidence for colour constancy in 4-5 month old infants (Dannemiller, 1989; Dannemiller and Hanko, 1987).

If the pattern of categorical constancy found in adults has a perceptual origin in colour constancy, category development should follow this pattern. In contrast, if the pattern is the result of categorisation it should emerge when toddlers learn the categorical concepts that correspond to colour terms. In this case, toddlers with immature categories should produce a categorical constancy pattern that is specific to their idiosyncratic categories rather than to the adult categorical constancy pattern.

2. METHOD

2.1 Participants

To assess category development, we studied toddlers who just know all or almost all basic colour terms, but do not yet categorise all colours like adults. Hence, we focused on toddlers between 36-42 months, but some older children were also included for comparison. The sample consisted of 20 toddlers, whose age varied between 36.5 months and 52.9 months, with a median age of 41.8 months.

2.2 Stimuli and procedure

Before the main experiment we assessed toddlers colour term knowledge with the naming and comprehension tests of Pitchford and Mullen (2002), and we excluded colour deficiency with the number-free Ishihara plates (Ishihara, 2004).

We then asked the toddlers to assign each of 163 Munsell chips to one of the 8 chromatic basic colour terms (pink, red, orange, yellow, green, blue, purple, and brown). The task was made into a fun game where coloured chips were set in grey (Munsell N5) cardboard shapes (e.g., hats) and children were told that a toy animal (of neutral colour) would wear items of clothing only of one colour category (e.g., red) and were asked to give each animal their clothes. The chips varied across 40 Munsell hue steps and 5 lightness levels (Munsell Values 3-6, and 8), and were maximally colourful (Munsell chroma). Only 3 chips were included at lightness four. The categorization task was repeated twice under neutral, and once under red, and green illumination.

3. RESULTS AND DISCUSSION

All toddlers were able to name and comprehend at least 10 of the 11 basic colour terms in the naming pre-test. This was necessary to make sure that toddlers could accomplish the categorization task at all.

We tested whether the toddlers' categories build around the colours whose category membership was particularly stable in adults. For this purpose, we calculated categorical consistency as the relative frequency of same-classifications across measurements (number of given same-classifications divided by the maximum number of possible same-classifications). For example, if a child used the same colour term for a particular chips in 3 out of 4 conditions, this results in a consistency of 0.66 (2 out of 3 possible same classifications). In this way, we calculated the consensus across observers and the consistency across repeated measurements (i.e. the different illuminations) for each chip.

We calculated an overall consistency map for adults for 5 observers and across 5 different illuminants, as measured by Olkkonen and colleagues (2010). In adults, category membership was most stable for colours in the centre of the categories, and the consensus across observers correlated with the consistency across illuminants (cf. fig. 8 in Olkkonen, et al., 2010).

If category development is completely determined by perceptually stable colours, even toddlers with a low category maturity should show a consistency map that is similar to the adult one. In contrast, if category development is driven by the toddlers' concepts of categories, the consistency map should follow the idiosyncratic category pattern of each toddler.

To quantify the relationship between the consistency maps of toddlers and adults we calculated their correlations across colours. The consistency maps of 18 out of 20 toddlers correlated positively with the adult consistency maps (all $p < 0.05$). The average correlation was 0.35, and significant across observers ($t(19) = 8.4$, $p < 0.001$; based on Fisher transformations). These results indicate that the pattern of consistencies across colours was highly similar between toddlers and adults

However, it might be the case that the toddlers in our studies were too advanced in category development. In this case, the similarity between the consistency maps might just be due to the fact that their categories were very similar to the adult ones. To control for the similarity between the toddler and adult categories, we identified for each toddler those chips that they assigned to the same categories as adults. We calculated partial correlations between the adult and toddler consistency maps, controlling for the similarity between their categories. The average correlation was $r = 0.25$ and significantly larger than zero across toddlers ($t(18) = 6.8$, $p < 0.0001$; based on Fisher transformations). These partial correlations show that there is a systematic similarity between the toddler and the adult consistency maps beyond their similarities in categorization.

4. CONCLUSIONS

Children with immature colour categories showed a highly similar pattern of categorical constancy as adults. These findings show that this pattern exists during category development and is not just the result of adult categorisation performance. These findings support the idea that categories develop around colours that are perceived as particularly constant. Alternatively, this pattern may also arise because adults teach toddlers the categorical concepts based on particularly stable and representative prototypes, such as the typical greens or reds. At the same time, this alternative explanation does not contradict the idea that categories develop around perceptually stable colours. In fact, the stability of these colours might also explain why adults tend to use these colours in order to teach category concepts to toddlers.

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Colour Shift: Perceived and Measured

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ABSTRACT

This paper presents further results from the research project “Translucent facades” that was initially presented at AIC 2012. In the present paper the results of the colorimetric measurements are presented and compared to the results from visual matching carried out by observers. Interestingly, those two methods lead to the same results for all colour samples examined in the project. Both methods, the visual matching and the colorimetric measurements, may be used in the examination of colour appearance, particularly in research projects dealing with glazing solutions.

1. INTRODUCTION

How much do interior colours change their visual appearance due to a given type of glazing and in which direction do they change, e.g. hue and nuance?

The study aiming at answering this question was carried out in the overcast sky simulator in Daylight Laboratory at NTNU and was presented at the AIC 2012 Interim Meeting, Taipei. In this study, 28 NCS colour samples were tested in a scale model, to which different glazing types (or no glass) were fixed. Visual matchings were made between samples seen behind glass (or no glass) and samples behind blinds, both lit by artificial daylight. All glazings were evaluated twice, with the colour samples seen against a white and a black background, respectively. With both backgrounds, the colours shifted towards the same direction, also the shifts were slightly larger when the samples were seen against the black background. As our aim was to detect patterns and tendencies rather than exact measurements of colour shifts, we decided to use only the observations against black background for further analysis, see Figure 1.

The main goal of the present work is to verify:

whether and in that case how the human judgement correlates with the colorimetric measurements.

2. METHOD

In order to answer this question the samples were measured under the same experimental conditions as the observers made the visual matching i.e. the spectral power distribution was measured in the same model in the same illumination (Daylight Laboratory at NTNU) for the same NCS-samples and for the same glazings. The measurements were taken in Feb. 2012 using the Spectro-radiometer CS-1000 from Konica Minolta. The model had two chambers with equal surfaces and geometry, Figure 1A. The reference chamber was equipped with the especially designed, vertical and white blinds-system that enabled precise adjustment of the light flux from the Artificial Sky; different types of glazing could be fixed to the test chamber. To keep equal light level in both chambers the blind-system was used, and the illuminances were measured in both chambers (Hagner EC1 lux meters) before each colorimetric measurement was performed.

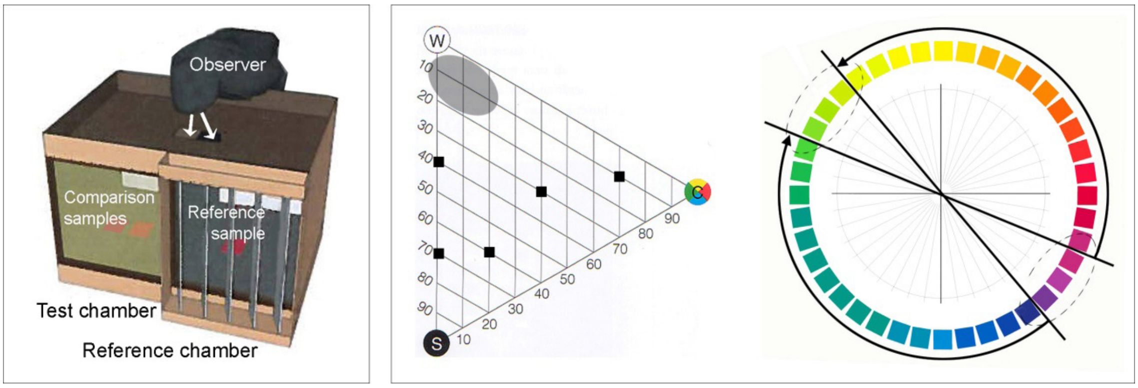

Figure 1: A: Illustration of the model. B: To the left; approximate area where the nuances proved sensitive to hue shifts caused by glazings (shaded area). The points show tested nuances that did not prove sensitive to such shifts. To the right; principle of hue shifts.

3. RESULTS

The results for six NCS-samples and for two situations: no glass and blinds are presented in Figure 2. By comparing the results for each sample, we may find out that blinds reduced the light level to about 43% of the level measured with no glass, without any significant change of spectral power distribution pattern. Due to en almost linear shift, it may be concluded that blinds do not cause any colour change.

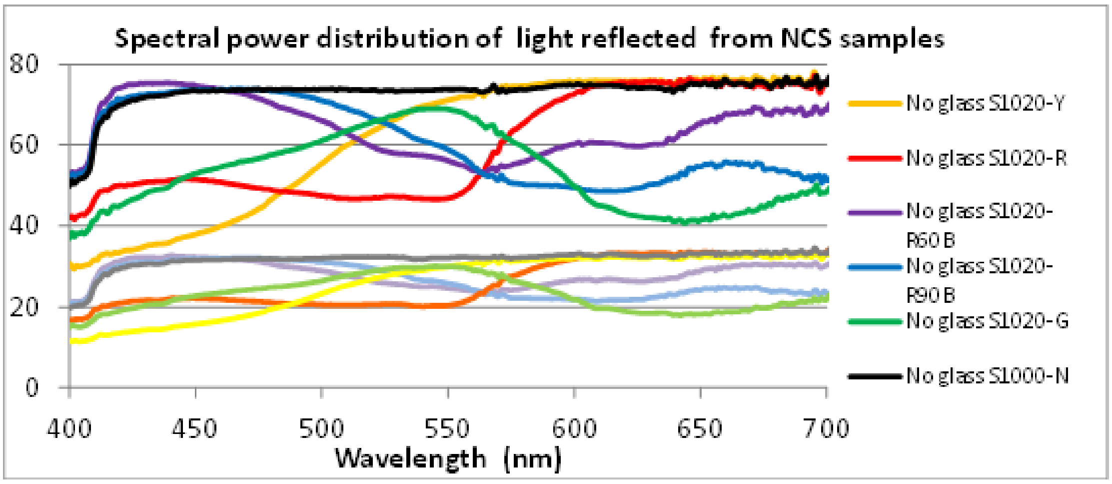

Figure 2: Spectral power distribution of light reflected from the NCS-samples, indicated in percentage of a perfect white sample. No glass versus blinds.

Figure 3 presents the results for the same six NCS-samples in two situations: no glass and 3-layers low-energy glazing. The power of light is strongly reduced by the glazing in the whole spectrum and the reduction varies between different wavelengths. This may be observed by examining the spectral distributions of the grey sample (S1000-N) measured with and without glazing. The reduction in both ends of the spectrum is respectively, down to 35% of "no glass" for blue and to 26% of the "no glass" for red. The reduction in the middle part of the spectrum (yellow-green) is lower, i.e. to 47% of the “no glass” level. Similarly wave-length dependent reductions may be observed for all other colour samples.

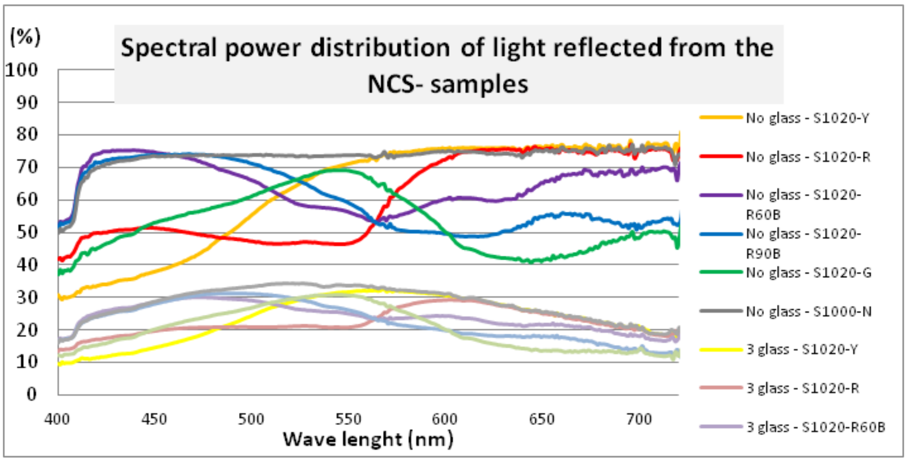

Figure 3: Spectral power distribution of light reflected from the NCS-samples, indicated in percentage of a perfect white sample. No glass versus 3-layers glazing.

Since the illuminance level measured at the sample in both chambers was nearly equal and the samples had very similar reflectances, the luminance level of the samples placed in the chamber with blinds and in the chamber with 3 layer of glass was very similar too. The CIE colour system characterizes colors by a luminance parameter Y and two color coordinates, x and y, which specify the point on the chromaticity diagram. Since the luminances for the respective samples were similar, we may show all the examined colours at the same chromaticity diagram, see Figure 4.

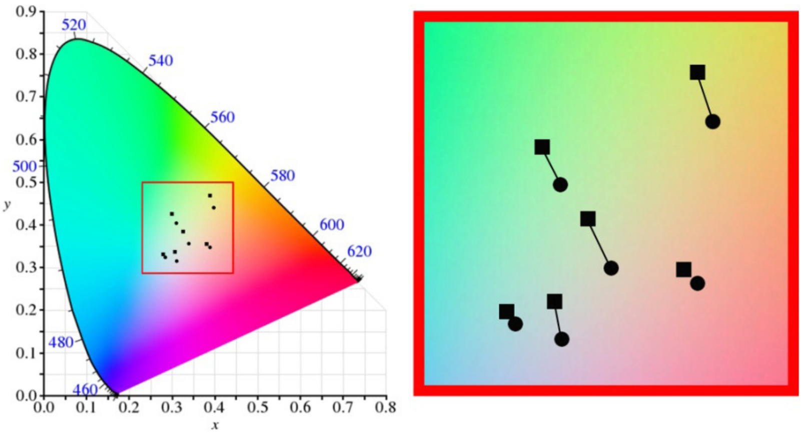

Figure 4: Chromaticity diagram with the results of colorimetric measurements for situations: Blinds and 3-layers glazing for the six NCS-samples. The results for blinds are shown with circles and for 3-layers glazing with squares.

The measured colours of the NCS-samples behind 3-layers glazing (squares) are situated nearer to the green area of the chromaticity diagram than the measured colours of the same NCS-samples without glass (circles). We see the colour shift toward yellowish green as caused by the glazing.

Is it possible to counteract colour shift toward yellowish green? Many different NCS samples were examined, both visually and with the colorimetric measurements, to find out if it is possible to find a sample that placed behind 3-layers glazing has a colour equal to the test sample placed behind blinds; the results for the yellow colour are presented in Table 1. To find out which of the NCS samples placed behind 3-layers glazing is closest to the S1020-Y (Blinds), the distance at the chromaticity diagram was calculated, D(m) in Table 1.

Interestingly, the sample S1015-Y20R (3 glass) which, according to the colorimetric measurements, is the closest one to the S1020-Y (Blinds) was also evaluated as the closest one to the S1020-Y (Blinds) with the visual matching, see the last row in the table! Corresponding observations were done for the other colour samples, i.e.: red: S1020-R, violet: S1020-R60B, blue: S1020-R90B, green: S1020-G and grey S1000-N.

Table 1. Colorimetric measurements for the yellow sample S1020-Y placed behind blinds and a series of NCS-samples placed in the test chamber, behind 3-layers glass.

	Blinds	**3 glass**					
	S1020-Y	**3S1020-Y**	**S1020-Y20R**	**S1010-Y20R**	**S1020-Y10R**	**S1020-G90Y**	**S1015-Y20R**
Y	29,488	30,248	28,229	29,808	29,795	31,109	30,793
x	0,3717	0,364	0,371	0,352	0,367	0,359	0,363
y	0,4124	0,428	0,422	0,405	0,426	0,430	0,415
D(m)	0	0,0181	0,0097	0,0205	0,0148	0,0214	**0,0092**
Vis. match	sample						Best match

4. CONCLUSIONS

The results of this study lead to the following conclusions:

- The visual matching and the colorimetric measurements are both good methods for testing the appearance of colours in rooms.
- The glazing used in the study, 3-layers low emmisivity glass, causes the colour shift of interior colours in the direction to the yellowish green.

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The Effect of Age on Observer Variability

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ABSTRACT

The present experiment investigated observer metamerism between four stimuli sizes (2°, 6°, 10° and 20°) and between 2 age groups (average age of 26 and 61 years old respectively). The intra- and inter-observer variations of eight experimental phases in cross-media colour-matching were reported. Twenty observers were divided into 2 age groups. Sixteen printed colours were matched three times on a calibrated LCD monitor.EAch stimulus was matched three times by each observer. The samples were mounted on a neutral grey background wall with a reference white having the chromaticity close to D50 Illuminant and a luminance of 100cd/m^2. The results showed that young observers had a slightly lower intra- and inter-observer variability than the elder observers. The fitted 95% confidence ellipse plots reflecting the intra and inter variations, indicated that the orientation for certain colour-stimuli varied between the young and old group. It was suggested that the known physiological changes of the eye that occur with aging were more likely to induce inter-variation for certain stimuli colours than others.

1. INTRODUCTION

The inter-variations found in a group of observers when performing a colour-matching task are dependent on a number of factors. A theoretical approach to modelling observer variation due to physiological differences as a factor of age and field size has been suggested in the CIE technical report (CIE, 2006). It offers a physiological based framework that allows the computation of normalised cone fundamentals (lms), based on age and viewing field, which can be converted into colour-matching functions (CMF) through linear transformation. Sarkar *et al*. (2010) found 8 types of CMFs to quantify observer metamerism. This study attempted to generate reliable data to test these CMFs.

2. EXPERIMENTAL SETUP

A cross-media colour matching experiment was designed between the colours printed on a paper substrate and a stimulus on a liquid-crystal display monitor. The observers were asked to match the printed stimuli on the display for 4 field sizes (2°, 6°, 10° and 20°). The light source for viewing prints was a CIE D50 Illuminant simulator. It was measured against the surface of a reference white having a luminance level at 100cd/m^2 with CIE 1931 chromaticities of x=0.3986, y=0.4022. The monitor used for the matching was a 21.3” LaCIE 321 wide gamut LCD and its stimuli were viewed in a dark ambient condition. Prior to the experiment, the display was evaluated and characterized via PLVC model (Post and Calhoun 1989), with a median of 1.19 ΔE^*_{ab} of 48 test colours It was setup so that its white peak luminance to have a close match of the reference white illuminated under the light source. The experiment was attended by 20 normal colour vision observers, which were divided in two age groups of 10 observers ranging from 20-30 years with an average age of 26, and 50-79 years with and average age of 61 respectively. Sixteen colour-centres were chosen, which reasonably spread in CIELAB space and some of which have been used in the previous studies concerning observer metamerism in cross-media colour reproduction (Oicherman 2008). The colours were printed on a matt paper substrate and were presented against a medium grey background wall. The final matching results were measured using a Konica Minolta CS1000 tele-spectroradiometer (TSR) in cd/m^2 unit.

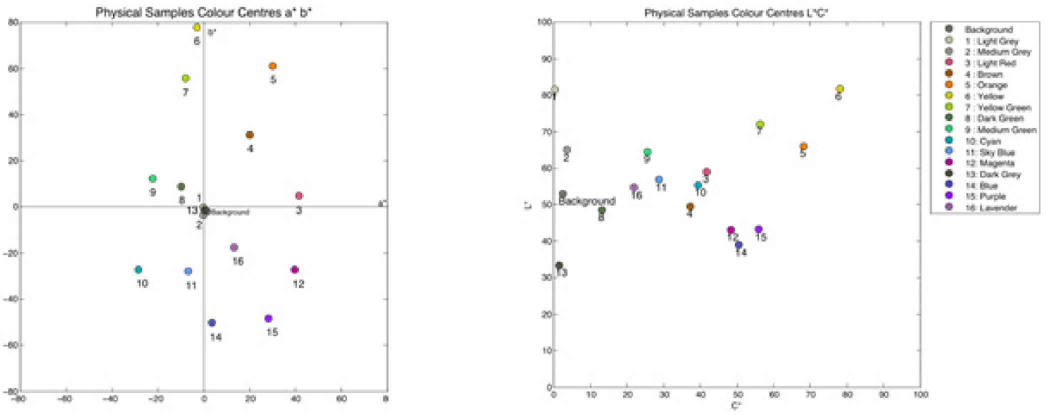


Figure 1: Illustration of the experimental colour stimuli in CIE a*b* (left) and L*C* (right) dimensions.

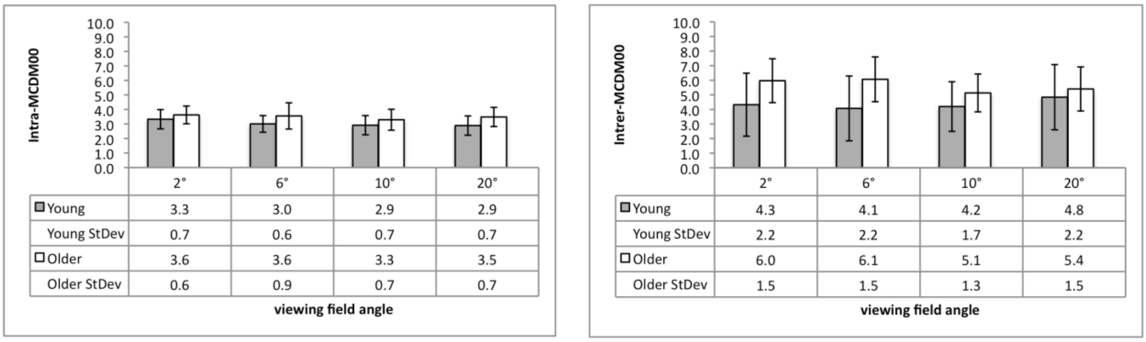
3. PSYCHOPHYSICAL EXPERIMENT

The viewing distances were 180cm from the physical sample and 80cm from the LCD monitor. A divider separated the two fields. The stimulus on the wall was viewed to have a white luminance as that on LCD screen. Prior to commencing the colour matching, the observers were given 10 minutes to adapt to the room lighting conditions. A colour-matching software interface was developed that enabled the modification of the L*, C$^*_{ab}$ and h° hue angle of the stimulus via a set of controlled buttons. The first task was to match the screen background colour to that of the wall surface surrounding the printed stimuli. The second task was to modify an initial grey patch on the screen to match each of the reflection stimuli presented on the wall. Each colour-match commenced from a medium grey and the colours were presented at a random sequence. The stimuli were presented at 4 different sizes: 2°, 6°, 10° and 20°, whereas the size of the patch on the LCD screen was always at 10° field. Each observer repeated the process three times. The matched colours as well as the printed samples SPDs were measured from the observer's position using the TSR. The SPD was converted to XYZ tristimulus values using the CIE 1931 standard colorimetric observer for the present 2° data and the data of the rest fields using the CIE 1964 standard colorimetric observer.

4. RESULTS AND DISCUSSION

The intra-observer varability of each observer was evaluated by calculating the measure of mean colour difference from the mean (MCDM) between the three repeated colour-matches using CIEDE2000 formula (Intra-MCDM00) (Luo *et al.* 2001). The results presented in Figure 2a indicated that the observers performance was consistent throughout the experiment with the young and old groupshaving mean ΔE_{00} values of 3.1 and 3.7 units respectively. The variance among the colour-matches between the members of each group was estimated by computing the MCDM00 (Inter-MCDM00) between the average colour match of the group and the average of each observer. The findings are given in Figure 2b, which did not suggest any trend affected by the changing viewing field size. An interesting observation was that the old group seemed to have a larger variation compared to the young group, with a mean

5.6 against 4.8 Inter-MCDM00 units and at the same time a smaller standard deviation of 1.5 against 2.1.



	2°	6°	10°	20°
▨ Young	3.3	3.0	2.9	2.9
Young StDev	0.7	0.6	0.7	0.7
☐ Older	3.6	3.6	3.3	3.5
Older StDev	0.6	0.9	0.7	0.7

	2°	6°	10°	20°
▨ Young	4.3	4.1	4.2	4.8
Young StDev	2.2	2.2	1.7	2.2
☐ Older	6.0	6.1	5.1	5.4
Older StDev	1.5	1.5	1.3	1.5

(a) *(b)*

Figure 2: (a) Intra-Observer MCDM00 and (b) Inter-Observer MCDM00 of young and elder group for the different viewing field sizes. The error bars reflect the standard deviation of each dataset.

To get some further insight on the intra and inter variation, two types of 95% confidence fitted ellipse plots were created. To construct the intra-variation ellipsoids the covariance matrix, which derived by averaging the participant's covariance from their repeated sessions, was used. The inter-observer ellipses were constructed using the covariance of the observer's average matches in each group. It was found that the trends for all sizes are very similar. Hence, only the 2^{o} and 10^{o} ellipses are plotted in Figure 2 for discussion.

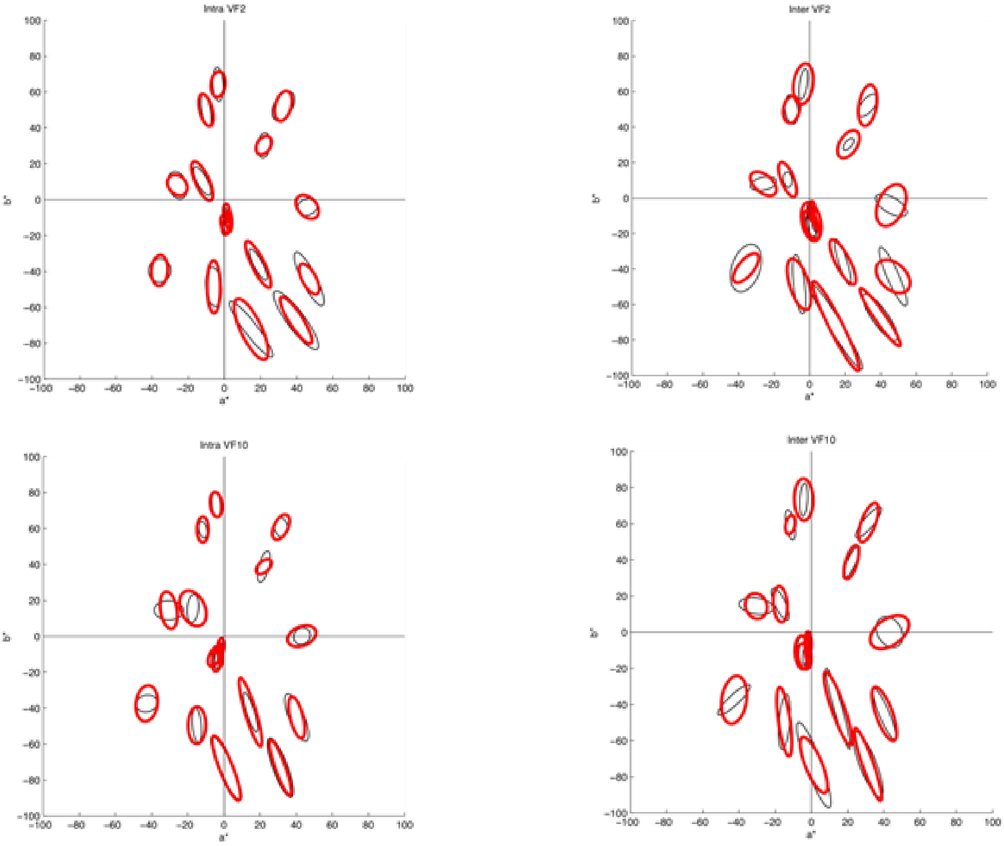


Figure 3: Left-hand column: intra variation; Right-hand column: inter variation 95% confidence fitted ellipsoids in $a^{*}b^{*}$ CIELAB dimensions (thin line: young group; thick line: elder group).

The intra- and inter-observer ellipses are plotted in the left- and right-hand columns respectively. Overall, most of the ellipses in the same colour region on the left-hand column agree well with each other, with the exception of the difference in the orientation for green and cyan colours for the 10° data. On the right-hand column, the largest variance in the size and orientation of ellipses is noticed in the 10°, with a noticeable difference in the direction of the light red centre. The mean of the ellipse area of each stimulus was also calculated. The old group had a mean area of 21.2 and 23.7 for intra and inter variance, respectively, which was larger than the 17.1 and 16.7 for the young group. The quantitative colour-appearance shift among the viewing size conditions was attempted for the two age groups, using the difference between the 2° matches to the other three sizes. The data was examined in the CIECAM02 appearance space in the directions of the J lightness, C chroma and H hue composition attributes. To determine the statistical significance of the ΔJ, ΔC and ΔH shift the Student's *t*-test was used. The findings suggested that for the young group the specimens appeared significantly lighter when viewed in the 20° field with a median ΔJ of 6.05 (*t-stat* 2.67, *p* 0.01). The elder group perceived the stimuli significantly lighter, for the 10° and 20° size and more chromatic with a shift in chroma with median ΔC of 4.65 (*t-stat* 2.24, *p* 0.03 and 4.70 (*t-stat* 2.54, *p* 0.01). Finally there was a good agreement in H hue composition suggesting that there was no evidence of hue shift due to the effect of varying size for both groups.

CONCLUSIONS

A comparative study between two age groups of observers performing a colour-matching experiment was attempted. The inter-variation analysis between the groups suggested that the elder participants indicated a larger and different direction some certain colours compared to the young group. The quantitative colour-appearance shift among the viewing size conditions revealed a significant difference in chroma for the elder group only.

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Use Digital Colour Vision Test Plate to Judge the Degrees of Colour Vision Deficiency

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ABSTRACT

A method named Digital Colour Vision Test Plate (DCVTP) was developed to examine deuteranomalous vision in the authors' previous studies. It was operated on a colour calibrated LCD monitor. The software based on the experiment of just-noticeable chromatic difference (JNCD) were established by normal colour vision subjects and deuteranomalous subjects. The aim of the present study is to further develop colour vision analytical method to predict the degrees of colour vision deficiency. To judge the degrees of severity of deuteranomalous colour vision, the four parameter based on a deuteranomalous JNCD ellipse are used , i.e., length of major axis, length of minor axis, eccentricity and the angle (between tilt angle of ellipse and confusion line). Additionally, the test accuracy of developed DCVTP was compared with Farnsworth-Munsell Dichotomous D-15 Test and Heidelberger Multi Colour Anomaloscope (HMC-MR).

1. INTRODUCTION

Normal colour vision (NCV) is trichromatic. However, for colour vision deficiency (CVD) subjects, any colour stimulus which possesses the cones with reduced or shifted sensitivity characteristics to the wavelength of light (Fairchild 1997). There are about 8% male and 0.2% female suffering from CVD (Hurvich 1981). The people with NCV could enable to discriminate the mixing of object (text) colour and background colour clearly when colour differences between them are larger than the just-noticeable chromatic difference (JNCD). Conversely, CVD subjects would be confused by any of two colours along their corresponding confusion lines of the CIE 1931 chromaticity diagram (Brettel 1997).

In the authors' previous studies, computer software named Digital Colour Vision Test Plate (DCVTP) was developed. It relies on a colour-calibrated LCD monitor (Tsai 2011a and 2011b). The examples of DCVTP are shown in Figure 1. For example, DCVTP (3, 3) means the test plate composed of 3 kinds of text colours and 3 kinds of background colours. The DCVTP model can be described by Eq. 1,

$$DCVTP(i,j) = Text(i) + Ground(j); \quad i=1\sim3, j=1\sim3 \tag{1}$$

where i and j represent number of colour used as text and background respectively (Tsai 2011b). The earlier experimental data based on just-noticeable chromatic difference (JNCD) was established by four NCV subject and four deuteranomalous subjects. The results showed that NCV subjects yields an ellipse close to a circle. Conversely, the long axes of JNCD ellipses for the deuteranomalous subject lie approximately towards the direction of D-type's co-punctal point (see Figure 2). It hinted that the DCVTP possibly accurately detect deuteranomalous vision. It needs to accumulate more experimental data to verify its accuracy.

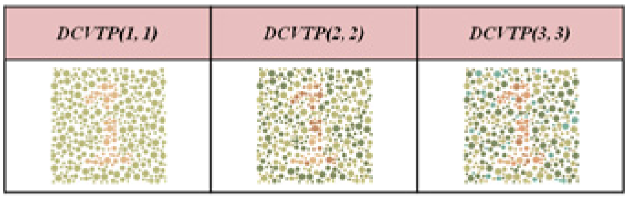


Figure 1. Examples of DCVTPs.

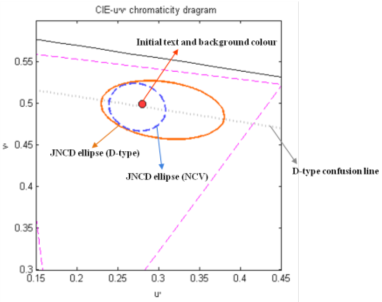


Figure 2. An example of the JNCD ellipses of a NCV and a VCD.

2. METHOD

The aim of the present study is to further develop colour vision analytical method to judge the degrees of colour vision deficiency. To realize the degrees of severity of deuteranomalous colour vision, the four parameter based on a deuteranomalous JNCD ellipse are analyzed, i.e., length of major axis, length of minor axis, eccentricity and theangle (between tilt angle of ellipse and confusion line) (see Figure 3).

The DCVTP (3, 3) was adopted in this study becuse it gave the most reliable performance in both intra-observer and inter-observer variability (Tsai 2011b). The DCVTPs were displayed on a well-calibrated sRGB monitor in a dim room (64 lux). Both ten NCV and ten CVD subjects were asked to participate the experiment. Total 10 moving paths for each initial colour designed in DCVTP, where eight of them were 0, 45, 90, 135, 180, 225, 270 and 315 degrees and the other two directions were based on the line linking the initial colour towards the copunctal point for a deuteranope in CIE u'v' chromaticity diagram (see Figure 4). Figures 5(a)-5(c) show the examples of adjusted chromatic differences in terms of Δu'v' of 0.00, 0.02 and 0.14, respectively.

Totally eight CVD and eight NCV subjects, having a mean age of 25, participated in this experiment. Additionally, there were five initial colours designed in the test DCVTP(3, 3). Additionly, the moving path of each initial colour had ten directions, and each subject performed 50 times (1 test plate × 5 initial colours × 10 directions). Moreover, each subject repeated the experiment three times. Consequently, 2400 (50×3×16 obs) data were accumulated. The test results of DCVTP were compared with Farnsworth-Munsell Dichotomous D-15 Test and HMC Anomaloskop MR.

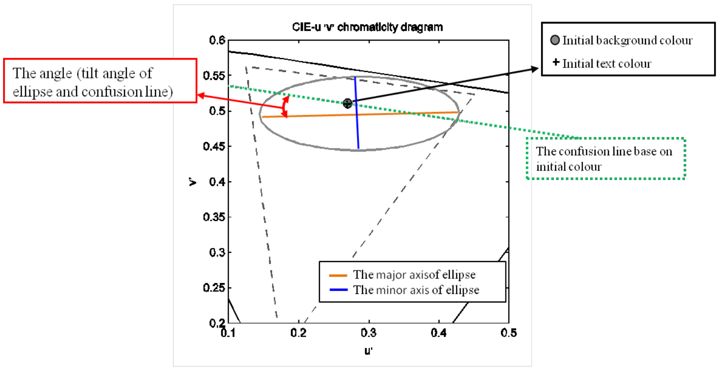


Figure 3. The analytical parameters of an ellipse.

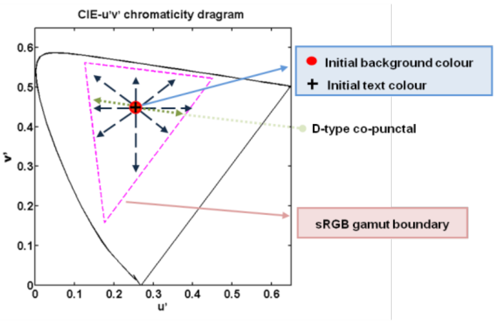
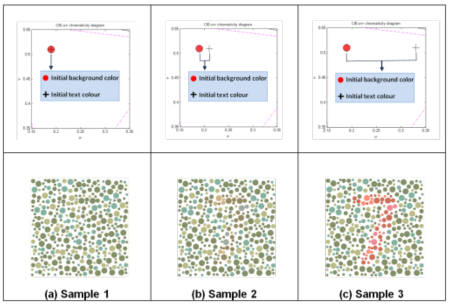


Figure 4. The 10 paths for each initial in CIE u'v' chromaticity diagram.

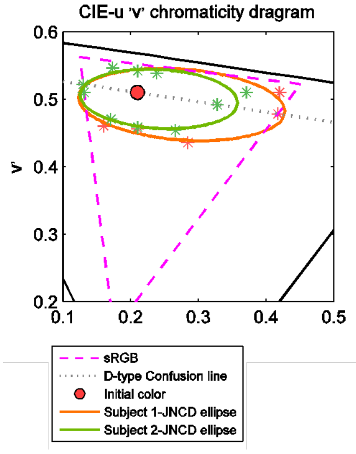


(a) Sample 1 (b) Sample 2 (c) Sample 3

Figure 5. The examples set with different levels. (a) ***Δu'v****'=0, (b)* ***Δ****u'v'=0.02 and (c)* ***Δu'v****'=0.14 between test colour and background colour.*

3. RESULTS AND DISCUSSION

An example of results compared with two degrees deuteranomalous vision as shown in Figure 6. The subject 1 with severity of deuteranomalous vision would show the length of major axis (0.29) longer than the one of subject 2 (0.25). Moreover, subject 1 had the smaller included angle between major axis lines and confusion line than the subject 2. It implied the subject 1 had the better fitting on the confusion line. In other words, the subject would be more influenced in colour discrimination by the types of confusion line types. Compared with Farnsworth-Munsell Dichotomous D-15 Test and HMC Anomaloskop MR, there was a good agreement among three kinds of colour vision test methods.



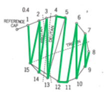
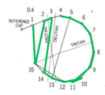
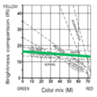
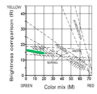
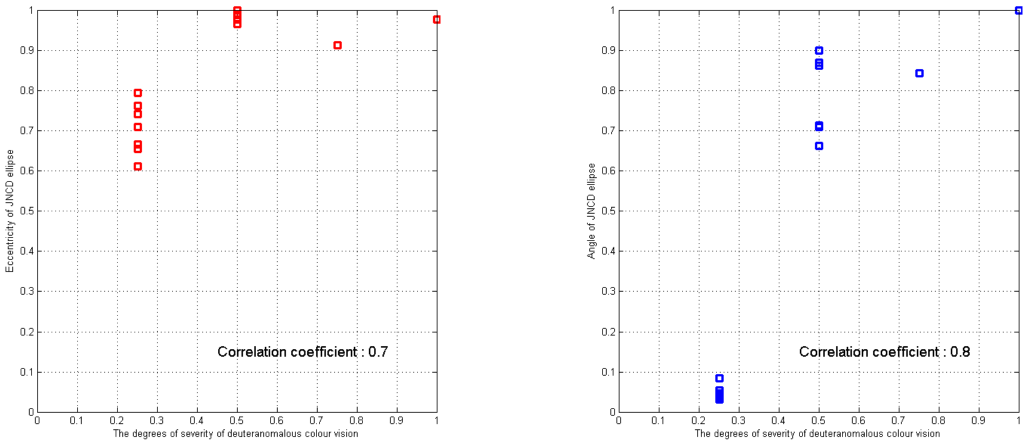
Observers / Instruments	Deuteranomalous Subjects 1	Deuteranomalous Subjects 2
(major axis, minor axis)	(0.29, 0.11)	(0.25, 0.10)
Eccentricity	0.93	0.91
The angle (between tilt angle of ellipse and confusion line)	3.24	7.35
D-15 Test		
HMC Anomaloskop MR	 AQ : ∞~0	 AQ : ∞ ~ 3.21

Figure 6. An example of results compared with two degrees of deuteranomalous vision.

For the reason that correlation coefficient is a vital aspect used to calculate how strong the correlation of two quantities is. The correlation coefficients between two parameters (eccentricity and angle) and the results of HMC Anomaloskop MR are 0.8 and 0.7 individually. It implied that there is a strong correlation between them (see Figure 7(a)-7(b)).



(a) *(b)*

Figure 6. The correlation coefficients between two parameters and the results of HMC Anomaloskop MR.

4. CONCLUSIONS

In this study, the performance of Digital Colour Vision Test Plate (DCVTP) to examine the degrees of deuteranomalous vision based on just-noticeable chromatic difference (JNCD) was developed. The experimental results showed that subjects have more serious degree in deuteranomalous vision when they had the better fitting on the confusion line. In additions, the subject would be more influenced in colour discrimination by the types of confusion lines. The both of correlation coefficients between two parameters (eccentricity and angle) and the results of HMC Anomaloskop MR are strong. It's implied both of them can judge the degrees of colour vision deficiency.

ACKNOWLEDGEMENTS

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Colour Space to Express Colour Attributes of Dichromatism: A Trial Study

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ABSTRACT

Dichromatic colour vision defects are often characterised through the illustration of confusion lines radiating outward from the copunctal point on the xy chromaticity diagram. When such an illustration is used, the dichromatic character seems to be understood easily, and the people who see this illustration presume that two different colours placed on the same confusion line on the xy chromaticity diagram are always indistinguishable for dichromats, but this presumption is false. It is better to use the LMS colour space to avoid drawing such a false conclusion; nevertheless, the LMS colour space may not be suitable for expressing the colour attributes of dichromatism, because the lightness and chromaticness perceived by dichromats are not explicit and are scaled separately in the LMS colour space. For solving this problem, the construction of a two-dimensional colour plan has been attempted in the present study. The colour plan has two orthogonal axes, one for the lightness scale and the other for the chromatic scale. The lightness scale has been derived from the LMS colour space in accordance with an analogy to CIE 1976 L*. Conversely, the chromatic scale has been derived from the ratio of the two axes of the LMS colour space. The proposed colour plan enables independent handling of the two colour attributes. It is also expected to help in the construction of a uniform colour space (colour differences are calculable) for dichromacy.

1. INTRODUCTION

Colour vision defects occur when cone cells in the retina of the eye fail to function normally. Genetic factors, which affect a significant number of people, are responsible for these defects. In Japan, for example, it is estimated that about 5% males and about 0.2% females have colour vision problems. It is estimated that globally, more than 200 million people suffer from colour vision defects. Such people can be classified as dichromats, anomalous trichromats, and other categories (such as monochromats). In particular, protan and deutan dichromats are well known about the difficulty they face in distinguishing between certain pairs of colours such as red and green, black and brown, pink and sky blue, and pea green and yellow.

Dichromatic colour vision defects are often characterised by the centre of confusion (i.e. copunctal point) and the confusion lines radiating outward from a copunctal point on the xy chromaticity diagram. The combined use of confusion lines and the xy chromaticity diagram, however, can lead to the false conclusion that two different colours placed on the same confusion line of the xy chromaticity diagram are always indistinguishable for dichromats. Although indistinguishable colours are always placed on the same confusion line in the xy chromaticity diagram, the reverse is not always true. Such a false conclusion is caused by the improper consideration of luminance (i.e. parameter Y of CIE 1931 tristimulus values) of colours placed on the same confusion line. It is better to use the LMS colour space (e.g. as used in Brettel, et al., 1997) to avoid the false conclusion; however, the LMS colour space may not be suitable for expressing the colour attributes of dichromatism. The LMS colour space is not scaled linearly with lightness, such as by CIE 1976 L*; with chromatic scales, such as by CIE 1976 a*b*; or with the colour difference sensation perceived by dichromats. In other words, the lightness and chromaticness perceived by dichromats are not explicit or scaled separately in the LMS colour space.

For solving the abovementioned problem, the author has attempted to construct a two-dimensional colour space (i.e. colour plan) that consists of two orthogonal axes, one for representing the lightness scale and the other for representing the chromatic scale.

2. PROBLEM FORMULATION

Trichromatic colour vision (or normal colour vision) can be expressed using the LMS colour space with three axes, namely, the L, M, and S axes. Dichromatic colour vision can also be expressed using the LMS colour space, because a colour space with a minimum of two dimensions is adequate for expressing the dichromatic colour space. For example, protanopes lack L cone cells in their retina, whereby they cannot perceive the difference between colours along the L axis. That is, protanopia has a degenerated LMS colour space along the L axis, and hence, their colour space can be expressed using only the M axis and S axis.

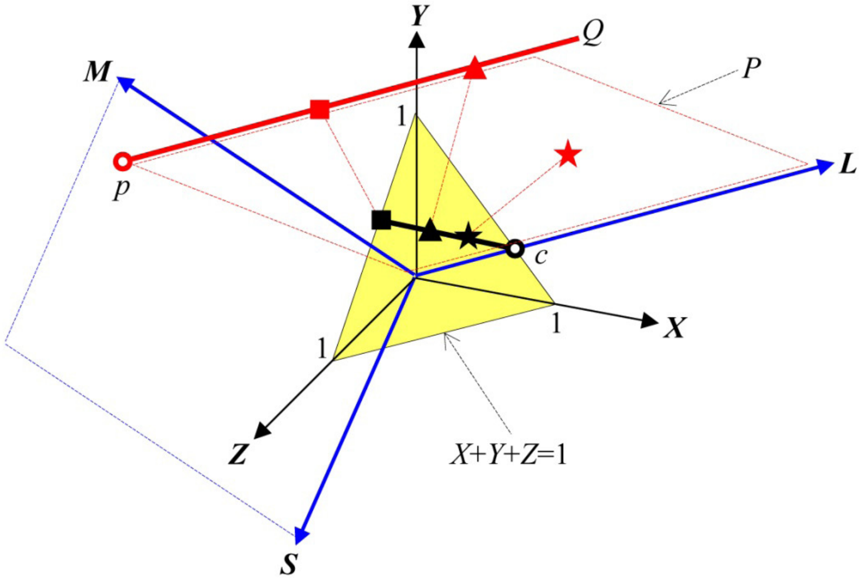

Figure 1: True confusion line Q that is parallel with the L axis of LMS colour space.

Fig. 1 illustrates an example of the abovementioned situation. The blue solid lines denote the L, M, and S axes. The point *p* (a white point on the red solid line), being on the MS plane, is an example of a colour perceptible to protanopes. In the LMS colour space, the corresponding colour at point *p* is expressed by the red solid line *Q*. In other words, the point *p* on the MS plane is a projection of the line *Q* along the L axis.

For the explanation regarding the confusion line in the xy chromaticity diagram, we consider the XYZ colour space and the unit plane (X+Y+Z=1) to be superposed on the LMS colour space, as shown in Fig. 1. There is an almost linear relationship between the axes of the XYZ and the LMS (ignoring stringent technical considerations) colour spaces. The unit plane (X+Y+Z=1) contains the xy chromaticity diagram, in which points denoted by the black square, black triangle, and black star represent the chromaticity points of the red square, red triangle, and red star in the LMS colour space. As shown in Fig. 1, the confusion line in the xy chromaticity diagram (black solid line in the unit plane) can be considered to contain the black square, black triangle, and black star. It seems that each of the three points can be confused with the other points. Factually, the red square and red triangle cannot be visually distinguished between by protanopia, because both these colours are present on the red solid line *Q*. Conversely, there is no colour confusion between the colour present at the red square and that present at the red star, or between the colour present at the red triangle and that present at the red star. On careful inspection, it can be noted that the confusion line on the xy chromaticity diagram corresponds not only to the red solid line *Q* (true confusion line in the LMS colour space) but also to the plane *P* that is parallel to the L axis and to line *Q*, and which includes the red square, red triangle, as well as red star. It is for this reason that an incorrect conclusion is drawn as described in this work.

3. SPECIFICATION OF COLOUR ATTRIBUTES

To express the colour attributes of dichromatic colour vision, a colour space with a minimum of two dimensions is needed. For example, the MS plane with the M and S axes, as shown in Fig. 1, is suitable for specifying the colour attributes of protanopia. In the MS plane, any confusion line is expressed as a point such as point *p*. Any point in the MS plane can be specified by the coordinates (*m*, *s*), but such coordinates do not explicitly indicate the colour attributes perceived by protanopes.

From the analysis of dichromatic colour attributes based on several records of visual experiences of dichromats, it is certain that dichromats perceive lightness and chromaticness. For example, dichromats perceive chromaticness as a chromatic variation between blue and yellow (Brettel, et al., 1997). Scales of the M and S axes (i.e. *m* and *s*) indicate the strength of light perceived by M cones and S cones, and hence, chromatic variation must be expressed as the ratio of *m* and *s*, or as arctan(*m*/*s*). Conversely, the strength of light must be expressed as the sum of *m* and *s*, although Smith and Pokorny (1974) suggest that S cones do not contribute to lightness, and hence, only the M axis is expected to be related to lightness.

From the abovementioned considerations, the author proposes the formulation of the lightness scale and chromaticness scale as follows:

[Lightness] Let the lightness scale be measured by α:

$$\alpha = \begin{cases} 116\left(\lambda/\lambda_{\max}\right)^{1/3} - 16 & \lambda/\lambda_{\max} > 0.008856, \\ 903.29\left(\lambda/\lambda_{\max}\right) & \text{otherwise,} \end{cases} \tag{1}$$

where λ denotes the strength of the M axis (i.e. *m*) in the case of protanopia, strength of the L axis in the case of deuteranopia, and strength of L+M in the case of tritanopia. Equation (1) has the same form as the definition of CIE 1976 L* (CIE Publication, 1986).

[Chromaticness] Let the chromaticness scale be measured by β:

$$\beta = \arctan\left(\mu/\nu\right) - \arctan\left(\mu_E/\nu_E\right), \tag{2}$$

where μ denotes the strength of the M axis (i.e. *m*) and ν denotes the strength of the S axis (i.e. *s*) in the case of protanopia. In the same manner, μ and ν correspond to the L and S axes in case of deuteranopia, and the L and M axes in case of tritanopia. Measures μ and ν with the suffix *E* each denote an equal-energy stimulus (i.e. neutral colours), and if the L, M, and S axes are normalized, then $\mu_E=\nu_E=1$. It is to be noted that neutral colours are not necessarily achromatic colours (e.g. white).

Based on this formulation, a two-dimensional colour plan with two orthogonal axes, α and β, can be constructed. The proposed colour plan would enable the independent handling of the two colour attributes, lightness and chromaticness.

4. DISCUSSION

Conventional methods that are used to evaluate the colour differences perceived in the presence of colour vision defects are based on CIE 1976 L*a*b* or L*u*v* (CIE Publication, 1986), and dichromatic simulators such as the one written in Brettel et al. (1997). L*a*b* or L*u*v* are, however, established, being consistent with the colour differences perceived by trichromacy (normal colour vision); conversely, they are not uniform with regard to the colour differences perceived by dichromats. For solving this problem, a uniform colour space considering dichromacy must be constructed and a formula for dichromatic colour differences must be derived.

The proposed colour plan may offer a good basis for discussing such a uniform colour space and colour differences. The measure α is derived in a manner similar to CIE 1976 L*, and hence, there is a strong probability that the measure α is linearly proportional to the lightness sensation perceived by dichromats. However, it is uncertain whether measure β is factually linear in proportion to the sensation of chromaticness perceived by dichromats.

For the convenience of the discussion, let f( ) be a linearization function and let γ = f(β) be linear in proportion to the sensation of chromaticness perceived by dichromats. Function f( ) also must be selected such that measure *d* becomes linear in proportion to the dichromatic colour differences:

$$d = \sqrt{(\alpha_{p_1} - \alpha_{p_2})^2 + (\gamma_{p_1} - \gamma_{p_2})^2} \quad \text{, where} \quad \gamma = f(\beta) \, . \tag{3}$$

The author expects function f( ) to be determined by protanopic and deuteranopic visual observations about the chromatic threshold of discrimination.

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Evaluation of Neutral Grey Settings

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ABSTRACT

Despite the theoretical importance of neutral grey (unique white), there is little agreement on its precise chromaticity. An equal-energy white (CIE x=0.33; y=0.33) is employed for modern colour appearance models, whereas ecologically relevant illuminations, such as the sun's disk (x= 0.331; y = 0.344) and daylight (D65: x = 0.313; y = 0.329) have also been adopted widely for colour reproduction and imaging.

The objective of this study was to evaluate neutral grey settings under various luminance levels. The stimuli were displayed against a black background on a calibrated CRT screen in a dark room and neutral grey settings were recorded by 30 participants for three different luminance levels.

The average neutral grey in these conditions was located at CIE x=0.286; y=0.302. Observer variation was evaluated and results showed that the inter-observer variability was less than twice the intra-observer variability, indicating a fair amount of reliability.

1. INTRODUCTION

An achromatic stimulus is defined as a patch of light that is devoid of any hue. This is usually achieved by asking observers to adjust the stimulus such that it looks neither red nor green and at the same time, neither yellow nor blue. In terms of opponent-colour theory, both chromatic opponent mechanisms are at equilibrium (for a colour-normal observer) and the output of the chromatic channels is hypothesised to be at zero. This idea that the chromatic system is in a 'resting state' at the achromatic locus has led to its use as a means to scale the cone fundamentals (Bompas, Powell and Sumner 2013; Walraven and Werner 1991), to establish the effect of illumination and to assess spatial or temporal context effects (e.g. Doerschner, Boyaci and Maloney, 2004; Lee, Dawson and Smithson 2012).

Despite the theoretical and practical importance of these achromatic settings little is known about the reliability with which observers can make these judgements, and how invariant these settings are under changes in luminance. This knowledge is crucial if one is to assess the reliability of models and theories that use the concept of achromatic loci. The purpose of the current study was to evaluate how achromatic judgements vary with luminance in a dark room. The study found that the inter-observer variability was less than twice the intra-observer variability, indicating that the observers are fairly consistent at making these settings.

2. METHOD

2.1 The apparatus

Stimuli were generated using the CRS MATLAB toolbox on a 14-bit ViSaGe system and observer responses were collected using a CB6 response. They were displayed on a calibrated Mitsubishi DiamondPro 2070 CRT monitor. The monitor had a correlated colour temperature of about 8100 K with a peak luminance of 103 cd/m^2. Care was taken to switch on the monitor at least 30 min before the start of the experiment.

2.2 Observers

Thirty subjects (18 females and 12 males; mean age: 24.24 years; age range: 18–60 years) participated in the experiment. All participants had their colour vision assessed using the Cambridge Colour Test and were found to be colour normal. Observers were compensated for their time with a small fee.

2.2 Experimental Procedure

The observer adapted for at least 5 minutes to the dark room. In each trial, the observer was asked to adjust the colour of a central circular patch (~2.6°) such that it contained neither red nor green and neither yellow nor blue. The participant could make these adjustments in both directions along the two axes of a standard CIE LUV colour space by pressing one of the four marked buttons on the controller. Each trial started with an initial greyish colour chosen randomly from a pre-defined radius of colours at distances of ~25 u^*v^* units around the point (0,-5) in the u^*-v^* plane; this central point is a typical display white point.

The task was programmed as a cancellation algorithm with a step-size of 5 u^*v^* units. This means that when the observer chose a particular direction, the refreshed achromatic point was shifted 5 u^*v^* units in the direction opposite the choice made by the observer. There was no time limit and when the observers were satisfied with their choice they pressed a fifth button and the next trial commenced.

3. RESULTS AND DISCUSSION

Comparison of variabilities across different regions in a chromaticity diagram is only meaningful if distances in these regions represent similar perceptual differences (Wuerger, Maloney and Krauskopf 1995). For this reason, all achromatic settings will be reported in the relatively more uniform u’v’ chromaticity plane rather than the x-y chromaticity plane.

The average results are presented in in *Figure 1*. To quantify the variability in the settings the intra- and inter-observer variabilities were computed (Xiao, Fu, Mylonas, Karatzas and Wuerger 2012; Xiao, Wuerger, Fu and Karatzas 2011). Intra-observer variability is a measure of how consistent each observer is, whereas inter-observer variability measures the extent to which each individual observer agrees with the average observer. The ratio of these is an indicator of how consistent the settings are (Kuehni 2005). *Table 1* shows that the judgements made by observers were fairly consistent.

Furthermore, the settings obtained in the study compare well with other studies which measured the achromatic locus under similar conditions (*Figure 2)*.

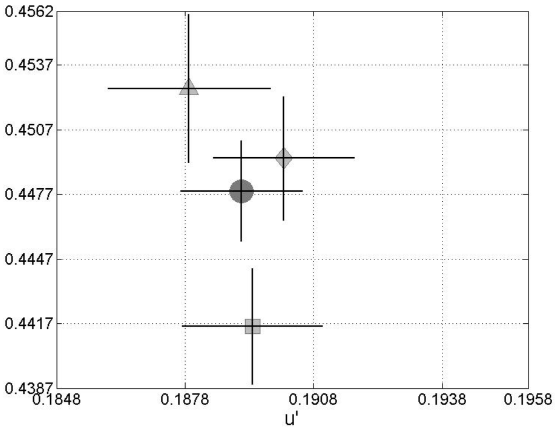

Figure 1: Average achromatic settings in dark conditions. p *represents the average achromatic setting for 5 cd/m², ¢ for 20 cd/m², and* u *for 50 cd/m².* ˜ *represents the average setting over all luminances.*

Table 1. Intra- and inter-observer variabilities (in 1e-3 units) of achromatic settings.

	Intra	Inter	Ratio
5 cd/m^2	11.5	18.3	1.59
20 cd/m^2	10.2	14.7	1.44
50 cd/m^2	8.8	15	1.70
Average	10.2	16	1.57

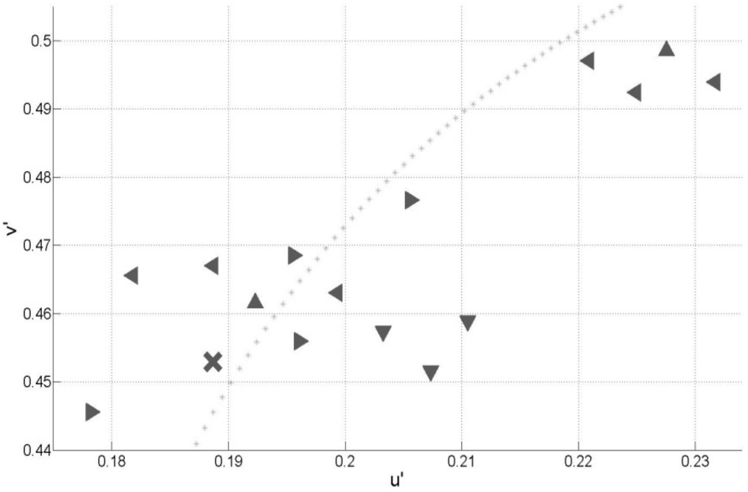

Figure 2: Achromatic settings. ✳ *CIE Daylight locus;* ✖ *Current Study;*
▶ *Valberg 1971;* ◀ *Werner and Walraven 1982;*
▲ *Walraven and Werner 1991;* ▼ *Werner and Schefrin 1993.*

4. CONCLUSIONS

The purpose of this study was to evaluate how reliably colour-normal human observers can make achromatic settings. From the results it can be concluded that in dark conditions, the human visual system can produce fairly reliable achromatic settings. These settings lie close to, but not on the daylight locus, and are distinct from an equal energy white.

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Electrophysiological Correlates of Focality

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ABSTRACT

This article investigates focal colour perception. The aim of the research is to use a combination of behavioural, physiological, and neurological methods to investigate focality. A brief introduction explores the two main theories of categorical colour perception, and the shift towards prototype theory. Finally, stimuli and proposed experiments for investigating focality are outlined.

1. INTRODUCTION

Human perception of colour space is widely believed to involve 11 basic colour categories. These categories are defined by salient prototypes, or foci, recognised more or less universally in anthropological studies (Berlin and Kay 1969). Focal areas are rated as the best examples of a given colour category (Boynton, Maclaury and Uchikawa 1989), and they differ across people (Paggetti Bartoli and Menegaz 2011), and cultures (Roberson et al. 2005).

Focal areas are salient parts of colour space, defined here as co-ordinates that are named faster and more accurately than other nearby co-ordinates (Berlin and Kay 1969). Focality is traditionally measured by monolexemic colour-naming tasks, consensus between subjects about colour names, and within-subject consistency of naming (Sturges and Whitfield 1997). Such measures are assumed to be indicative of saliency and form the basis of what is colour focality.

Not all languages fit the basic colour term model, leading to the counter argument, that colour categories are linguistically mediated. This is referred to as the linguistic relativity hypothesis. Debate is ongoing regarding the universality of categorical colour perception.

Roberson, Damjanovic, and Pilling (2007) propose that activation of language codes also activates category prototypes stored in memory, biasing perceptual memory towards the prototype. Different cultures may sort category boundary swatches differently due to focal differences for that culture (Roberson et al. 2005). When two stimuli straddle a category boundary, they vary in perceptual and conceptual cues. Within-category distinctions may be harder as only perceptual information separates the stimuli (Hanley and Roberson 2011). Existing categorisation studies usually select good category boundary stimuli, but often neglect to consider the typicality of the stimuli (Hanley and Roberson 2011).

Perceptual warping could account for the discrepancies regarding the categorisation of colour. Categorical perception could result from a combination of memory, linguistic codes, and perception, depending on the resources available. To truly understand the underlying mechanisms these need to be separated or controlled for (Franklin et al. 2005).

Focality, or salient and prototypical examples of stimuli, and category adjustment are present for facial expression (Roberson, Damjanovic and Pilling 2007), and in speech sounds (Feldman, Griffiths and Morgan, 2009). For those modalities examined thus far, focality appears as a robust phenomenon.

Nevertheless, no clear evidence exists for a correlate of colour focality, its definition deriving from little more than perceptual phenomena and response times. Neurological evidence exists for a hard-wired and pre-linguistic effect of language on category boundaries (e.g. Thierry et al. 2009), confirming the linguistic relativity hypothesis. No such investigation is paralleled in the area of focality. It is hypothesised that similar differences are recordable for focality. The present author proposes an investigation into focality that combines behavioural, physiological, and neurological measures to provide a comprehensive account of colour perception. A description of the possible methods follows.

2. METHOD

2.1 Stimuli

Assuming that colour space is tri-dimensional, there are three ways to vary focality.

The first, and the most common technique in naming studies, is to vary hue, keeping lightness and saturation constant. This avoids unwanted luminance effects. Hue may be a more important modifier for English than in other languages (Alvarado and Jameson 2005). Categorisation effects due to category boundaries or linguistic inputs confound this.

Alternatively, value or saturation can be manipulated. The difficulty with this method is ensuring that the contrast of the background luminance does not interfere with colour perception. Roberson et al. (2005) investigated naming at the lowest saturation for four lightness values. They found that decreased saturation leads to decreased nameability. Naming confidence is negatively related to saturation, but increased confidence is not necessarily related to focality (Alvarado and Jameson 2005).

2.2 Colours

To avoid cross-category and linguistic inputs, the colours green, blue and to a lesser extent, purple, are ideal for focality research. These categories are less sensitive to changes in luminance than other basic colours (Paggetti Bartoli and Menagaz 2011). They are also recognised quicker than the other basic colours (Sturges and Whitfeild 1997). Expansion of the current research to include the other basic colours is also recommended. A verbal interference task may help problems associated with language and categorical perception.

2.2 Other Issues

It is wise to select focals for each person based on a group of best representatives, as focality differs across people (Paggetti Bartoli and Menagaz 2011). Estimation of the centroid is recommended if it is not possible to have participants name an array of close-to-focal examples.

3. MEASURES

3.1 Psychological

The Stroop effect is the interference that occurs when the colour and meaning of a word do not match. If there is larger between-category response time for focal colours, this suggests that focal colours indeed are more salient than their non-focal counterparts. Stroop has already been applied to categorisation research (e.g. Wiggett and Davies 2008). A similar experiment that manipulates lightness with reference to consensus and non-consensus data is suggested.

3.2 Physiological

Evidence of colour categorical perception using physiological methods is inconclusive. Baronchelli et al. (2010)'s computer simulation supported the universal categories using just noticeable differences. However, Roberson Hanley and Pak (2009) show no such increased sensitivity at Korean or English colour boundaries. To the author's knowledge, colour categorisation or focality is unexplored in the realm of temporal thresholds.

If focality is physiological, evidence of it should appear during temporal threshold testing utilising state of the art tachistoscope technology (Thurgood et al. 2010).

3.2 Neurological

The effect of language in colour appears to be both implicit and explicit, although the latter is less researched thus far.

The salience related P300, and it's related waveforms (P1 N1, N2, and the N400) are obvious choices for investigating focality. Research involving P300 requires a highly controlled testing environment. Anything that modulates attention modulates the P300 (Andreassi 2000). Therefore factors such as hours of sleep, caffeine and nicotine intake, and time of day need to be accounted for. Holmes et al. (2009) considered explicit colour matching tasks and found P3 for categorisation. However, only one stimulus was focal, and the green stimuli were less consistently named than the blue stimuli.

The MMN (Miss-Match Negativity) is a preattentive difference wave that is specifically elicited by change detection for stimulus changes that are irrelevant to the task. Categorisation studies have focused extensively on the vMMN (Visual analogue). The vMMN's ability to detect mismatches in visual information makes it ideal for investigating focality. Other advantages include that explicit attention is not required to elicit the waveform.

Czigler, Balázs and Winkler (2002) found no change detection between pink and red, however Thierry et al. (2009) found a difference between green and blue. It is noted that Thierry et al.'s results revealed no vMMN for English speakers when comparing light and dark blue. Therefore a larger luminance difference is needed for elicitation of the vMMN. Crigler Balázs and Winkler (2002) suggest that the minimum difference required to elicit the vMMN is larger in the visual, than in the auditory modality.

4. CONCLUSIONS

Research is currently underway to investigate focality in different partitions of human perception. If new methods of investigation are identified they could confirm focality, category and linguistic effects, and used in other domains, such as assessing the emergence of additional basic colour terms (e.g. Sturges and Whitfield 1997).

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A Study on the Measurement of Color Appearance under Illumination of a Given Color Temperature

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ABSTRACT

In this study, we made an experiment to determine the transition of the apparent color of several colored fabrics under different illuminations by means of a visual comparison method using Munsell color chart. From the obtained results, it was suggested that the proposed method of visual color matching can be applied to the measurement of the color appearance under illumination of a given color temperature.

1. INTRODUCTION

Color is an important factor in forming an impression of clothing. In apparel shops, lighting condition affects the color appearance of clothing. Color of illumination especially has a great effect on the color appearance (Lee 2011). To determine what color of illumination is suitable for display of clothing, we have to measure, as a first step, the apparent color of a fabric under a given color temperature of illumination.

From our experience, for example, a red color fabric appears brighter and yellowish when it is under yellow color illumination, compared to when it is under white color illumination. However, the difference between stimulus values of illumination can be calculated by the present color system, e.g. CIEXYZ, but the difference in apparent color is rather difficult to be expressed by the color system for object color, because the latter color system is designed to describe the color after chromatic adaptation of our vision to illumination.

In this study we will determine the apparent color under given illumination by means of a visual comparison method using Munsell color chart. The color chart is used as a standard scale under given reference illumination, which will visually match the apparent color of a fabric under different test illumination.

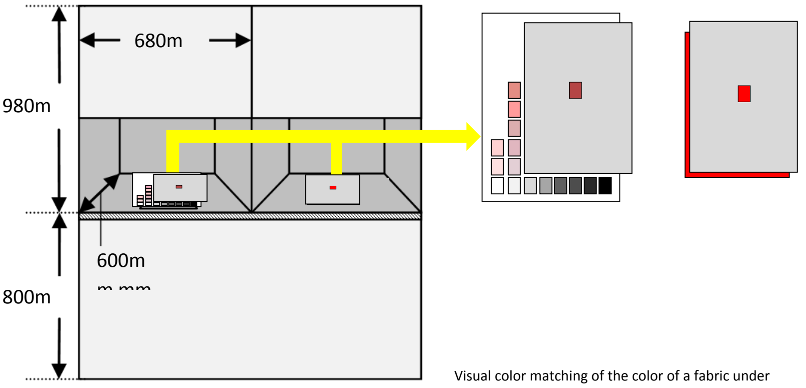
2. SAMPLE AND MEASUREMENT

2.1 Sample

As experimental samples, seven colored fabrics — RED, YELLOW, GREEN, BLUE, PURPLE, WHITE and BLACK — which are made of No.40, 100% cotton broad (Inc. Kurabo Japan), commonly used in apparel industry, and least affected by lighting, are used.

Two wooden boxes of the same size, 980mm in height, 680mm in width and 600mm in depth, are placed side by side in an experimental booth (Figure 1). The inside surface of each box is covered by grey cloth (N6.0) of the same kind cloth as experimental samples. The outside of the boxes are covered by matte cloth of grey color. Furthermore the whole experimental booth is covered by a blackout curtain to block off the light from outside.

Two kinds of LED lamps, one is neutral white of color temperature 5000K and the other is incandescent lamp color (yellowish color) of color temperature 2800K, are mounted at the ceiling of each box to create different illuminating environments. The illuminance on the floor of each box is set up to be the same, which is approximately 1000 lx.



Visual color matching of the color of a fabric under different illumination is carried out using Munsell color chart.

Figure 1: Experimental booth for visual color matching.

2.2 Measurement

Method of the experiment is listed below:

For each sample fabric, perform the following steps to determine the change of the apparent color of the fabric under different illuminations.

(Experiment A)

Step1: Compare the color of a sample fabric with the Munsell color chart under the white color illumination (illumination W) to determine the object color of the fabric itself.

Step2: Move the fabric used in Step1 into the other box illuminated by the incandescent lamp color illumination (illumination Y), and compare the color of the fabric with the Munsell color chart in the former box under the illumination W to determine the apparent color of the fabric under the illumination Y.

Step3: Determine the change of apparent color under the different illumination by the Munsell values obtained from Step1 and Step2.

(Experiment B)

The same experiment as described above except exchanging the illumination W and the illumination Y.

Note that the sample fabric and the reference chip of Munsell color chart are both masked by N6.5 grey paper with a small square window.

Subjects for the experiment were five women of age of twenties with normal vision.

3. RESULTS

The results of the experiment A and the experiment B are shown in Table 1. Munsell value

(*H V*/*C*) in the table is the average of Munsell values obtained by five subjects. The variance of the values was small.

In case of the experiment A, the obtained Munsell value of the sample RED, for example, changed from 5R 4/14 to 7.5R 4/14, which shows that the apparent color of RED changed slightly towards orange under the illumination Y. This transition of hue corresponds well with our perception.

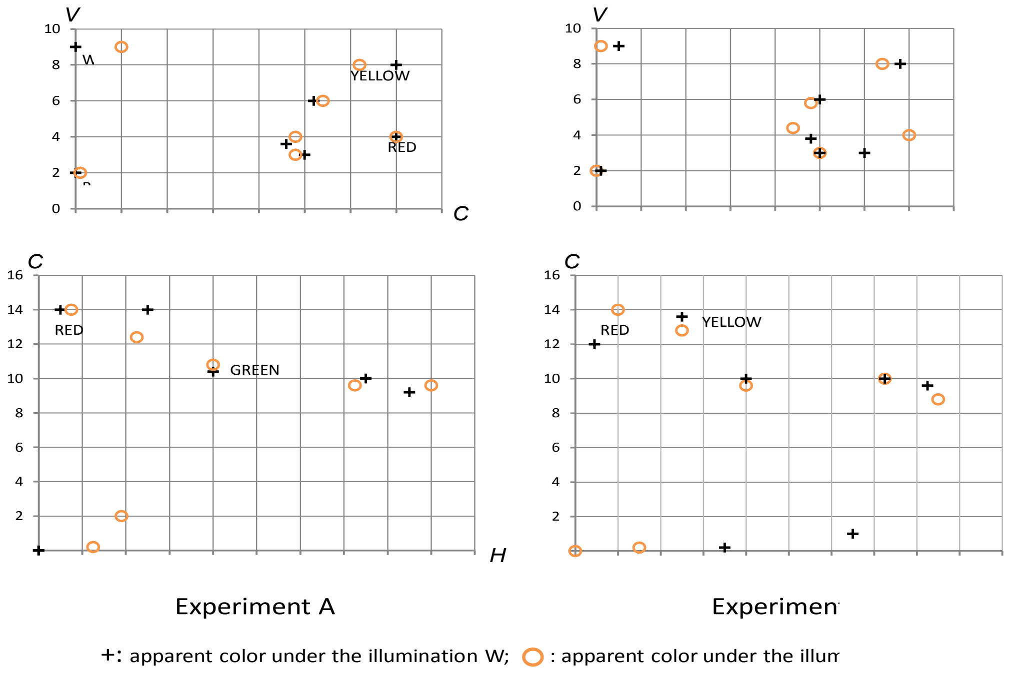
Transitions of hue in the direction of orange were also found in other samples, YELLOW, BLUE, PURPLE and WHITE, but the lightness of these samples was not changed. With regard to the chroma, decrease was found in YELLOW.

It is interesting that almost no change was found in any of hue, lightness nor chroma of GREEN and BLACK.

In case of experiment B, transition of Munsell values of the samples has almost the same attitude as experiment A.

Table1: Apparent color of the sample fabrics under different illumination.

Sample fabric	Experiment A		Experiment B	
	(illumination Y)	(illumination W)	(illumination Y)	(illumination W)
RED	5R 4/14	7.5R 4/14	10R 4/14	4.5R 3/12
YELLOW	5Y 8/14	2.5Y 8/12.4	5Y 8/12.8	5Y 8/13.6
GREEN	10GY 6/10.4	10GY 6/10.8	10GY 5.8/9.6	10GY 6/10
BLUE	5PB 3/10	2.5PB 3/9.6	2.5PB 3/10	2.5PB 3/10
PURPLE	5P 3.6/9.2	10P 4/9.6	5P 4.4/8.8	2.5P 3.8/9.6
WHITE	N9	9YR 9/2	5YR 9/0.2	5B 9/1
BLACK	N2	2.5YR 2/0.2	N2	5GY 2/0.2



Experiment A

Experimen

+: apparent color under the illumination W; ○ : apparent color under the illum

Figure 2: Transition of apparent color under different illumination.

The experimental results shown in Table 1 are illustrated in Figure 2. As for the above two figures, the abscissa is chroma and the ordinate is lightness, while as for the two figures below, the abscissa is hue and the ordinate is chroma. The black "+" mark indicates apparent color of a sample under illumination W and the orange circle indicates apparent color of a sample under illumination Y.

4. CONCLUSION

The results of our experiment suggest that the transition of apparent color of a colored fabric under different illuminations can be determined by means of a visual comparison method using Munsell color chart. It is necessary to pursue the reliability of the proposed method by refining the experimental procedure and increasing the number of subjects.

For the future work, we are attempting to experiment the possibility of applying the current color system for object color, e.g. CIELAB, to the measurement of the color appearance under illumination of a given temperature.

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Introducing Modern Memory Color

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ABSTRACT

Long-term memory color has been studied extensively in the literature. Traditionally, the colors used in such experiments of memory matching are often color chips from Munsell Color Atlas or familiar objects such as green grass, blue sky, or skin tones. In this work, we investigate long-term memory color in a more contemporary real-world context, hereby referred to as *modern memory color*. Our target is memory colors of popular commercial logos and brand names, something that observers are exposed to frequently and therefore we hypothesize that memory color is formed in a similar manner as with traditional memory colors. The effect of image context on modern memory color is also explored.

1. INTRODUCTION

The term *memory color* refers to color perceived or recalled after some delay from earlier sensation. Examples of memory colors are blue sky, green grass, yellow banana, skin color, autumn leaves, etc. We tend to associate blue color for the sky, green for grass, etc. These memory colors are more specific and represented in a smaller color gamut than general terms such as “blue”, “green”. Several cognitive effects (Derefeldt *et al.,* 2004) and color preference (Bartleson, 1960) influence memory color, resulting in a *color shift* between the original color and memory color. Memory color of familiar objects could also help estimating the illuminant’s color and therefore be an important factor in establishing color constancy (Granzier and Gegenfurtner, 2012).

Memory color can be categorized into short-term or long-term, depending on the delay between adaptation and reproduction. There is not yet a clear definition on this delay limit between short-term and long-term memory color. In one experiment, observers was asked to adapt to a color for 3 minutes, then to reproduce the color he/she remembered after certain delay, in particular after 15s, 15 minutes and 24 hours (Pérez-Carpinell *et al.,* 1998). Most color shift in reproduced colors occur only in seconds to minutes after adaptation. Mean color difference increased with time in this time frame, yet observers’ memory color stabilized eventually. In particular, after 24h, mean color difference is not getting worse. The result suggests that short-term memory color could refer to situations when observers reproduce color within minutes after adaptation, and long-term memory color refers to hours of delay between adaptation and reproduction. In experiments concerning long-term memory color, subjects will be given certain cognitive and/or perceptual cue and asked to match or reproduce a color that he/she has seen previously. The cue can be without or with image context (Tarczali, 2007). In the first case, names of familiar objects are given, e.g. “green grass”, and subjects need to reproduce the memory color corresponding to this text cue. In the latter case, an image context is given, in the form of texture, or shape, or an image with blank areas. Subjects are tasked to fill in the missing colors.

Methods of reproducing colors can be categorized into: (1) Color mixing: subjects adjust the red-green-blue (RGB) or hue-saturation-lightness (HSV) to mix the desired color; (2) Color selection: subjects pick color from a predefined set of colors; (3) Deciding: subjects decide if the color shown is his/her memory color (Tarczali, 2007). With color mixing, all colors within the device's gamut can be reproduced, but depending on their ability to use the mixing tool, subjects may not be able to reproduce the exact color that they desire. Color mixing technique is not recommended due to high intra-observer variance (Hardeberg *et al.,* 2007). The color selection method is easy for subjects, yet limits the number of colors that can be reproduced. One weakness of the deciding method is that consecutive presentation of many color patches may confuse observers' memory.

Objects in long-term memory color experiments are often familiar to observers, referred to as "everyday objects or scenes such as human complexions or landscapes with which people have frequent visual experience and are likely to produce memory colors that are common to many people" (Bartleson, 1960). Similar to how red apple, blue sky, yellow banana are considered familiar objects in these experiments, we hypothesize that well-known commercial products such as Coca-Cola and McDonalds also qualify as such objects, something we are exposed to frequently and therefore memory color is formed in a similar manner as traditional memory color. We refer to this type of memory color as *modern memory color*. This work examines modern memory color and the effect of context towards modern memory color.

2. EXPERIMENTAL SETUP

16 subjects of age ranging from 20 to 30 participated in the experiments. All of them had normal color vision. There were 12 males and 4 females. The monitor in use was ASUS K43S LCD display, calibrated by EyeOne calibration device at a luminance of 106cd/m2, reference white (x = 0.3534, y = 0.3490). The room is lit with 5000K, 530lx illumination. Subjects sat in front of the monitor, at a distance of 60cm. Initially, subjects were asked to adapt to a uniform neutral gray background for one minute. Subjects were given as much time as they want to complete the task. Generally they took less than 40s to select their desired color for each sample. In total there were 11 samples (3 traditional color samples, 4 modern color samples each for experiments with and without context), which took about 10 minutes to complete. Therefore we could assume that the effect of eye-strain due to prolonged monitor viewing on experimental results is not profound.

Instead of using one of the traditional methods for color subjects to reproduce colors (mixing, selecting, deciding), we introduced a two-step reproduction tool. The first step resembles color selection tool and takes advantage of its simple use for observers. The color swatch is comprehensive and covers a wide range of color gamut. Subjects can elaborate their choice further by selecting one color from this swatch as base color, then proceeding to the second step for finer definition of this base color. The second step covers the whole gamut of continuous colors, which takes the first step's selection as principal hue and allows subjects to vary saturation and lightness. This allows reproduction of the whole gamut covered by the display, which is the advantage of color mixing systems. Subjects were asked to compare the effectiveness of traditional RGB mixer (provided as another option) and our mixer, with all in consensus that it is easier to reproduce the desired color with our mixer. The XYZ values of selected colors were measured with a Konica Minolta CS-1000 Spectroradiometer.

In Experiment 1 (Traditional memory color), subjects were asked to reproduce traditional memory colors: blue sky, green grass, Caucasian skin with text cue. The purpose of this experiment was to validate our color selection tool by comparing with results from the literature, and provide a reference point for our second experiment.

In Experiment 2 (Modern memory color), subjects were asked to reproduce colors of well-known commercial brands: Coca-Cola (red), McDonalds (yellow), Heineken (green) and Facebook (blue). The choice of brands followed two rationales: (1) brands are well-known; (2) brands have four colors: blue, red, green, yellow, which were widely used in the literature and described as distinctive, basic colors (Bartleson, 1960) or focal colors (Derefeldt *et al.,* 2004). This choice is to ensure that subjects have long-term memory color of these logos. Subjects were asked to confirm their familiarity with these brands. Tests were conducted in two scenarios: with context (subjects are to fill in the missing color within the logos, e.g. the missing color of M letter in McDonalds logo) and without context (text clue only, e.g. “Coca-Cola red”). The aim is to investigate effects of context on memory color.

3. RESULTS AND DISCUSSION

The observer’s matched colors as well as the computed ellipses of 95% confidence for subjects’ memory color in CIELAB space are shown in Figure 1.

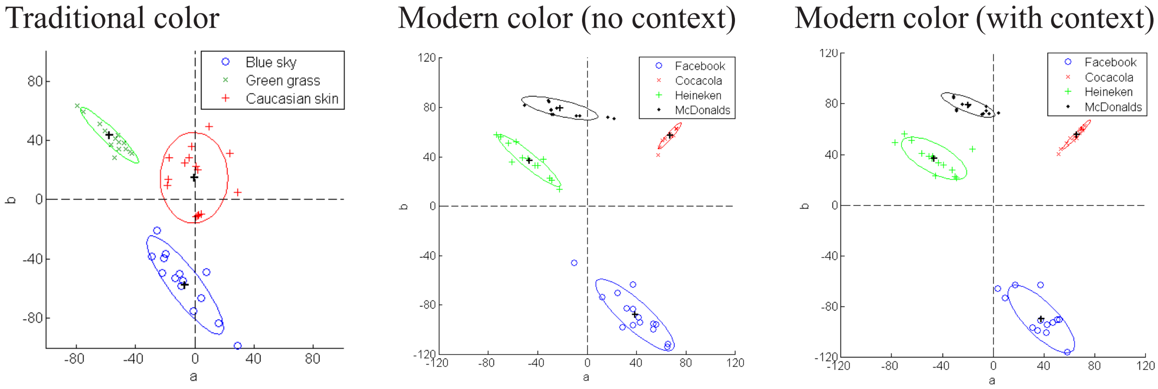

Figure 1:Confidence ellipses of reproduced colors.Plus signs (black) are ellipse centers

In the first experiment, the ellipse of “green grass” sample tends to orient towards the reference white, in other words, in the direction of constant hue. This indicates subjects are less accurate with chroma matching, while they are more in consensus with the hue matching of green color (Pérez-Carpinell *et al.,* 1998). On the other hand, the ellipse of blue color spreads over a wider range of hue. This is consistent with common knowledge that the Human Visual System (HVS) is less sensitive to blue spectrum and more sensitive to green spectrum. The ellipse for blue color does not orient towards the reference white, a notion that could also be accounted for by the non-uniformity in blue region for CIELAB space. High deviation was observed for Caucasian skin sample, which can be explained by the variability on the impression of skin color among individuals and a tendency of subjects to remember skin color as being more yellow (Bartleson, 1960). Subject diversity may also contribute to the deviation. It was noted that our subjects came from different cultures: Cyprus, France, Germany, India, Indonesia, Norway, Romania, Spain, Turkey, Venezuela and Vietnam. People from different cultures could memorize color with slight difference. An investigation on long-term memory color of Hungarian and Korean observers also revealed that Korean subjects perceive the sky as more saturated, the skin as more yellow and the grass as lighter than their Hungarian counterparts (Tarczali *et al.*, 2005).

For the second experiment, some similar results are observed from the confidence ellipses. Subjects are more sensitive to hue than chroma for green and red color, with ellipses pointing towards the white reference. The hue of McDonalds logo spreads the widest range compared to others. Red color of Coca-Cola logo is most agreed by subjects.

CIE1994 color difference was further calculated for each subject between reproduction with and without context. is significant for the blue color and green color, with more subjects producing a color difference above 10, indicating a high shift of memory color when context is present. tends to be below zero for Facebook's blue and McDonalds' yellow, meaning that subjects remember these logos as darker with image context. In the literature, skin and sky color was also reproduced with reduced lightness when context is present (Bodrogi and Tarczali, 2000). The opposite is observed for Coca-Cola's red color. is low (||~0-5) and positive for red and yellow, indicating subjects' memory color tend to have more chroma for red and yellow, an observation that concurs with other work (Bartleson, 1960). tends to be positive for red, blue and green, suggesting a hue shift towards higher hue angle for these colors. Yellow incurs both negative and positive hue shift, a result consistent with reports about the reduced capability of the HVS to remember the hue of yellow (Pérez-Carpinell *et al.,* 1998; Hardeberg *et al.,* 2007).

4. CONCLUSIONS

Long-term memory color of well-known commercial brands exhibit some characteristics that are very similar to traditional memory color, and hence maybe these so-called modern memory colors should be given more attention in future research and applications where memory colors are considered. Results of this work could for instance be applied in marketing and design of commercial products. Knowing typical ranges of hue and chroma that human memorize best, we can take advantage in design so that logos are most appealing and memorable to customers. Furthermore colors which are remembered more precisely may have higher customer requirements with regards to color reproduction.

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Color Terms and Perception in a Cortical Model

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ABSTRACT

A neurocomputational model of the integration of vision and language has been developed in order to investigate categorical perception in three different environments and languages: English, Berinmo, and Himba. It is based on a simulation of cortical processes in human visual and auditory perception, and develops its functions through exposure to stimuli that are provided in a sequence that parallels those of human development.

1. INTRODUCTION

How much of what we perceive is influenced by the terms taught to us by our linguistic community? What cognitive and neural processes are called into play in our continous endeavour of categorizing the world. A mechanism proposed to explain how the categories humans make may influence or alter how the perceived world appears, is called categorical perception (CP). It was first described by Harnad as being a phenomenon in which "equal-sized physical differences between stimuli are perceived as larger or smaller depending on whether the stimuli are in the same category or different ones" (Harnard, 1987, p. 3). Research in the categorical perception of color has served as an important test bed for hypotheses on CP and for those that link language to cognition, with the domain of color terms being traditionally a privileged terrain. Color terms have been taken as evidence in favor of the linguistic relativism thesis, whose best-known formulation is the Sapir-Whorf hypothesis. Berlin and Kay's cross-cultural studies (1969), supposedly settled the debate, sustaining that basic color terms follow a rigid "evolutionary pattern". The last two decades, has seen research on two languages with five basic color terms, Berinmo, spoken in Papua New Guinea, and Himba, spoken in Northern Namibia, challenge the mainstream universals view (e.g. Roberson, Davidoff, Davies, & Shapiro, 2004, 2005).

We propose a computational model of visual and linguistic processing paths in the cortex, previously used for simulating the influence of Berinmo and Himba color terms (Plebe, Mazzone, and De La Cruz, 2011).

2. A VISUAL AND LINGUISTIC CORTICAL MODEL

The model is made up of a series of artificial neural maps, part of which correspond to maps found in the human cortex. All maps are based on a mathematical abstraction of cortical structure known as LISSOM (Laterally Interconnected Synergetically Self-Organizing Map) (Sirosh and Miikkulainen, 1997). It is a two dimensional arrangement of nodes, that uses intracortical excitatory and inhibitory connections. Each unit receives input from a neighboring receptive field in the model's simulated thalamic input, or from a lower cortical map. When the model is exposed to stimuli, the synaptic weights of all connections are changed according to Hebbian plasticity, combined with homeostasis, to keep the average firing rate constant. The overall scheme of the model is shown in Figure 1.

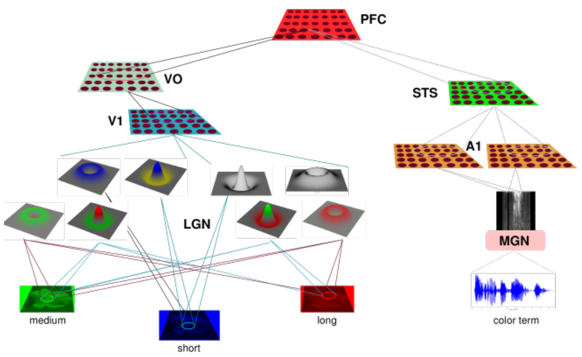

Figure 1: Overall scheme of the model, composed by LGN (Lateral Geniculated Nucleus), MGN (Medial Geniculated Nucleus), V1 (Primary Visual), A1 (Primary Auditory), VO (Ventral Occipital), STS (Superior Temporal Sulcus), PFC (PreFrontal Cortex).

There are two main paths, one for the visual process and another for the auditory channel. In the visual path, the external incoming signals are converted from their standard color representation into long, medium, and short wavelengths components, using filters with frequency responses corresponding to that of retinal receptors. The LGN block in the model simulates the responses of both the ganglion cells of the retina and the cells in LGN (see Bednar et al., 2005). The cortical process moves on to the primary visual map V1 and the color center, here called VO. The hardwired extracortical MGN component is just a placeholder for the spectrogram representation of the sound pressure waves. The thalamic afferents are collected by a LISSOM module, acting as the auditory primary cortex. The auditory path of the model is found in STS, the main brain area responsive to vocal sounds (Belin, Zatorre, and Ahad, 2002). The ventral visual path and the auditory path meet in PFC, the area most involved in higher-level categorization (Fuster, 2001).

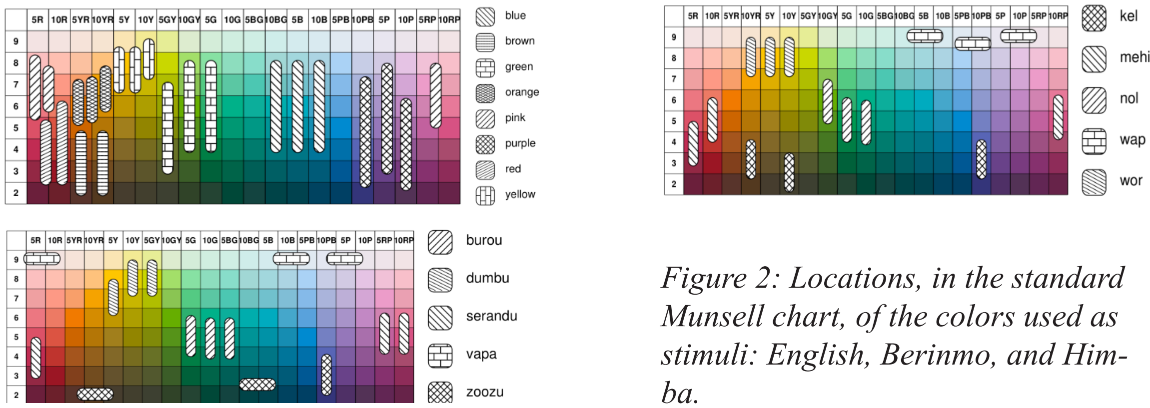

Figure 2: Locations, in the standard Munsell chart, of the colors used as stimuli: English, Berinmo, and Himba.

2.1 Model development, environments and language

The model has been exposed to a variety of stimuli, at three different stages of development, corresponding to the pre-natal stage, pre-linguistic and linguistic periods of human development. In the prenatal stage, only V1 and A1 maps are allowed to modify their synaptic weights. The stimuli presented to V1 are synthetic random blobs that mimic waves of spontaneous retinal activity. The prelinguistic phase starts in coincidence with eye opening, and natural images are used as stimuli for the visual pathway. We developed three different models, exposed to sets of images that simulate three different natural environments: a "neutral" one lacking dominant hues, similar to modern day urban environments, and the other two corresponding to the typical environments of the Berinmo and the Himba. The auditory stimuli are synthesized waves of the 7200 most common English words (from http://www.bckelk.uklinux.net/menu.html), with length of 3 to 10 characters, or Spanish words for the Berinmo and Himba versions of the model. At the end of this stage, different organizations are found in the lower maps, that enable the performance of processes that are essential to vision, and that are similar to those found in corresponding brain areas, such as orientation selectivity. Overlapped to orientation, there is an organization with respect to color, with cells sensitive to specific hues. The third stage of development is the linguistic phase. The stimuli used simulate events in which colored patches are viewed, and a word corresponding to its basic color category is heard contemporaneously. All the maps are active, including the PFC upper map.

Figure 3: Triads of color stimuli used for the categorical perception tests. On the left for blue-green, nol-wor in the middle, and dumbu-burou on the right. The black line marks the linguistic category boundary.

3. SIMULATED CATEGORICAL PERCEPTION: INITIAL RESULTS

To test for categorical perception, the models have been exposed to sets of triads of color stimuli, where two of the stimuli lie within one linguistic category, while the third belongs to a different category. The activities in the PFC neural sheet are compared for similarity using all nodes, without taking into account their partition in population coding for categories, to prevent a biased judgment of similarity.

The boundary categories are blue-green for English, nol-wor for Berinmo, and dumbu-burou for Himba. The six triads used are depicted in Figure 3. All color stimuli are equally spaced in the Munsell chart. For English categories the Munsell H values are 5B, 10BG, 5BG, 10G; for Berinmo are 7.5Y, 2.5GY, 7.5GY, 2.5G; for Himba 10Y, 5GY, 10GY; 5G; all Munsell V values are 5, and C values are 8. These values match those used by Roberson et.al. (2005). For each color 32 images have been generated, posing the colored chip at different retinal positions, therefore combining all samples of 3 colors, each triad requires 4096 different similarity tests. All tests have been performed on the English, Berinmo, and Himba models. The results of the similarity tests have been collected by the proportion of responses following the prediction that the two color stimuli within category are judged more similar than that crossing the category boundary. Results shown in Table 1, demonstrate a clear categorical perception effect for all languages, with the blue-green boundary, in particular, strongly affecting the English model, while having an indifferent effect on Himba and Berinmo.

Table 1. Mean proportion of similarity judgements following predictions based on the category boundary for sets of stimuli crossing blue-green, nol-wor, and dubu-burou.

	Himba	Berinmo	English
Blue-green boundary	0.53	0.54	0.78
nol-wor boundary	0.60	0.79	0.56
dumbu-burou boundary	0.78	0.27	0.44

The model presented, while being an abstraction of many of the brain areas and processes involved in visual perception, shows categorical color perception effects. They are based soley on the exposure to different environmental "visual diets" and color terms learned in three different languages. This can be interpreted as an added piece of evidence to support the hypothesis that both experience of the physical environment as well as experience with the language of our linguistic community, affects what we are able and inclined to perceive.

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A Study on the Identification of Representative Memory Colours

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ABSTRACT

The study investigated colour preference of the familiar objects on a display. These objects were captured by a digital camera, and then displayed on a LCD monitor. Each image was then rendered to cover a limited range. Observers were asked to choose one to be the closest to their memory colour. The experimental results showed the culture difference between the European (Smet et al. 2010) and the present Oriental observers, and between the female and male observers in this experiment.

1. INTRODUCTION

The colour quality of a light source can be represented by a colour rendering index. Some test samples were used to calculate the colour difference under the reference illuminant and the test illuminant. The index is finally calculated from these colour differences. This is the concept based on colour fidelity, i.e. the smaller colour difference between the reference and test illuminants. The indices include CIE-Ra (CIE 1965), CIE-CAM02UCS (Li et al. 2012). On the other hand, some indices based on the concept of colour preference have also been developed such as Memory Colour Memory Index (MCRI) (Smet et al. 2010), Colour Quality Index (CQS) (Davis and Ohno 2010). This paper is aimed to establish a set of memory colours based on Oriental observers and to compare with those used in MCRI based on European observers.

2. EXPERIMENT

The experiment was conducted on a LCD monitor. Before the experiment, 12 test objects including cucumber, cauliflower, pepsi, guava, green apple, orange, red apple, banana, grapes, skin, lavender, and sky were collected and their images were captured under a filtered tungsten D65 simulator, except that the scene of blue sky was captured directly in a sunny day. The digital camera used was calibrated in terms of ICC profile. The LCD monitor and the digital camera were set to Adobe RGB mode to reproduce the images. Experiment was carried out in a dim ambient (D65, 64 lux), and monitor white had a chromaticity of D65 and a luminance of 100 cd/m^2.

There are three stages to prepare the images for each object following the method described in (Chen et al. 2012 and n.d.). The general idea is to generate a range of images from an original image in CIELAB space. Furthermore, for each test object, a representative uniform area was chosen and was measured by a tele-spectroradiometer (see Figure 1) to define its initial center in the first and second stages. Figure 2 shows the typical experimental interface used in this study. Twenty-five image candidates were generated by shifting the initial centre in a*b* diagram. Three more experienced observers were asked to select the most liked image (Stage 1, Figure 3a) and the most disliked image (Stage 2, Figure 3b) respectively. In the third stage (see Figure 3c), 49 (7×7) images were generated by shifting shifting the initial centre along CIELAB a* and b* directions.

Sixteen observers were asked to evaluate each image candidate by using categorical judgement method having a 1-6 categories, in which Scores 1 and 6 represent the most disliked and the most liked, respectively. Eight of the 16 observers repeated the experiment. In other words, each object was assessed by 24 times by 16 observers.

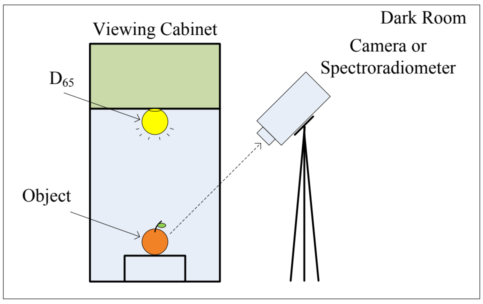


Figure 1: Instrumental environment

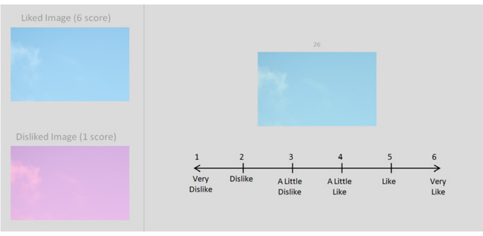
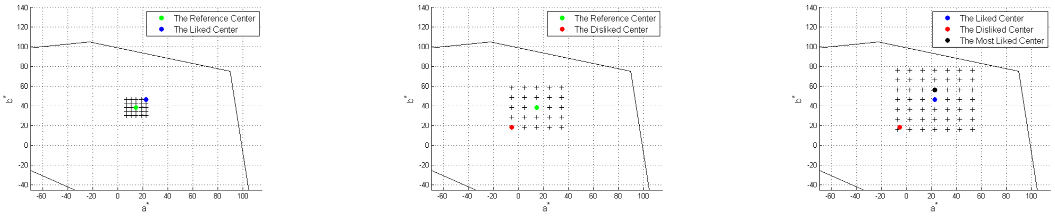


Figure 2: Experimental interface



(a) (b) (c)

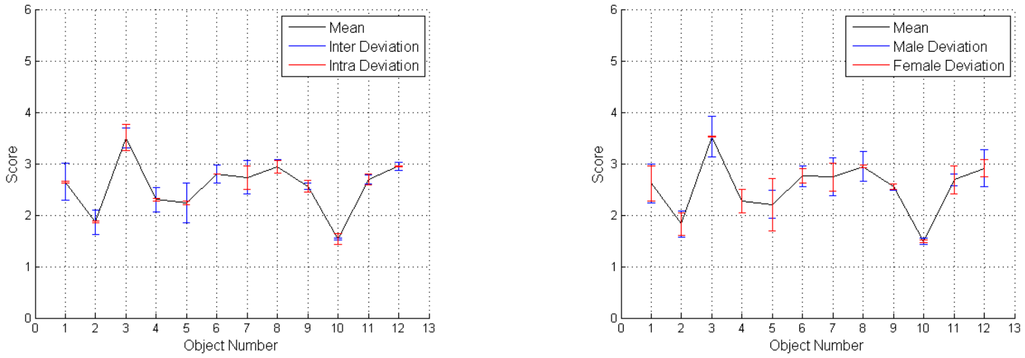
Figure 3: The three stages for generating the test images for each object.
(a) Stage 1: Produce 5×5 image candidates to choose the most liked reference image.
(b) Stage 2: Produce 5×5 image candidates to choose the most disliked reference image.
(c) Stage 3: Produce 7×7 image candidates to conduct the main experiment.

3. RESULTS AND DISCUSSION

Observer uncertainty was first conducted. The root-mean-square difference (RMSD) was calculated to express inter- (IRV), intra- (IAV), male- (MEV) and female- (FEV) observer variability. Figures 4a and 4b show IRV and IAV, and MEV and FEV uncertainties respectively in terms of error bar in RMSD units. The numbers in x-axis represent the objects of (1) cucumber, (2) cauliflower, (3) pepsi, (4) guava, (5) green apple, (6) orange, (7) red apple, (8) banana, (9) grapes, (10) skin, (11) lavender and (12) sky. The results showed that RMSD values of 0.19, 0.09, 0.25 and 0.19 for IRV, IAV, MEV and FEV respectively. This implies that inter-variability is larger than intra-variability as expected, and male observers performed slightly more consistent than female observers.

Figure 4a shows that No. 1, 3, 5 and 7 objects had larger variability than the other objects in the inter- and intra- observer variability. Figure 4b shows that male and female colour preference had larger variability for No. 3, 8 and 11 objects.

The preference scores of our experimental data were prediced by MCRI's gaussian model (Smet et al. 2010) for No.5 (green apple) and No. 8 (banana). However, MCRI's gaussian model can not accurately predict these evaluated scores because preference scores of partial objects distributed on a*b* plane asymmetrically.



(a) Inter- and intra- observer variability *(b) Male- and female- observer variability*

Figure 4: Observer variability results. The number corresponds to object of (1) cucumber, (2) cauliflower, (3) pepsi, (4) guava, (5) green apple, (6) orange, (7) red apple, (8) banana, (9) grapes, (10) skin, (11) lavender and (12) sky.

Figures 5 and 6 are the plots of colour shifts of colour centres between Smet's and the present experiments, and between the female and male results from the present experiment, respectively. The European memory colours were obtained by transforming the Smet et al's reference colours from IPT space to XYZ, and then to CIELAB. Figure 5 shows that Oriental observers prefer more colourful colours for high chroma objects than European observers. This discrepancy could also be caused by the media used, i.e. in Smet et al's exepriment, they used real objects illuminanted by LED lights in contrast of the display images used here. Figure 6 shows that the prefer colours for male and female agreed well with each other, except that female prefers more colourful cucumber, orange, and sky colours.

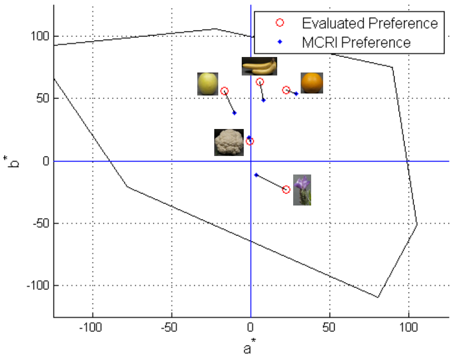


Figure 5: Comparing the most liked colours for evaluated preference and MCRI preference.

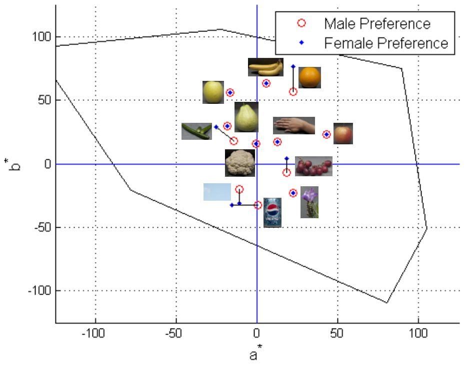


Figure 6: Comparing the most liked colours for male and female.

4. CONCLUSIONS

A psychophysical experiment was conducted to investigate the colour preference trend between male and female, and between Oriental and European observers.

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Differential Colour Perception Theory

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ABSTRACT

Trichromatic and Opponent-process color theories has introduced some complicated systems for color mixing and color perception. Both theories has assumed three color receptors as principle color sensors for generating any colored scene; one receptor for shortwave called Blue and another for medium wavelength called green and another one for long wave length called Red.

Our approach to this inspiring phenomena has different simple assumption and distinct proposal for color mixing and perceiving. Human color sight vision can be distinguished only by two color receptors, *Red* and *Green*. Each receptor gain signal has its own value and polarity with respect to each incident electromagnetic wavelength through the whole visible spectrum. ±(Red+Green) is a differential color relation which can express any specific color on the visible spectrum. Accordingly; Blue is only a color summation of (negative Red) and (negative Green) stimulus, or it is just as – *(Red + Green)*. Blue sensitive cones with rods surrounding the fovea of our retina work together for night vision and dim light perceiving. According to the color differential relation mentioned above color sense is now analogous to the other four known human senses since it has only two relative variables, i. e Positive (Red+Green) and negative (Red+Green). After-image phenomena and simultaneous contrast explain the color polarity for the same receptor as well. Logically; Since we have accepted Yellow as *(Red+Green)* also we have to accept Blue to be *-(Red+Green).* Also it is very clear that cones topography on the retina coincide with our principle assumption, i.e. blue cones is absent from the fovea spot (the most color sensitive part of our retina) and they spread with relatively very small population around the fovea in between rods.

1. INTRODUCTION

Through a fast examination to our four sensing systems, smell, touch, taste and hearing we can discover that all of those systems working with the same principal, depending on the rule of opponency, as easy as we consider that bitter is only the lack of sweat, cold is the lack of heat, darkness is the lack of light and blue is only the lack of yellow. It is going exactly with the law of conservation of energy, you can't get something from nothing. In general, negative values is only the lack of the positive ones. It goes as Psychophysical process throughout our sensing systems as well.

Although Trichromatic and opponent process theories have solved some puzzles of the color phenomena but they still have some complicated three dimensional explanations to our fifth beautiful sense of vision and color perception. Accordingly it seems wise enough to have some other theory for better understanding and simpler manipulation analogues to the other four senses in due.

“Differential Color Perception Theory” has been considered as a new color theory very analogues to the four human senses in the way mentioned above. It is simple as “blue is only the lack of yellow”. This will go correct for all the components of blue relative to the components of yellow.

2. METHOD

Differential colour perception theory assumptions has to be introduced and analysed with respect to the given data referred to our mind defaults about colour mixing and some other related phenomenas as after image and opponents cancelation.

2.1 Biological differential colour perception amplifier

Figure 1 illustrates a synaptic network analogous to the conventional electronic differential amplifier (Delton T. Hom, 1994). The red triangular block shown on Figure 1 stands for the whole synaptic network including red cone receptor at the input gate followed by bipolar cell ended with ganglion cell at the output. Horizontal cells are included inside the symbolic triangle to perform positive and negative feedback effects for color adaptation and hysteresis (Ido Perlman, 2012), this intelligent differential amplifier works for extracting the red characteristic curve from the whole input spectral radiation.

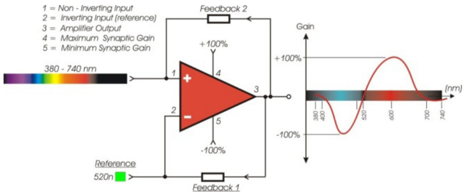

Figure 1: Red biological differential amplifier (RBDA).

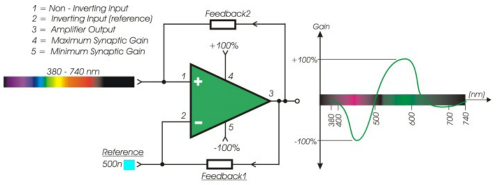

Figure 2: Green biological differential amplifier (GBDA).

Figure 2 shows the network effect of green biological differential amplifier**.** The green triangular block contains green light receptor at the input followed by bipolar cell and ganglion cell at the output, horizontal cells function for negative and positive feedbacks to perform gain control and hysteresis.

2.2 Red and Green receptors characteristic curves

Red and Green characteristic curves is only an output response signals of RBDA and GBDA respectively (Figure 3).

2.3 Assumptions Analysis

According to the analogues electronic differential amplifier principal the red biological differential amplifier shown on Figure 1 will flip its output to negative response for all the incident wave lengths less than a reference wave length of 520 nm, our mind will perceive cyan with peak value at 480 nm. For all the incident wavelengths more than *520 nm* it will flip the output to positive response and our mind will perceive red color with a peak value at around 600 nm. If the incident color is *520 nm* the output will be zero and our brain will perceive black. For Figure 2 the green biological amplifier will flip to negative response as far as the input incident spectrum is less than 500 nm, this will lead to magenta perception with a peak value at 460 nm.

For all the incident wavelengths more than a reference wavelength of 500 nm the green biological differential amplifier will flip to green with its peak value at 570 nm. If the incident color is *500 nm* the output will be zero and black will be perceived as default. Our brain will receive two outputs one from the red differential amplifier and another from green differential amplifier, this will lead to full visible spectrum perception or color mixing as shown on Figure 3.

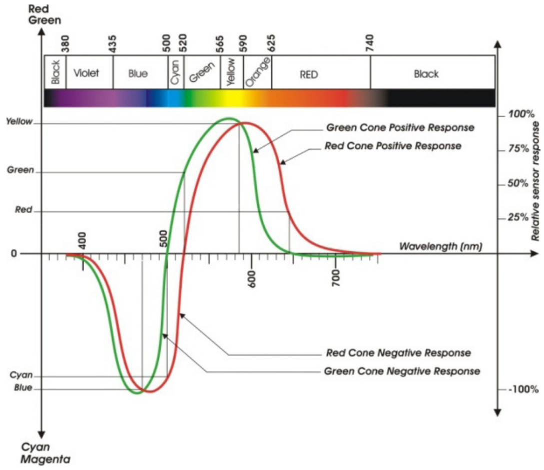

Figure 3: Red and Green receptors characteristic curves.

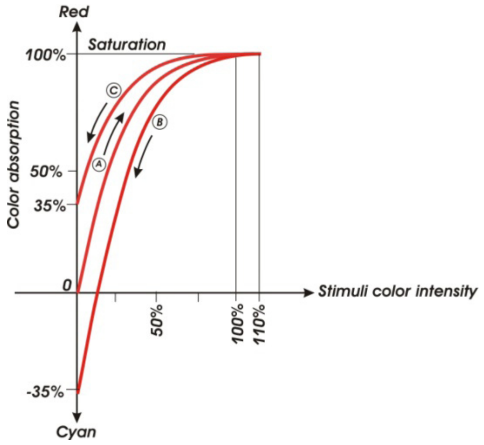

Figure 4: Hysteresis of red biological differential amplifier.

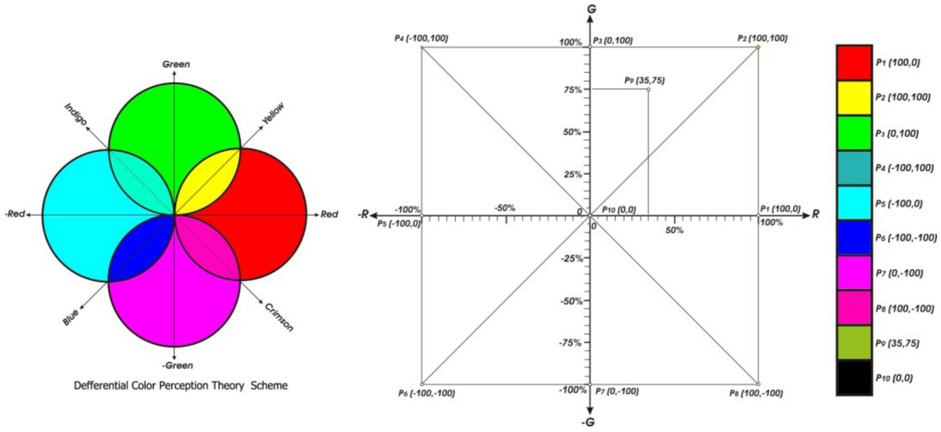

Figure 5: Colour scheme and color space of differential color perception theory.

2.4 Afterimage

Considering Figure 4 the excessive red colour application to our retina will lead to signal saturation at the receptor output through the path A. Slow rate dissipation of the accumulated energy at the red receptor will follow the path B. This will take place if we look at a red spot for a long time and turn our spot of looking to a nearby empty area, cyan color will replace the red color spot, this is called negative afterimage since cyan is the negative of red. For higher rate of energy dissipation the curve will follow C path, this will lead to positive after-image, in other words, we will see red color when we close our eyes after a long exposition to a red spot for example.

2.5 Colour space of differential color perception theory

Only two axws in the Cartesian space are enough to represent any color of our visible spectrum (Figure 5). Any point on the colour space of Figure 5 expressing a specific colour with two components of Red and Green, P_1 is a point on the R-axis with 100% Red and 0% Green, it can be written as $P_1(100,0)$ which is 100% Red, Blue can be located at $P_6(-100,-100)$.

3. RESULTS AND DISCUSSION

Our eye ball is an ctive optical component working in two modes, night vision (scotpic) and daylight vision (photopic). In the day light mode, red and green receptors or cones will function with some other color sensetive cells to perform some sort of defferential biological amplifiers, one for each photo recptor. Red biological defferential amplifier used to extract a characteristic curve of positve response (red) and a negative response (cyan).

While green biological defferential amplifier used to extract a characteristic curve of positive response (green) and a negative response (magenta). Our brain simply add the two chracteristc signals of red biological defferential amplifier and that of the green biological defferential amplifier to performe full visible color spectrum. Accordingly it is possible now to define any spacial color by using only two coordinates Red and green as shown on Figure 5. It is clear now that our color sense is analogues to the other four senses from the point of opponency since we can represent any visible color by two coordinates. In the photopic mode Yellow and Blue are both secondary colors since yellow is only (Red+Green) and blue is only as –(Red+Green). In the night mode and dimm light, rods and blue sensetive cones will function for best night vision. That is why blue cones population is very low as approximitly as 2 – 3% 0f the total cones population on our retina. Also it explains why the blue cones being spread around the fovea in between rods (Hecht, 1987).

4. CONCLUSIONS

Two dimentional color space of red and green can express any color of our visible spectrum. For our daylight color vision blue is not a principle color it is a secodary color as yellow. Blue color cone receptors with rods work for better night vision. Experimentally found that the reflected light from human eye adapted for night vision shows a lack of blue while at day time the light reflected from a human eye shows a lack of red and green (Cyclopaedia Britannica, 2013). It shows clearly that rods and blue cones work for dim light and night vision. Defferential color perception theory opponency is analoguse to the other four human senses. Since cyan is a lack of red it is not possible to see both red and cyan at the time on the same place. Also it is not possible to see magenta with green color at the same time at the same place since magenta is the lack of green with respect to some reference color. Respectively, it is not possible to see yellow and blue at the same time at the same place since blue is a lack of yellow with respect to some threshold reference (Figure 3).

ACKNOWLEDGEMENTS

According to the characteristic curves of red and green biological differential amplifiers color sets for color mixing should be ±Red and ±Green or simply as Red, cyan, Green and magenta. Or as an abriviation of (RcGm). *R* stands for Red, *c* stands for cyan, *G* stands for Green, *m* stands for majenta.

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Towards a Psychology of Normal and Iridescent Colours

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ABSTRACT

Do people react in a different way when looking at normal or at iridescent colours? We studied the different impact that uniformly coloured and shot silks exercise on observers. We used cloths of changeable and normal colours, with four colours (cyan, blue, orange and pink), and two sizes (small and large disc) for a total of 16 objects. They were rotated at slow speed under an A source of light, in an otherwise dark room, and observed at a distance from which texture was not discriminable. Therefore the perceivable variations were only in colour and size. A new semantic differential was used in which three verbal scales (activity, power, evaluation) and seven intersensory (visual, auditory, tactile and haptic) scales were intermixed. It resulted that evaluations in all scales significantly discriminate the normal from the changeable colours; a number of interactions put in evidence very interesting differences in perceiving changeable and normal colours. From a factorial analysis we found that one factor could be identified with colour heat, as normally happens in this kind of research; two more factors included a hard-soft, and a heavy-light components; the last factor quite interestingly comprehended the three verbal scales.

1. INTRODUCTION

The perceptive difference between normal (uniform) and iridescent colours is that hue and colourfulness, in the case of the shot silk, show large changes when the cloth is rotated in relation to the observer and to the light source, while normal colours can show trivial changes in hue, colourfulness and brightness. Producing iridescent, or changeable, colours is not easy and in nature amazing ways can be found, especially in animals (Meadows et al, 2011). The most common artificial changeable colours are found in shot silk, in which the warp yarn is shot through with a different coloured weft yarn, although nowadays some good but quite expensive results are obtained in car painting too. Our aim was to demonstrate that the psychological reactions to the two types of colours by observers are different, and to specify by which qualities they are characterized.

2. METHOD

After discarding various materials and paintings because of the difficulty in inducing strong impressions of changeable colours, very traditional cloths appeared to be the most suitable objects to be studied in this research.

2.1 Material

We used four pieces of shantung silk of changeable colours (two warm colours: orange/fuchsia and pink/bluette; two cold colours: cyan/green and blue/purple) and four pieces of indian cotton of normal (plain, solid) but very similar colours (orange, pink, cyan, blue). An example of the different charactiristics of the two kinds of cloths is given in Figure 1.

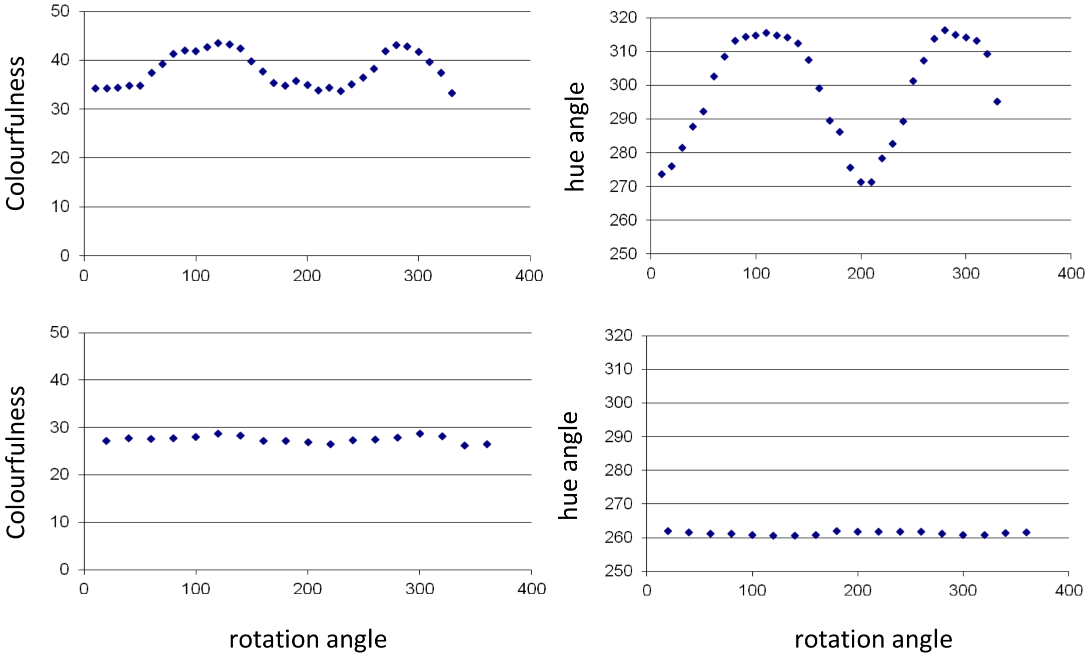

Figure 1: Variations in colourfulness and hue of the 'blue' cloths as a function of their orientation as respect to the light (and consequently to the observer). Top: changeable colours; bottom: normal colours.

The texture of these cloths was rather similar, and from the viewing distance the observer could not discriminate between them. The cloths were put on disks of two different sizes (5 cm Æ and 25 cm Æ) and all were rotated at a constant speed (12 rpm) to highlight their changeable appearance (when present). They were lit by an incandescent light source (CIE standard illuminant A) at about 650 lx in a completely dark room with black walls.

2.2 Tests

A new version of the Osgood semantic differential was used to evaluate the expressive characteristics of colours and their psychological effects on the observers. Three verbal scales corresponded to the three main Osgood's factors (activity, power, evaluation), while other seven scales comprehended different sensory impressions, paired in opposite dipoles.

1. *Visual scales*: A visual scale was made up by a white circle and a white triangle on a black background; after half experiment, because of the bias in similarity with the circular shape of the cloths, they were changed with the visual scale corresponding to the bipolar interval 'maluma - takete' (Figure 2), by Köhler (1929).
2. *Tactile scales*: - Cold / Warm: cold (about 5°) and hot (about 40°) water; - Smooth / Rough: N 90 and N 30 sandpapers; - Hard / Soft: a piece of wood (25×2.5×2 cm) - a strip of cotton wool of the same size;
3. *Haptic scales*: - Light / Heavy: An empty (35 g) and a stone filled (1 kg) plastic 1.5 l bottle;
4. 4. *Auditory scales*: - High pitch / Low pitch: a sound at high frequency (5120 Hz) – and at low-frequency (32 Hz); - Loud / Quiet: an aloud and a weak sound (difference of 60 dB).

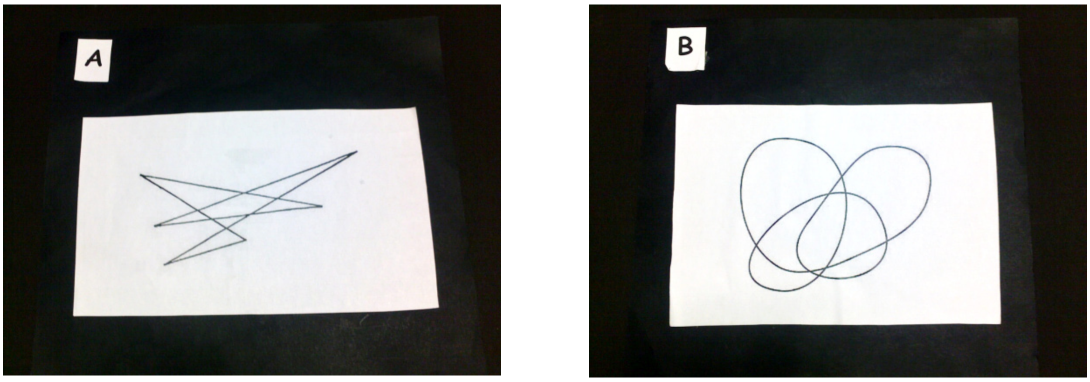

Figure 2: The 'Takete – Maluma' scale in its visual form.

2.3 Procedure

A group of 52 young participants (25 males and 27 females, aged 20-30 years), with normal colour vision, volunteered in the experiment. Each participant, after adapting to the environment, was presented with all coloured disks in random order and performed the task of evaluating the observed colour on each semantic scale, in random order, by means of a visual analogue scale. Participants were from time to time invited to pay particular attention to the sensorial impressions they were using for the evaluations. Because of the length, the experiment could performed in two-three different sessions. At the end of the experiment participants were asked to comment their impression.

2. RESULTS

First of all no difference was found between males and females. From a variance analysis it resulted that evaluations in most scales significantly discriminate the normal from the changeable colours: normal colours appear more circle-maluma ($F_{1,51} = 12.734$, $p < .001$), cold ($F_{1,51} = 8.23$, $p < 0.006$), smooth ($F_{1,51} = 40.393$, $p < .000$), soft ($F_{1,51} = 4.743$, $p < .034$), light (only pink, $F_{3,153} = 5.166$, $p < .002$), quiet ($F_{1,15} = 21.531$, $p < .000$), while on the contrary changeable colours appear more triangle-takete, warm, rough, hard, heavy (only pink), and loud, with the exception of the sensory scale high - low pitch and the verbal scale pleasant – unpleasant, according to which the two kinds of colours were not differentiated.

A number of interactions put in evidence very interesting differences in perceiving changeable and normal colours: the changeable pink is cooler than the normal pink, while the cold colours blue and cyan appear still cooler if normal ($t = -2.3$ and -3.9, $p < 0.048$ and $p < 0.001$). The warm colour pink appears harder ($t=4.17$, $p< 0.0001$), heavier ($t=3.19$, $p< 0.008$), and louder ($t=7.12$, $p< 0.0000$) in the changeable form; orange, whether normal or changeable, is more pleasant than pink ($F_{3,153} = 2.943$, $p < .035$); while the warm pink is much more active than orange ($t = 4.42$, $p < .0000$), the cold cyan and blue are of intermediate activity whether normal or changeable.

Four components were disclosed by a factorial analysis, one of which (warm-cold temperature) is very common in colour studies (da Pos and Valenti, 2007), and in this research changeable colours appear warmer than the normal colours. Another component we found (hard-soft appearance) is also very common, and here normal colours appear softer than the changeable ones ($F_{1,15} = 16.084$, $p < .000$). A third interesting component distinguishes colours on the basis of heavy - light impressions, but this component does not differentiate normal from changeable colours.

Lastly a still more interesting component collects the three verbal scales of the semantic differential in a coherent structure: strong, active, aloud, pleasant vs weak, passive, quite, unpleasant, and changeable colours are significantly more positive than the normal ones ($F_{1,15} = 27.618$, $p < .000$). It seems that associating colours to words implies different evaluation criteria from associating colours to sensory experiences.

3. CONCLUSIONS

The hypothesis that normal and changeable colours produce significantly different psychological reaction in the observers has been confirmed. The analysis of variance highlighted the distinctive characterizations which make changeable colours different from the normal ones. The factorial analysis revealed how different criteria are organized in the evaluation of colours along the different semantic scales: a part from the commonly found factors soft-hard, light-heavy, cold-warm, an independent factor was interestingly discovered which includes all three verbal scales, with the two positive – negative aspects in coherent opposition. Changeable colours globally receive more positive evaluations than the normal ones, and this result should encourage researchers to improve their production in view of a larger and large use in many different fields of the our life.

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Influence of Cognitive Factor on Lightness Perception

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ABSTRACT

Lightness perception of a target can be affected by its surroundings. A representative instance of this phenomenon is White's illusion, in which the apparent lightness of a gray target is incompatible with the predicted lightness according to the contrast of the target with the surroundings that are most prominent in its background. White's illusion is frequently explained with the help of previously proposed theories, such as the theory of local spatial filters, which explains the low-level mechanisms occurring on the retina that are responsible for sensing the border contrast and orientation of viewed objects; the theory of the middle level perceptual transparency or figure-ground organization, which are composed of the spatial configuration of the stimulus; and the theory of the higher cognitive perception of luminance relationships between two spaces divided by gratings. I present here a new type of spatial configuration, which is characterised by no differences in the magnitude of borders between lighter and darker areas, no perceptual organization of transparency, and no illuminant space with the T-junction of gratings. Four observers participated in the experiment, in which the apparent lightness of the gray target area was determined using the method of adjustment and the constancy method. Results for all participants engaged in the experiments showed that the paradoxical apparent lightness of White' illusion was perceived without any difference in the edge length between two different borders, without the perceptual phenomenon of transparency, and without the cognition of different illuminated spaces between gratings. Data showed that the apparent lightness depended on the cognition of the background rather than on the actual background. The experimental results were consistent with the results predicted with the theory that emphasizes the perceptual figure-ground organization.

1. INTRODUCTION

There has been a great number of perceptual studies on the brightness induction which depends on the luminances of adjacent regions, and many models and hypotheses have been proposed to predict intensive aspects of brightness induction (Kingdom 1988, 1997, 2011). The luminance modulation of the adjacent area produces strong brightness induction in the target surface, mostly in antiphase to the adjacent modulation: when the adjacent area is darker the target surface appears lighter, and vice versa. Surprisingly, brightness modulation is sometimes reported to induce in the target surface in opposite brightness direction: such as White effect (White 1979) and a demonstration of Todorovic (Todorovic 1997).

Some of classical explanations to understand precisely the way in which the adjacent region affects the brightness of a surface have been based on the fact that on-center and off-center neurons play different roles in the processing of visual information, being concerned with the perception of brightness (Barlow et al. 1957). Many of these models have been based on the detection of orientation of a border which exist between two different brightness.

On the other hand, some alternative explanations have emphasized the importance of cognitive factor (Logvinenko 1999, Logvinenko et al. 2002, Logvinenko and Ross 2005, Gilchrist 2006). Some models have been made to explain White's illusion in terms of T-junctions because T-junctions act as depth cues where the lateral region is seen as in front of the collinear regions (Anderson 1997, Todorović 1997, Melfi and Schirillo 2000, Ross and Pessoa 2000), however some attempts have demonstrated the effects without T-junctions (Howe 2005, Koizumi and Sakata 2005). And Blakeslee and McCourt have showed a simple but powerful filtering model named the oriented difference-of-Gaussian (ODOG) filters in which multiscale spatial filters produce normalized convolution outputs of lightness (Blakeslee and McCourt 1999, 2004, 2011, 2013).

2. METHOD

2.1 Subjects

The author and three naïve observers participated in the experiments and all observers possessed normal or corrected-to-normal vision.

2.2. Stimuli

The stimuli of the experiment was the circular black and white gratings on which the same gray disks were lined up vertically and horizontally. The length of border between gray and black were just same as the length between gray and white. These stimuli had no T-junction, no depth among the elements of stimuli, and no specific, representative orientation of borders. Four type of the position of gray disks were used: four deviations of gray disks from the grating were manipulated alternative background of disks. The circular black and white gratings alternated at 0.5Hz. The apparatus used in experiment consisted of Windows PC and Nanao T571 monitor of which reflesh rate was 120Hz, and data were measured by Photo Research PR-650 SpectraScan Colorimeter. The size of each gray disk was approximately 0.6 degree, and whole size of stimulus was 12 ´ 12 degree.

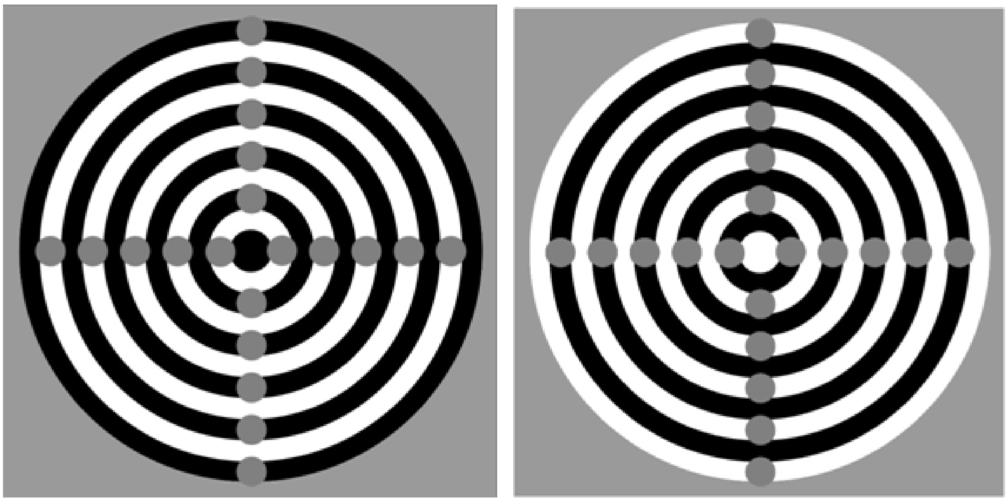

Figure 1: The stimuli of the experiment in which the apparent brightness of gray patches were measured.

2.2. Procedure

Observers maintained a stable head position with a chin rest and adapted to gray background of stimuli for 5 min. In each trial, an observer fixated the center of the stimuli and adjusted to the same brightness of two series of gray disks which altered every second. Observers used a method of adjustment to adjust the luminance of a series of gray disks to match to the other series of gray disks in brightness.

3. RESULTS AND DISCUSSION

The result of observer KS is shown in Figure 1 which shows the gray disks on white circular grating were brighter than disks on black grating. The deviations of gray disks affected on the brightness of gray patches, however the length of borders contact with white were just the same as the length of borders with black. The equality of the both borders suggests that the contrast was also same between black and white. That is, the cognition of background has obvious influence on the brightness of the gray disks.

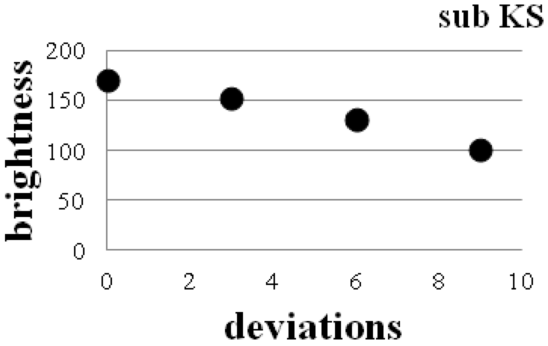

Figure 2: The results of experiment (sub: KS). Gray patch deviations show the effect on brightness.

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Evaluation of Visual Impressions of a Space Illuminated by a Colored Light Selected from a Wide Range of the Chromaticity Diagram

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ABSTRACT

We examined visual impressions of a space illuminated by a colored light selected from a wide range of the color space. In the experiment, subjects viewed the inside of the test space illuminated uniformly by colored light and evaluated its visual impressions; brightness, comfort, openness, activity, warmth, naturalness and stimulation. We chose 36 test color of light from the u'v' chromaticity diagram and set three illuminance levels of 30, 100, 300 lx. The results were mapped on the chromaticity diagram for each of three illuminance levels. It was shown that the sense of brightness of the space was mainly determined by the illuminance levels. On the other hand, the sense of warmth was strongly influenced by the colors of lighting. The naturalness and the comfort were highly evaluated when the color of lighting was close to white. The comprehensive data obtained in this study will be expected to provide a scientific basis for lighting design and useful information to connect our perception of practical lighting environment and human color vision.

1. INTRODUCTION

Progress in LED technology has opened new possibilities to introduce colored light into lighting design. Most of the studies on psychological effects of color of lighting focused on colors along the blackbody locus (Kruithof 1941; Ishida, et al. 2007). Little is known about the effect of colored lighting selected from a wide area of the chromaticity diagram. In this study we examined visual impression of a space illuminated by a colored light selected from a wide range of the color space. The systematic results obtained in this study may provide useful information for lighting design using colored lights.

2. METHOD

We set up a test model space equipped with 11 fluorescent lamps covered with red, green or blue tubes as shown in Figure 1. By adjusting the amount of light emitted from each of the three colored lamp sets, the inside of the test space was illuminated uniformly by a selected color of lighting. To provide a precise and stable color of light, we used the light control system and slits of various size inserted under each of the fluorescent lamp units. The actual color of lighting in the test space was monitored using a color illuminance meter placed inside of the box.

In the experiment, subjects viewed the inside of the test space and evaluated its visual impressions; brightness, comfort, openness, activity, warmth, naturalness and stimulation. A reference space placed aside served as an anchor (score = 100) for the judgements of the impressions. Figure 2 shows the view of the inside of the test space and the reference space. Before observing the test space, subjects viewed the inside of the reference space for

2 minutes to keep their state of color adaptation constant. After viewing the reference space, the subjects observed the inside of the test space for 30 seconds through a viewing window. Then they gave evaluation scores for each of seven impressions.

We chose 36 test colors from the u'v' chromaticity diagram and set three illuminance levels of 30, 100, 300 lx. The reference space was illuminated by white light (u', v') = (0.23, 0.51) with illuminance of 300 lx. Seven subjects from the department of architecture participated in the experiment. They performed 216 trials in total. (36 colored lights × 3 illuminance levels × 2 times).

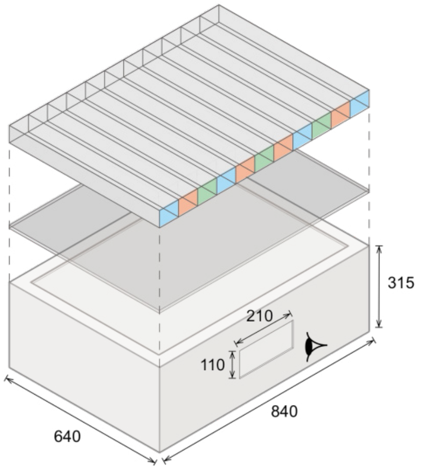

Figure 1: The test space.

Figure 2: View of the inside of the test space illuminated by colored light (left) and the reference space illuminated by white light (right).

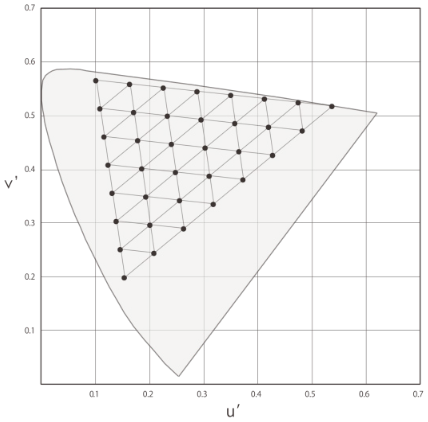

Figure 3: Test colors of lighting plotted on u'v' chromaticity diagram.

3. RESULTS AND DISCUSSION

The results are mapped on the chromaticity diagram for each of three illuminance levels in Figure 4(a)(b). Evaluation scores for each of the test colors were averaged among the subjects and plotted for each of the visual impressions. The size of a plotted circle represents the difference from the average score of all color in three illuminance conditions. Open circles indicate that the scores are higher than the average and filled circles lower than the average. In addition, the result map was colored according to the absolute difference from the average as shown in the Figure 4.

It was shown that the sense of brightness was mainly determined by illuminance levels. The space with higher illuminance was perceived as brighter. On the other hand, the sense of warmth was strongly influenced by the colors of lighting, not by the illuminance levels. The naturalness and the comfort were given high evaluation scores when the color of lighting was close to white. The highest scores for openness were given to the colors with higher color temperature and illuminance. Highly saturated red lightings were judged to be most stimulative. Red lightings with high illuminance were evaluated as active.

The comprehensive data obtained in this study may provide useful information for lighting design. Also their distribution on a color space must give a scientific basis to understand relations between our perception of practical lighting environment and properties of human vision.

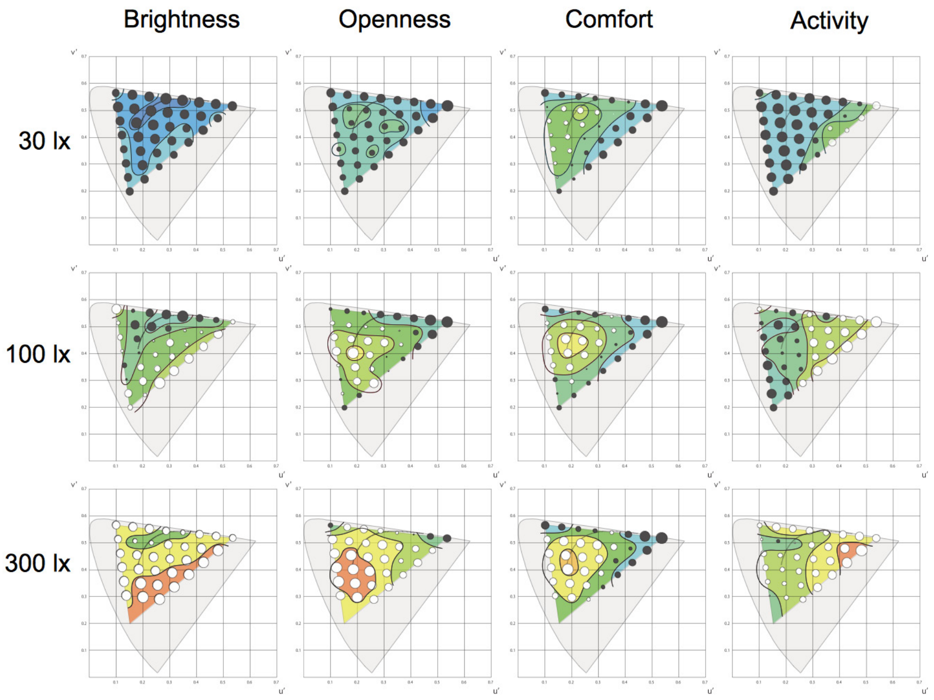

Figure 4(a) The experiment results: The evaluation data of brightness, openness, comfort and activity are plotted on u'v' chromaticity diagram. The size of plotted circle indicates the absolute difference from the average score of all colors in three illuminance levels. Open circles show that their score are higher than the average. Filled circles show that their score are lower than the average. The maps were colored according to the difference between evaluation scores and the average as shown in the color scale.

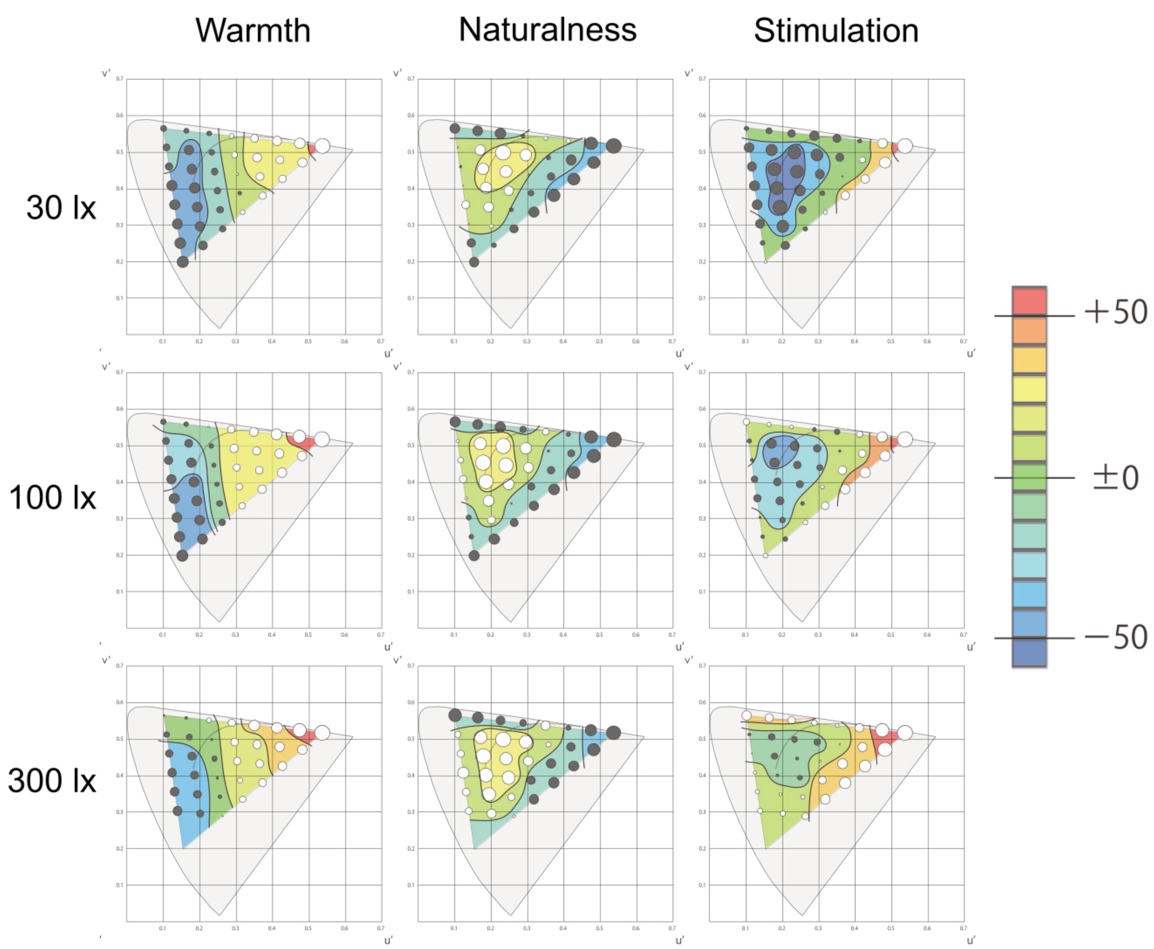

Figure 4 (b) The experiment results: The evaluation data of warmth, naturalness and stimulation are plotted on u'v' chromaticity diagram as in Figure 4(a).

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Can a Hybrid Methodology Facilitate a Collaborative Approach in the Assistance of Establishing How Colour Can Support a Healthy Interior Space for the Ageing Population including People with Dementia?

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ABSTRACT

Colour produces powerful sensory responses, yet its role in Interior Design for the ageing population is poorly researched. This paper interprets the phenomena of colour in interiors for older people through review of metadata and visual analysis of case studies in Northern Ireland and Amsterdam. Innovative investigations will seek to explore how a hybrid methodology facilitates a collaborative approach in the assistance of establishing how colour can support a healthy interior space for the ageing population. Colour is not passive; it is a functional component of the environment that can induce powerful sensory responses. The ageing population is a global research priority and there is demand for active and fluid functionality from all elements of the designed environment. Therefore by necessity, the complexity of interior design and colour research for the ageing population has had to bridge disciplines and in doing so not only opens up possibilities for interior designers, but begins a relationship with a process of enquiry that is intensely human, capturing how colour can shape space connecting one environment to another.

1. INTRODUCTION

As the title implies this paper is concerned with the intimate and personal use of colour in Interior Design for older people. Colour has been described as the wavelength medicine of the future, yet constantly questions about colour and its application to interior space are frequently raised. How can designers apply colour research to mirror the emotional needs that remain integral to ourselves, very often in long-term health care this is over looked and what is often forgotten is colour becomes essentially a lost fundamental element in the human experience. The majority of current recommendations work from a scientifically based premise and psychosocial validation, DSDC[1]. Josef Albers states that his book 'Interaction of colour,' offers a new way to study colour – 'there is no new theory of colour, but there is a way in which to learn to see[2]. Exploration of how we see colour is observed through the use of the Natural Colour System[3] demonstrated in this project. In the 1950's the NCS evolved into a system using a universal language based on the requirements of the colour user (the person) and human perception. The way the ageing eye sees and perceives information depends on the light source, whilst natural light is of prime importance the LRV and perceived colour will change depending on the position of the sun (Brawley 2001). As depth and colour perception become diminished with age, reflective surfaces and busy patterns in materials, floors and walls may cause confusion for older people such as flower and leaf patterns that represent real life.

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[1] Dementia Services Dementia Centre, (DSDC). University of Stirling. UK.
[2] Albers, J. Interaction of Colour, 1963.
[3] Natural Colour System, (NCS). Stockholm, Sweden.

This research seeks to articulate the theoretical argument for colour in Interior design as a priority in care homes and supported housing, highlighting the urgent need for professionally colour designed supportive environments. Recent findings suggest that the environment needs to be a place where residents can personally identify, a place that will evolve to become home, (Calkins, 2001).

2. METHODOLOGY

The methodology of this research adopts a different approach, as a decision has been made not to include the service user due to changes in health-care statistics[4] and an emphasis on ageing in place. The approximate life expectancy of a person entering long-term healthcare is 2.3 years. Two of the most common philosophical approaches that have influenced this design research are Post-Positivism and Constructivism.

For this research project to think holistically and synthetically an approach in contextual understanding is required, this will be achieved using mixed methods. The way research informing colour design decisions has been conducted in the past raises ethical concerns (poor methodologies), however this current research by contrast takes a different approach.

The results will seek to reverse these methodologies by incubating a new way of thinking - a reliable forecast (consensus) given the variableness of human opinion. Therefore the ethical implications are for safer participants and a more valid conclusion.

2.1 Methods

The research is based on a mixed method approach using a qualitative/quantitative study on the use of colour in interior design. A preference for in depth semi-structured interviews, open-ended questions, the use of field notes and case studies including small-scale studies within the qualitative paradigm will be studied. Eligibility for inclusion in the study has been decided by geographical location, years experience and qualifications.

2.2 Online Survey and Interviews

However a more formal on-line survey approach (The Delphi Technique) will facilitate the framework in establishing a panel of experts in the field of colour. An on-line questionnaire will seek consensual values that will be used in the application of multi-criteria analysis. Vignettes may also be used to permit Professionals (those deemed experts in their field of study) to define colour perceptions, beliefs, opinions and attitudes in their own terms.

2.3 Case Studies

Theoretical sampling sites will be chosen for comparison and contrast to test out emerging concepts and verify developing colour theory as research progresses. The case studies chosen from different locations in Northern Ireland represent a cross section of colour-designed interiors. There are five locations that represent 1 rural, 1 coastal, 1 city and 2 town sites. The sixth study is in Amsterdam.

The colour samples will be in the form of readings taken with a NCS hand-held colour scanner from areas of the walls and floors of bedrooms, corridors and day rooms. Photographs may also be taken for identification of the area from which the colour samples are

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[4] Oxford Journals. A census based longitudinal study of variations in survival amongst residents of nursing and residential homes in Northern Ireland, 2009.

gathered. Meta-data from the case studies will be identified and matched using the NCS Navigator Premium, qualitative and quantitative data will be coded, transcribed, analysed and used to distinguish emerging patterns using the software analysis programme NVivo9.

3. DISCUSSION AND CONCLUSION

When we consider the language of colours in interiors, colour theory has become rooted with colour standards, classification and harmonious palettes stretching across the globe. Although the understanding and perception of colour is scientific, taste is subjective. However, part of the problem is evaluation of colour in space according to the American architect Louis Kahn. Colour is to develop an understanding of the space this involves an intense empathy with those that are going to use the building and an accepting that leads to tranquillity in the human soul.

This research project is not yet conclusive, however from samples and observations gathered what this research seeks to find is not an answer that is definitive or to establish prescriptive guidelines, but to find out what exists in relation to colour in Interior Design for the ageing population and why it exists. The research will look at the influence of colour trends – slapdash or objectivity (professional), examining who makes decisions in combating rules and how difficult translation into practice is to achieve. The standardised language of colour in today's market of Interior design tends to be a one size fits all. Establishing the relationship of colour design for older people in their interior environment is essential yet it is still largely untested from the perspective of design. Is it the weakness of design methods, a mistrust of qualitative approaches to decision-making and evaluation that lacks clarity and makes it impossible for certainty? In seeking recommendations for colour in Interior Design, a design framework of hybrid interdisciplinary melding, shared values and beliefs may bridge the gap in design thinking between academic cultures, namely the sciences, humanities, and design.

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Lighting Effects on Visual Impression of a Real-Room Space

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ABSTRACT

A psychophysical experiment was carried out in a “shooting studio” to investigate visual impression of a real-room space. A total of 36 experimental conditions were adopted, generated by two correlated colour temperatures, three lighting directions and six wall colours. Nineteen Taiwanese observers participated in the study. Each observer was asked to sit in the room and rated for each experimental condition using 10 scales. The experimental results show that the observers liked the room most when the room appeared warmth and spacious. The 6500K light source tended to induce bright or cool impression, while the 2700K tended to induce warm or dark feelings. Female observers tended to be more sensitive than male observers to changes in wall colours and lighting conditions, while the male observers tended to be more stringent when rating the experimental rooms.

1. INTRODUCTION

Many existing studies tended to use computer-simulated indoor images as the stimuli when investigatng visual impression of an indoor environment (e,g, Shen et al., 2000; Brengman and Geuens 2005). However, it is unclear whether the findings based on simulated images can apply to a real indoor space. Recent studies have developed a number of quantitative models of colour emotion and colour harmony with satisfactory predictive performance using interior images (Ou et al. 2004; Ou and Luo 2006; Ou et al 2012). The same question arises regarding whether such models can be applied in a real-room environment. To address these issues, a psychophysical experiment was carried out in a real-room space, in an attempt to investigate visual impression of a real room induced by lighting conditions and the wall colour.

2. METHODS

A “shooting studio” with a size of 3m (width) × 3m (depth) × 2.5m (height) was used as defined by three “walls” in the form of coloured cloth sets. A total of 6 wall colours, black, grey, white, light yellow, light blue and light green, were used. The former three colours were achromatic but differed in lightness level; the latter three colours were selected to create “warm”, “cold” and “medium” feelings.

Six lighting conditions were adopted, generated by two correlated colour temperatures (6500K and 2700K) and three lighting directions, including (A) light travelling up and sideway, (B) a non-directional floor lamp, and (C) light travelling down. This resulted in 36 experimental conditions, as illustrated in Figure 1.

Ten semantic scales, selected based on results of a questionnaire by 19 participants (11 females), were used in this experiment to measure the observers’ visual impression of the room. The 10 scales are like/dislike, comfortable/uncomfortable, warm/cool, spacious/small, bright/dark, clean/dirty, relaxing/tense, elegant/inelegant, classical/ modern and harmonious/disharmonious. All observers have passed Ishihara's test for colour deficiency before the experiment. Each observer was asked to sit in the experimental room, and for each experimental condition the observer started to rate the room using the 10 scales in Mandarin after 30 seconds of adaptation. The sequence of the 36 experimental conditions was randomised. Each of the 10 scales consisted of forced-choice 6 categories.

Figure 1: The 36 experimental conditions.

Table 1. Component loadings for the 10 semantic scales used in the experiment.

	Principal component 1 (Warmth)	Principal component 2 (Brightness)
Warm/cool	**.963**	-.050
Classical/modern	**.904**	.270
Relaxed/modern	**.852**	.436
Comfortable/uncomfortable	**.833**	.427
Like/dislike	**.752**	.452
Elegant/inelegant	**.736**	.570
Bright/dark	-.002	**.978**
Spacious/small	.377	**.855**
Clean/dirty	.456	**.748**
Harmonious/disharmonious	.620	**.659**

3. RESULTS AND DISCUSSION

Principal component analysis was used to classify the 36 experimental conditions and create a semantic map where the interrelationships between these experimental conditions are demonstrated. Two principal components "warmth" and "spaciousness", accounting for 86.7% of the total variance, were extracted, as demonstrated in Table 1 and Figure 2. This suggests that the observers liked the experimental room most when the room appeared both warmth and spacious. Figure 3 (a) and (b) show distribution of the 36 experimental conditions in the component plot, based on the component scores for male and female observers, respectively. As both graphs demonstrate, the correlated colour temperature seems to have a strong impact on visual impression of the room for both male and female groups. The 6500K light source tended to induce either bright or cool impression, while the 2700K tended to induce either warm or dark feelings.

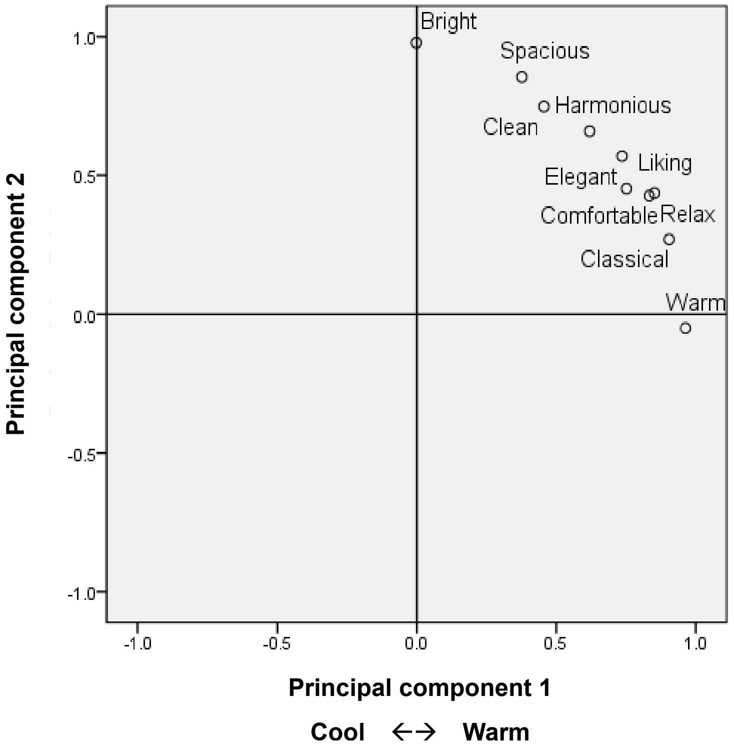
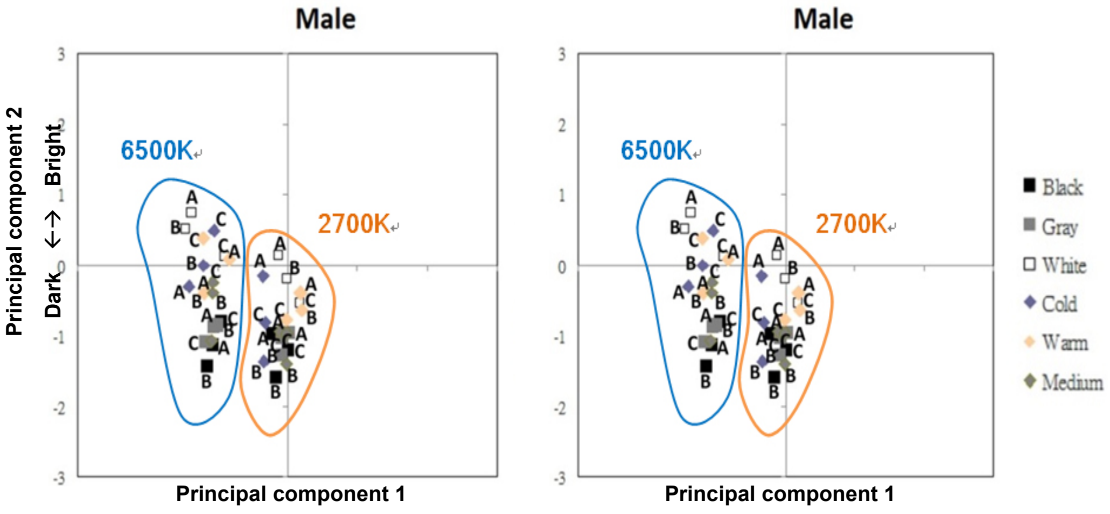


Figure 2: Component plot for the 10 semantic scales used in the experiment.



(a) (b)

Figure 3: Distribution of the 36 experimental conditions for (a) male and (b) female observers, in the factor plot where A, B and C represent the three lighting directions: A. light travelling up and sideway, B. a non-directional floor lamp, and C. light travelling down.

4. CONCLUSION

This study aimed to investigate the influences of lighting conditions and wall colours on the visual impression of a real-room environment. The results show that the 6500K work worst with black walls, while the 2700K light worked best with light yellow walls. The experimental data showed high correlation coefficients for the 10 scales between the two gender groups, suggesting good agreement between the two gender groups regarding their impressions of a real-room space induced by various lighting conditions. According to Figure 3: (a) and (b), however, the female observers tended to be more sensitive than male observers to the changes in wall colour and lighting conditions.

On the basis of the experimental results, lighting conditions and wall colours were found to have a significant interaction regarding their influences on the visual impression of a room and the visual impressions of a real-room space can be determined by two underlying factors, “warmth” and “spaciousness”. Furthermore, a light source with a high correlated colour temperature tends to give a spacious and bright impression, while a light source with a low correlated colour temperature tends to give a warm and relaxing feeling.

5. ACKNOWLEDGEMENTS

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Investigation and Evaluation of Interior Lightings of Recently Launched Express Bus

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ABSTRACT

In this study, investigation about interior lighting items, illuminated characteristics and design characteristics was carried out targeting the recently released 14 express buses. Moreover, sensitivity and preference assessment for the same vehicle were performed. After analysis, all of the 14 sruveyed vehicles had room lamp and reading lamp. Regarding the room lamp, 5 of the vehicles direct illumination approach, 7 of the vehicles employ indirect lighting method, 1 of the rest 2 vehicle had half indirect lighting system and the other vehicle had direct lighting system and indirect lighting system were mixed and applied. In addition, 9 vehicles were in the line type in the form of lighting fixtures. As for mood lamp, gangway lamp, bracket lamp and panorama lamp have been applied; blue and purple are mainly used for accent lighting. As for the emotion image assessment, In the image “Comfortable•Luxurious”, the vehicles which had a low color temperature with indirect lighting system were highly rated. In the image “Exciting•Fancy”, the vehicles with varied lighting colors were highly rated. In the “Simple•Modern” image, the vehicles with high color temperature and a small number of illumination were highly rated.

1. INTRODUCTION

Cars in the past were just a means of simple vehicle so the focus was on the development of technologies to maximize efficiency. However, as the users’ needs get diversified into emotional satisfaction, enjoyment and improved comfort and interest for vehicle lighting rise, expectations about the quality of the indoor lighting conditions in express bus is also on an increase. The change in the new trend has led to the application and development of a wide variety of vehicle interior lighting items. In this study, investigation about interior lighting items, illuminated characteristics and design characteristics was carried out targeting the recently released 14 express buses. Moreover, sensitivity and preference assessment for the same vehicle were performed. Later, the results are to be incorporated as a reference to establish the express bus interior lighting concept development and emotional lighting design criteria which the needs of consumers are applied.

2. METHOD

2.1 Survey Method for applying an interior lighting in express bus

This study was carried out to investigate the interior lighting of vehicle regarding the 13 express buses (B~N) displayed in 2012 Hannover Commercial Motor Show (IAA) and 1 express bus (A, A’) which is released in Korea. The overview on the vehicles surveyed is equal to the Figure 1 and the overview on the survey is shown in the Table 1 which were utilized by a checklist.

Figure 1: Overview of the vehicle surveyed.

Table 1. Overview of the survey.

Lighting items	Source of light	Room lamp, Reading, etc., Mood lamp (Panoramic lamp, Gangway lamp, Bracket lamp), etc.
Application-specific	Applying location	zenith, shelf (above, side, below), floor, duct
	The way of lighting	General lighting, local illumination
	Photometric method	Direct illumination, indirect lighting
	Arrangement	Column 1, Column 2
Design Characteristics	Luminaire type	Line type, standalone

2.1 Methods for sensitivity and preference evaluation

Methods for the sensitivity and preference evaluation of the 14 surveying vehicles were carried out using the 5 step value method for both of the experimental evaluation. In addition, the experimental evaluation indicator is given by subjective rating method and image adjective vocabularies which are going to be used in the emotional image evaluation were selected as 26 different vocabularies through the advanced research, the literature review and interviews. The vocabulary assessment rating scale presented to the subjects is the same as the following Table 2 and the subjects who participated in the evaluation are composed of the 4th grade or higher students major in Architectural Engineering in C University which is recognized for lighting conditions area.

Table 2. Vocabulary assessment and rating scale.

Vocabulary	Luxurious	Fancy	Stable
	Refined	Cheerful	Unified
	Delicate	Dynamic	Exciting
	Soft	Harmonious	Entertaining
	Simple	Brisk	Pleasant
	Neat	Joyous	Bright
	Comfortable	Tranquil	Fully portrayed
	Nice	Warm	High-tech
	Comfy	Modern	Preferred
Rating scale	Comfortable Extremely Fairly Average Slightly Absolutely		

3. RESULTS AND DISCUSSION

3.1 Interior lighting in express bus survey results

After analysis, all of the 14 surveyed vehicles had room lamp and reading lamp. After analyzing the application location of the room lamp, 7 of the vehicles had it on the ceiling, 2 of the vehicles had it on the shelf and 5 of the vehicles had it on the side of shelf. 13 of the vehicles had general light system. Analysis of the photometric method shows that 5 of the vehicles had direct illumination system, 7 of the vehicles had indirect lighting system and 1 of the rest 2 vehicle had half indirect lighting system and the other vehicle had direct lighting system and indirect lighting system were mixed and applied. In the case of arrangement, 12 vehicles had column 2 applied and the other 2 vehicles had it placed in column 1 in the center of the ceiling. Plus, 9 vehicles were in the line type in the form of lighting fixtures. For mood lamps, there were two vehicles each set with gangway lamp, bracket lamp and panoramic lamp. It came out to be accent lighting in the 8 vehicles which are blue and purple color.

3.2 Sensitivity and preference evaluation results

Emotional image evaluation experiment about the 14 surveyed vehicles was conducted and after analysing the results of factor using SPSS Statistical program, it had 64.094% and was classified into 3 factor axis following the Table 3. The first factor had 26.325% and the representative image was comfortable and Luxurious. The second factor had 23.772% and its representative image was exciting and fancy. The third factor had 13.997% and its representative image was simple and modern. After analyzing the factors, based on the 3 derived factors, factor float chart about the 14 vehicles was shown in the Figure 2 and 3.

In the image "Comfortable•Luxurious", the vehicles which had a low color temperature with indirect lighting system were highly rated. In the image "Exciting•Fancy", the vehicles with varied lighting colors were highly rated. In the "Simple•Modern" image, the vehicles with high color temperature and a small number of illumination were highly rated.

After the preference assessment results, in the float chart, 'comfortable and luxury' had the most votes for preference. This means that direct lighting system is favoured. The change in lighting color was found to be not higher in preference, especially when the color temperature is primary color or the saturation is very high and direct illumination system is applied.

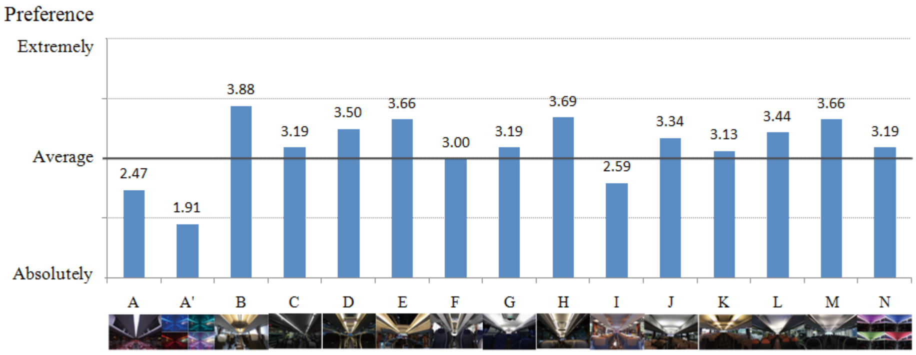

Figure 4: The result of preference assessment.

Table 3. The result of factor analysis

Factor	Evaluation term	Factor			Factor analysis
		1	2	3	
Ⅰ	Comfy	.885	-.010	.180	Comfortable · Luxurious
	Delicate	.816	-.029	.179	
	Comfortable	.815	-.049	.260	
	Soft	.814	.024	.183	
	Simple	.794	.147	-.174	
	Stable	.736	.023	.344	
	Luxurious	.691	.257	.302	
	Harmonious	.679	.101	.455	
	Tranquil	.616	-.192	.399	
	Refined	.590	.286	.480	
	Nice	.563	.151	.545	
Ⅱ	Exciting	.019	.848	.053	Exciting · Fancy
	Brisk	-.134	.838	.043	
	Dynamic	-.180	.831	-.020	
	Pleasant	.062	.799	.144	
	Fancy	-.014	.794	-.033	
	Entertaining	.066	.792	.043	
	Joyous	.229	.753	.095	
	Cheerful	.093	.691	.205	
	Fully portrayed	.156	.676	-.012	
Ⅲ	Neat	.483	-.037	.714	Simple · Modern
	Simple	.420	-.096	.668	
	Unified	.433	.002	.595	
	Modern	.405	.102	.572	
	Bright	-.025	.331	.567	
	High-tech	.092	.545	.548	
Eigen value		6.844	6.181	3.639	
Contribution rate		26.325	23.772	13.997	
Cumulative rate		26.325	50.097	64.094	

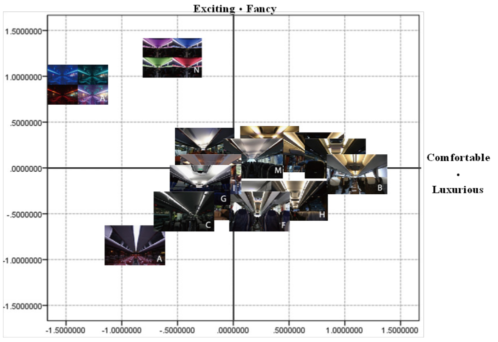

Figure 2: The result of positioning analysis(Ⅰ)

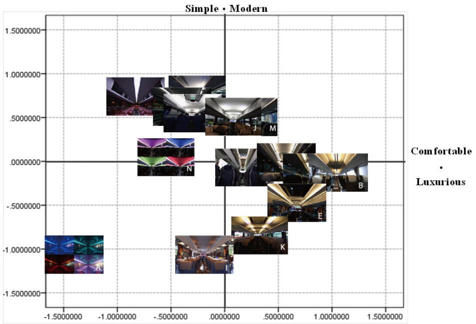

Figure 3: The result of positioning analysis (Ⅱ)

4. CONCLUSIONS

Indirect lighting system and the line system, the application of the gangway lamp and the accent lamp and as an integrated design, the system that has the variety of color of the light are to be presented for lighting items and lighting characteristics in express bus. After factor and positioning analysis, the derived images are expected to be utilized as a reference in the developement of the interior lighting concept in the future. Furthermore, the results show that the consumers favor direct lighting system that is described as "comfort and luxury' and this result is expected to be utilized as a reference in designing interior lighting in the future.

ACKNOWLEDGEMENTS

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Color Preference of the Interior Color Schemes Among Ages

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ABSTRACT

This study shows the similarities and differences between the color preferences for interiors among different age groups. We generated computer graphic stimuli with different door and floor color combinations based on actual colors used in interior spaces. Subjects were asked to select their most and least preferred interior color, preferred color for a private room, preferred color for a common room, and the reasons for their choices. This study comprised a total of 291 subjects aged 18-25, 26-40, and 41-55. As the results of simple tabulation and correspondence analysis, all age groups preferred light brown color schemes. Moreover, the choices of the most preferred color and the preferred color for a private room were similar in each age group. However, subjects aged 18-25 chose, as a different feature of their choice, a preference for black, despite the fact that the least preferred colors across all age groups were dark, inharmonious shades, which were bicolor schemes and color schemes using black, gray or dark brown. Furthermore, it was considered that a general preference was chosen for the common room unlike the private room, which reflected their personal preferences.

1. INTRODUCTION

One of the factors that constitute the visual environment for a residential space is interior color. The effect of interior spaces on color emotions has been studied in various research, in which colors were systematically selected from, for example, the Munsell color system(Acking and Kuller 1972, Hogg et al. 1979). While, there has been an increase in the *interior selection system*- using which purchasers can themselves select interior colors, especially for doors and floors in Japan. Therefore, we reported the results of an impression evaluation for interior color schemes using actual color in interior spaces (Yokoi and Saito 2012). This study reports the results of color preference of interior color schemes that were investigated simultaneously with the previous research. This report also summarizes the reasons for these selections.

2. METHOD

2.1. Stimuli

The interior colors were based on actual color sheets used in interior spaces. We selected eight colors and these were 2 brightnesses of light brown: ltB1, ltB2(ltB1 is brighter than ltB2); 2 brightnesses of dark brown: dkB1, dkB2(dkB2 is darker than dkB1); grayish brown: gB; reddish brown: RB; white:W; and black: Bk. Using computer graphics, we used each of the eight colors on a door and floor to produce 64 different patterns of interior colors. On the basis of the results of pilot studies, in which subjects were asked to identify the inappropriate color pattern for interior spaces, we eliminated 33 of the 64 patterns and used 31 patterns for this research. This study was concerned with examination of color patterns, therefore, we selected a base design for these color sheets that was almost plain.

2.2. Procedures

This study included a total of 291 subjects, of which 103 were between the ages of 18 and 25 (average age, 21.8 years, SD=2.1), 110 between the ages of 26 and 40(average age, 32.0 years, SD=4.5), and 78 between the ages of 41 and 55 (average age, 45.3 years, SD = 4.0). The subjects were asked to select their most and least preferred color, preferred color for a private room, and preferred color for a common room from 31 patterns arranged in a list. In addition, they were asked to state the reasons for their choices. Subjects were allowed to choose only one color scheme from the list.

3. RESULTS AND DISCUSSION

Simple tabulation for the selected colors and the ranking by selectivity were computed. Table 1 is the higher rank which is 5% above the selectivity in each age group. The results of the correspondence analysis are presented in Figures 1 and 2.

Table 1. Results of simple tabulation.

Preferred interior color						Unpreferred interior color					
18–25 years	Selectivity(%)	26–40 years	Selectivity(%)	41–60 years	Selectivity(%)	18–25 years	Selectivity(%	26–40 years	Selectivity(%	41–60 years	Selectivity(%)
Bk × Bk	11.9	dkB2 × dkB2	11.8	ltB2 × ltB2	16.1	gB × Bk	15.8	Bk × Bk	18.2	Bk × Bk	18.3
ltB1 × ltB2	6.9	ltB2 × ltB2	9.1	dkB1 × dkB1	10.8	Bk × Bk	10.9	gB × Bk	13.6	gB × Bk	15.1
Bk × W	6.9	ltB1 × ltB1	8.2	RB × RB	8.6	dkB1 × dkB2	8.9	RB × ltB2	10.9	W × W	7.5
ltB1 × ltB1	6.9	ltB1 × ltB2	7.3	ltB1 × ltB2	7.5	W × W	6.9	gB × gB	10.0	W × Bk	6.5
ltB2 × ltB2	5.9	gB × gB	6.4	ltB1 × ltB1	7.5	Bk × dkB2	5.9	W × W	6.4	Bk × dkB2	5.4
dkB1 × ltB2	5.9	W × ltB1	5.5			RB × RB	5.9			dkB1 × dkB2	5.4
dkB2 × dkB2	5.9	RB × RB	5.5			gB × W	5.9				
W × W	5.0					W × RB	5.0				
RB × dkB2	5.0										
ltB2 × ltB1	5.0										

Preferred color for a private room						Preferred color for a common room					
18–25 years	Selectivity(%)	26–40 years	Selectivity(%)	41–60 years	Selectivity(%)	18–25 years	Selectivity(%	26–40 years	Selectivity(%	41–60 years	Selectivity(%)
Bk × Bk	10.7	dkB2 × dkB2	13.6	ltB2 × ltB2	14.1	dkB1 × dkB1	13.6	ltB2 × ltB2	18.2	ltB2 × ltB2	17.9
ltB2 × ltB2	10.7	ltB1 × ltB1	10.0	ltB1 × ltB1	12.8	ltB2 × ltB2	12.6	ltB1 × ltB1	10.0	dkB1 × dkB1	15.4
W × W	8.7	ltB2 × ltB2	9.1	dkB1 × dkB1	11.5	dkB2 × dkB2	9.7	dkB1 × ltB2	9.1	ltB1 × ltB2	10.3
ltB1 × ltB1	7.8	gB × gB	8.2	RB × RB	9.0	ltB1 × ltB2	8.7	ltB1 × ltB2	8.2	ltB1 × ltB2	7.7
dkB1 × ltB2	6.8	Bk × Bk	7.3	ltB1 × ltB2	6.4	ltB2 × dkB1	8.7	dkB1 × dkB1	8.2	ltB2 × ltB1	7.7
Bk × W	5.8	ltB1 × ltB2	7.3	ltB2 × dkB1	6.4	ltB1 × ltB1	6.8	W × W	6.4	dkB1 × ltB2	6.4
dkB1 × dkB1	5.8	dkB1 × dkB1	6.4	gB × gB	6.4	dkB1 × ltB2	6.8	ltB2 × dkB1	6.4		
		Bk × W	5.5					RB × RB	5.5		
		RB × RB	5.5								

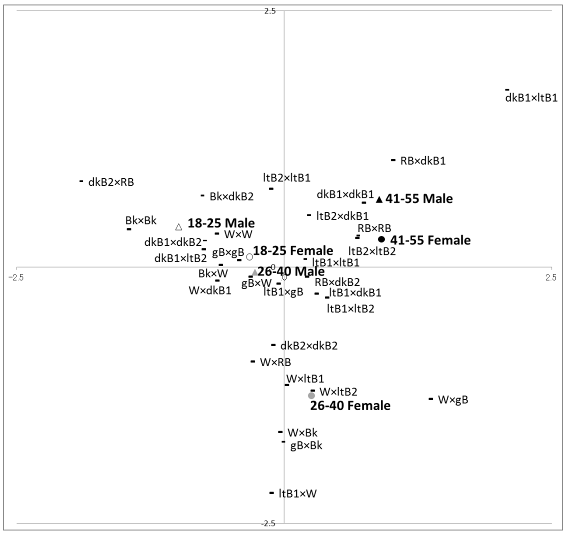

Figure 1. Preferred interior color.

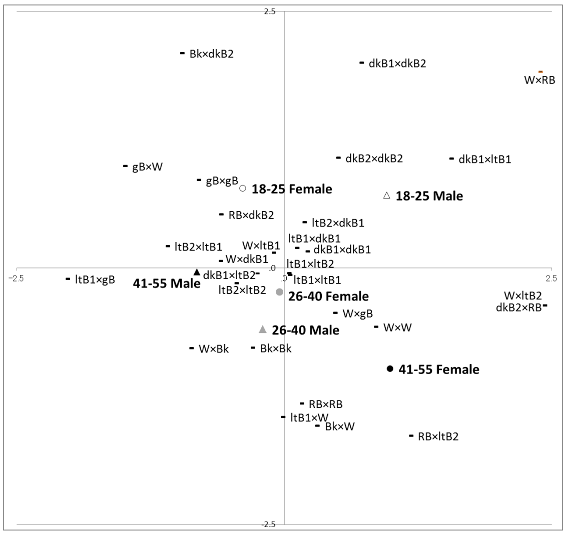

Figure 2. Preferred color for a common room.

3.1. Preferred interior color

On the whole, light brown color schemes were preferred across all age groups. However, the preferred interior color schemes chosen by subjects between the ages of 18 and 25 years were color schemes that used black in higher amounts. Subjects between the ages of 26 and 40 years chose, as the different feature of their choice, a preference for grayish and reddish color schemes, such as gB × gB (door color × floor color) and RB × RB compared to other age groups. Furthermore, RB × RB was also chosen by subjects between the ages of 41 to 55 years; they selected RB × RB the most among all age groups.

Figure 1 presents the results of the correspondence analysis for the preferred interior color schemes between age groups and sex. It is considered that female subjects between the ages of 26 and 40 years tend to prefer white color schemes compared with other age and sex groups. They primarily chose white color scheme because it was ‘bright’. Subjects, particularly, males aged between 18 and 25, chose color schemes that used black. The main reason for their choice of a black color scheme was its ‘stylishness’ and that it was ‘calm’. The preferred interior color has different features across the age groups.

3.2. Unpreferred interior color

All age groups chose Bk × Bk and gB × Bk in higher rank as their least preferred interior color because it was ‘inharmonious’ and ‘dark’. W × W was also chosen by all age groups because it was ‘unsettling’. Marginal differences were observed in the least preferred interior colors between age groups; however, some different results between age groups were the choice of dkB1 × dkB2 by subjects aged between 18 and 25, RB × ltB2 and gB × gB by subjects aged between 26 and 40, and W × Bk by subjects aged between 41 and 55 years. Except for gB × gB, the reason given for these choices was that it was ‘inharmonious’. As for the choice of gB × gB, subjects stated that it was ‘dark’ and they did ‘not prefer the color’. Subjects aged between 26 and 40 also chose gB × gB as their preferred interior color, and the same tendency was observed for the selection of Bk × Bk by subjects aged between 18 and 25. Thus, the preference for the color scheme that used grayish brown and black differs between the individuals in these groups.

In the results of the correspondence analysis for the least preferred interior color schemes between age groups and sex, almost all stimuli were attached near the starting point. This indicates that there are very few differences of least preferred interior color between the age and sex groups.

3.3. Preferred color for a private room

All age groups chose ltB1 × ltB1 and ltB2 × ltB2 in higher rank as the preferred interior color for a private room. This indicates that light brown color schemes are preferred for a private room. Moreover, the results of the preferred interior color for a private room were similar to those of the preferred interior color. Furthermore, the same color scheme for door and floor color was chosen frequently and those results were also the same as those of preferred interior color. It is considered that most subjects selected their preferred interior color as their preferred color for a private room.

3.4. Preferred interior color for a common room

Brown color schemes were the preferred interior colors for a common room across all age groups, especially schemes that used dark brown. The main reason for this choice was that it was 'acceptable'. Moreover, the same color schemes for door and floor color were also chosen in higher ranks. In this selection, subjects aged between 18 and 25 did not choose color schemes that used black, similar to the results for the preferred interior color.

Figure 2 indicates the results of the correspondence analysis for the preferred color for a common room between age groups and sex. Brown color schemes were attached near the starting point; moreover, the color schemes that used reddish and grayish browns were distant from other stimuli. Therefore, brown color schemes were identified as 'acceptable'. It is considered that a general preference which was regarded as preferred color across all ages was chosen, unlike the private room, which reflected the subjects' personal preferences.

4. CONCLUSIONS

Simple tabulation and correspondence analysis for the selected interior colors among the age groups revealed that all age groups preferred light brown color schemes. Moreover, the choices of the most preferred interior color and the preferred interior color for a private room were similar in each age group. Younger subjects aged 18 to 25 chose stylishness as the characteristic feature of their choice with a preference for black color schemes. The least preferred interior colors across all age groups were inharmonious and dark shades which were bicolor schemes and interior color schemes using black, gray or dark brown. The preferred colors for a common room were brown color schemes across all age groups and brown color schemes were considered acceptable. It was evident that a general preference was chosen for the common room, unlike the private room.

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Using Abstract Color Paintings Expressing Feelings to Design Textile Prints showing Emotional Human Factors of Design and Considering Differences of Color Perception between Humans

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ABSTRACT

This research is a Practice led research. It is made of two parts. First some experimental art paintings were made by the artist, based on abstract style, and using colors expressing various emotional feelings. These art paintings are made with power of human feelings and with the spiritual concentration to express these feelings especially into colors. The artist is a painter and a designer, also a PhD. Associate Professor who teaches color theory in art and design for over a decade. These art paintings are made with the intention to express and also to transfer the spiritual mood of the concept in each case, to the viewers of art and the users of the final product. Next, these art paintings are being used to design textile prints that will keep, and even exaggerate these human emotional factors, that would provide emotional semantics to the users of the product. The designer of the textile prints will consider the slight differences between the colors on the canvas of the paintings, and the colors on the computer screens, and also the final colors on the output fabric material; as a PhD. in Textile Printing Design, and also as an expert of the changes that will occur to the colors through the steps of achieving the design. All stages of the work will be revised by both the designer expert and the painting artist to make sure the massage will be delivered to the user exactly as it was created at the first step. The designer and the artist will also consider in the computer stage of design the differences of perception of colors between humans in order to avoid any wrong interpret of color or group of colors that might lead to expressing a different mood, semantic massage, to the user. This experiment will include a final comparison between the colors in the art paintings and the colors on the final textile print products to measure how accurate the stages of production went, and also a comparison between the concept of the art painting and the different concept of the textile print design.

1. INTRODUCTION

Art painting is a unique experience, design work needs mental awareness of the concept of art. In this practice led experiment, some explanation of the concept of the work has been provided to the printing designer, to help understanding and keep representing the same concepts and feelings resulting, while working from these art works into designs.

2. METHOD

The art paintings and the concept provided to the designer before starting to design;

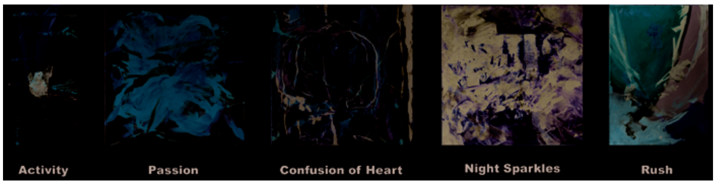

Figure 1: Original paintings.

(Figure 1) Activity; this painting represents the power of starting to move, activity of letting go, and opening up to freedom, all starting from a point in the center, that is the center of well and determination to achieve goals. The power of the centre is dark because all the power is concentrated in. At the explosion of power shows more vivid color like the cadmium yellow used and other light colors, like the pistachio, and other. Some brown lines show the direction of explosion, it is dark and concentrated as going out from the center. The small brush strokes like writing is achievements in reality after this activity rush, its in reds, that is the thing attractive to the eye, not the hard working of activity, being represented as a back ground.

Passion; This painting expresses feelings of love flowing rapidly from the heart that is hidden now by the feelings flowing every where and in all directions, dancing around the heart. All are representing the experiment in the light blue space of life in the background.

Confusion of heart; Confusion and emotional hesitation scattered the poor heart that became now like an empty cage with few week blood arteries and veins, not protecting any thing, but there is some light in the core, maybe from the soul, from faith, giving optimism to this situation.

Night Sparkles; This painting is a scene for a small place with the lights in the night glowing through the darkness, the leaves of the surrounding trees are moved b the soft are, making the yellow lights even sparkle more in the darkness.

Rush; Rush is represented here in dark, un-straight sharp brush strakes, showing tension and hesitation at the same time. Separating strong opposite colors like red, green, cadmium yellow, white, and brown, ordered in a way that the strong struggle is between the red and green areas. The white space is in the centre of rush lines and spaces, expressing the final moment of release and settlement after all.

2.1 Design Styles

Designs and styles of repeatation in design making, in (Figure 2).

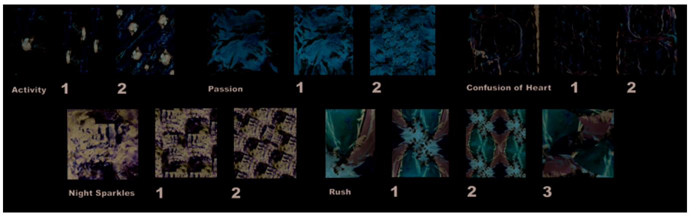

Figure 2: Designs from the original paintings.

Activity; 1: Alternative Repetition (alternating) in position and direction is vertical. 2: Diagonal repetition that suggests to fall and fall, meaning certain movement doing an activity, alternating repetition comes between two bands: the first is the center of well and determination to achieve the goal with dark color because it holds all the power stored inside in a small space so it is loaded with a lot at the starting and rush towards the goal and the launch of this determination shows the lightest dynamic colors such as light green, light yellow. The second is zigzag lines in red color, reddish-brown represent the achievements that are realized and filled with detail (the zigzag lines that resemble writing).

Passion; 1: Progressive repetition from the center where increasing brush strokes away from the center of the board in side horizontal and vertical flows so the overlap increases the red and grades. 2: Cyclic distribution in the middle (center) of the red color, and in the parties Brush strokes distributed in multiple directions at the form of arcs it means gradient from the dark red in the center to the lightest in outward direction.

Confusion of Heart; 1: Repeated in more than one direction. Horizontal: repeated alternating in space. Vertical: repeat alternating in the direction. 2: Repeated zigzag lines and colored spaces which Included in a vertical direction.

Sparkles of night; 1: Identical Horizontal repetition in shapes, colors, texture and direction. 2: Alternative repetition organized in a vertical direction, stressing on the movement of the refracted line.

Rush; 1: Repetitions around the horizontal and vertical axis in different direction .2: Regular quarter repetition in horizontal and vertical direction. 3: Repetition in circular direction for strong lines in black color and for spaces with contrasting red, green and yellow color by rotating around the square in the center of the design, the square appears in white color to reflect the arrival of the rush to the top in the white space that combines these lines and rallies to represent a moment of peace and stability in the end.

2.2 Correcting Colors and Printing Samples

Colors have been scaned by an accurate spectrophotometer called "Gretag Macbeth Spectro Eye" (Figure 3) , then all colors have been digitally corrected on the Photoshop software (Figuree 4).

Gretag Macbeth Spectro Eye

Gretag Macbeth Spectro Eye is an accurate spectrophotometer combining accurate measurements of LAB and Lch with standard densitometric functions.

Figure 3: Gretag Macbeth Spectro.

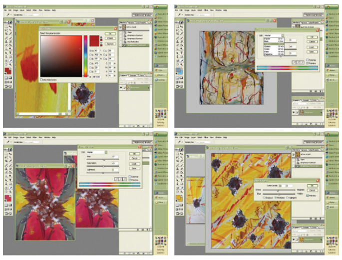

Figure 4: Correcting colors.

The printing samples included two types of cloth: Master 400 g, and Satan 160 g, and a comparison between print and real paintings has been done to correct for printing option and reprint again (Figure 5) And Original Samples of printed textiles will be attached to the poster.

Figure 5: Comparison to original paintings and printing materials.

2.3 Designs in case of vision deficiency

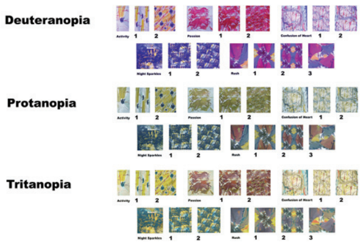

Figure 6: Modify to color deficiency vision.

Figure 7: Color deficiency vision.

We used guides for how color vision deficincy would see real color to modify the colors of the designs, and the painrings as well. Using the same software but with diferent tools to change specific colors, whereis an option to compare the real natural colors of the image and an editable one as the user modifies the colors and compares; shown at the colored lined of the tool box opened at (Figure 6), the results of how people with color deficiency would see the designs and paintings are shown in (Figure 7).

3. RESULTS AND DISCUSSION

Human Feelings expressed in works of art have been transferred into printed design products, with some color correction and compares.

People with vision deficiency will see different colors but with the contrast of hues and tones would still view the concept of the product.

Art paintings with simple, direct, and strong color, are good material for applied design.

One of the original paintings, and real samples of the designs will be attached to the poster in the conference.

4. CONCLUSIONS

Humans see color diferently, some humans have vision deficiency, but artist and designer can manage to prepare their work to get the meanings delivered better to these people.

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Analysis of Black Fabric Texture Recognition by Comparison between Observer Groups: Influence of Fabric Drape Complexity and Window Size

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ABSTRACT

This study aims to investigate the effect of knowledge and experience on one's ability to identify fabrics using visual and tactile information and to explore the key visual factors that affect fabric texture recognition. We conducted questionnaire surveys and a fabric-identification experiment using two groups: engineering observers (EOs) and clothing observers (COs). In the fabric-identification experiment, observers were asked to select a real fabric by blind tactile perception while looking at the fabric's image on a display. The experimental results were compared in terms of three points: fabric drape complexity, window size, and accuracy of light-source position estimation. The results of the questionnaire surveys show that the COs had significantly greater fabric knowledge and experience than the EOs. Additionally, the number of corret answers furnished by the COs was higher than the number of correct answers furnished by the EOs. Especially, when the window size effect is removed, drape complexity affects the number of correct answers, but the effect of drape complexity on fabric texture recognition is weaker than that of the window size. However, the COs number of correct answers for light-pattern recognition was slightly lower than that of the EOs.

1. INTRODUCTION

Currently, many people purchase clothes through online shopping (Office for National Statistics, 2013). Furthermore, a few reports indicate that almost half of the surveyed consumers prefer shopping for fashion online than offline (Graham 2011). However, because consumers must select items by looking at digital images presented on a display, they are sometimes disappointed that the colour, texture, and tactile sensation of the actual cloth differs from what they expected. It is believed that the causes of the disappointment include the consumer's inability to identify fabric based on knowledge and experience, and visual restriction from using the display. In our previous study (Tomoharu 2011), we carried out a fabric-identification experiment with EOs and COs having different levels of knowledge and experience as participants. Subjects were asked to select a black fabric by blind touch by looking at an image of said fabric on a display. Two types of photographs were used as the fabric images: with drapes and without drapes (Pattern A [PA] and Pattern B [PB], respectively). The results indicated that the COs performed better than the EOs. The number of correct answers was statistically higher among observers that looked at a photograph of PA than it was for observers that looked at a photograph of PB. This result suggests that the existence or nonexistence of a fabric drape is a key visual factor that influence textures recognition. The visual complexity of a fabric drape changes with the setting and lighting method, and both pattern perception and visual impressions are affected by the size of the visual field. Therefore, we conducted questionnaire surveys and fabric-identification experiment with sets of

EOs and COs comprising members different from those used in the previous experiment. In the questionnaire, observers were asked polar questions on their knowledge of fabric names, as well as their visual, tactile, and wearing experience of the fabrics. In addition, observers' fabric knowledge and interest were measured psychologically based on a visual analogue scale (VAS). The effects of fabric drape complexity, window size for observing the fabric drape, and accuracy of light-source position estimation were mainly investigated. From the obtained results, the effects of knowledge and experience on one's ability to identify fabrics using visual and tactile information, and the key visual factors that affect fabric texture recognition were determined.

2. EXPERIMENT

2.1 Questionnaire Survey and Psychological Measurement using VAS

We conducted surveys using four questionnaires and recorded psychological measurements using a VAS. The observers were asked four polar questions: 'Do you know the fabric name?' 'Do you have experience of seeing the fabric?' 'Do you have experience of touching the fabric?' 'Do you have experience of wearing the fabric?' In addition, the observers' knowledge and interest in general fabrics were assessed psychologically using a VAS. Eleven fabrics were selected based on their different characteristics.

2.2 Fabric-Identification Experimental Conditions

Eleven actual fabrics were prepared as test cloths and cut into 20 cm × 20 cm square pieces, as specified in JIS L1096. A small square tag was attached to a corner of each piece for indicating the piece's front surface. Four types of pictures of each fabric were captured on a digital camera (Nikon D50) for use as test images. To this end, each fabric was cut into circular pieces of diameter 40 cm. Three of these four picture types had the fabric covering an acrylic cylinder for forming drapes; cylinders of different heights were used for this purpose. All cylinders had a diameter of 12 cm. The captured images indicate the drape complexity level (1, 2, and 15) corresponding to the drape fabric shapes formed by covering acrylic cylinders of different heights (1, 2, and 15 cm, respectively). In the fourth picture type, the circular cloth flat was placed on a table and its photographs were taken using the same camera as for the other three types. The fourth picture type indicated the nonexistence of fabric drape and was assigned a drape complexity level of 0. Fourty-four images were considered as test images. Four photographs of the fabric 'Satin organdy' are shown in Figure 1 as an example.

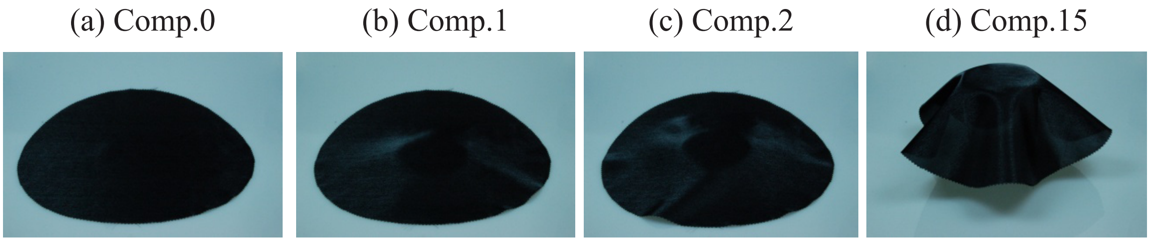
(a) Comp.0 (b) Comp.1 (c) Comp.2 (d) Comp.15

Figure 1*:* *D*rape complexity *levels for* Satin organdy.

To investigate the accuracy of the estimated light source position, we placed 88 test images in two groups: the 44 original test images were placed in the 'erected image' group, and inversions of these 44 images were placed in the 'inverted image' group. Additionally, to explore the effect of visual field size on the observation of drape fabrics, we created four window patterns for restricting observer's visual field. One pattern was without a window and called ‘N-win’. The other three patterns had window sizes of 2 cm × 2 cm (2 × 2), 4 cm × 4 cm (4 × 4), and 8.5 cm × 8.5 cm (8.5 × 8.5). In total, 352 images were employed as experimental stimuli. As for the experimental procedure, an observer entered the experimental booth, looked at a test image on the display, and then selected the test cloth corresponding to the test image after touching 11 test cloths without looking at them. Each observer was given as much time as desired to carry out the evaluation, and 362 images were evaluated in four sessions. The images were presented to the subjects in a random order. There were 20 observers, 10 EOs and 10 COs, and all of them had normal colour vision. To estimate the accuracy of light source position, we presented illustrations of six light patterns to each observer, who then selected one of them.

3. RESULTS

Total levels of the two observer groups’ knowledge of fabric name and visual, tactile, and dressing experiences with each test cloth were calculated. Figure 2 shows the level of knowledge and types of experiences of EOs and COs for all test cloths. These results showed that the COs had significantly greater knowledge and experience than the EOs. The VAS results showed the same tendency. The number of correct answers for each test cloth in all conditions was counted. The correct answers relative to window sizes, drape complexity levels, and selected light patterns were compared between the two observer groups. Figures 3 (a) and (b) show the total number of correct answers for all test cloths and all combinations of window sizes and drape complexity levels for EOs and COs, respectively. The results indicated that the COs’ total number of correct answers was higher than that of the EOs’. When the effect of the window size was removed, the drape complexity level affected the number of correct answers, but the effect of drape complexity level on fabric texture recognition was weaker than that of window size. In contrast, the COs’ number of correct answers for light-pattern recognition was slightly lower than that of the EOs’.

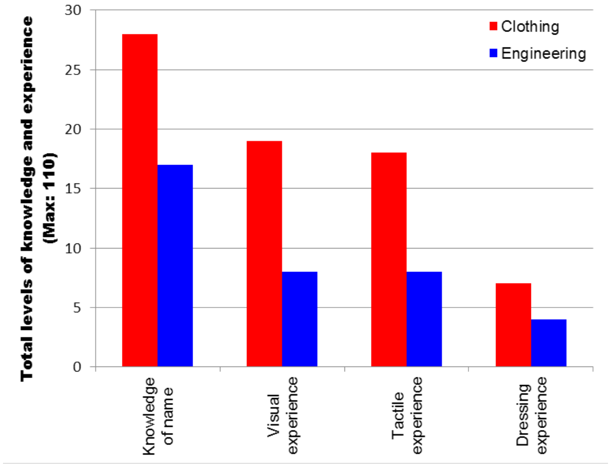

Figure 2: Total level of knowledge and experience of Eos and COs.

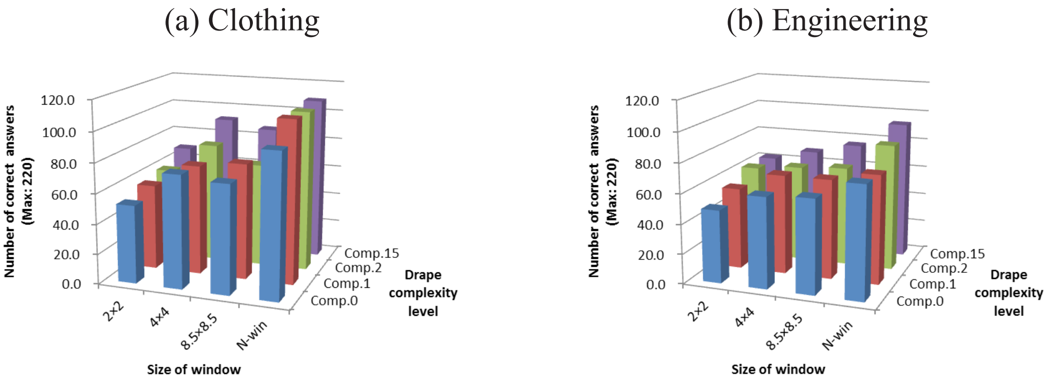

Figure 3: Number of correct answers by EOs and COs.

4. CONCLUSIONS AND DISCUSSION

We conducted questionnaire surveys and a fabric-identification experiment focused on three points: fabric drape complexity, window size, and accuracy of light-source position estimation. The results of the surveys as well as the experiment indicated that COs had significantly more fabric knowledge and experience, and a greater ability to identify fabrics by visual and tactile perception than did the EOs. In particular, the difference between the number of correct answers by COs and EOs was notable when N-win was employed. On the other hands, the number of correct answers for light-pattern recognition by COs was slightly lower than that by EOs. However, in the case where N-win was used, the COs' number of correct answers for light-pattern recognition was higher than that of the EOs'. The results suggest that COs ability of accurate light-pattern recognition plays an important role in identifying a fabric by eliminating the effect of window size.

ACKNOWLEDGEMENTS

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Colour Movements

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ABSTRACT

Colour Movements is a collaborative project between The University of Leeds and the Phoenix Dance Theatre, using dance and design methodologies to explore the relationship between colour and pattern perception in Fair Isle knitted fabrics.

Producing coloured stripes in Fair Isle knit creates complex colour interactions where changing one colour in a design can dramatically change the viewer's perception of the pattern. Colour change was produced through the use of coloured filters designed for stage lighting. Following the initial tenet of the research it was important that the design of costume and performance were as successful as the lighting experiment. The methodology used is a fusion of theoretical and practical and could have interesting application in further research in design.

1. INTRODUCTION

This paper gives a brief over view of Colour Movements, a collaborative project between The University of Leeds and the Phoenix Dance Theatre. Dance and design methodologies were used to explore the relationship between colour and pattern perception in Fair Isle knitted fabrics. The paper highlights broad areas of research which would be suitable for further study. As design research it was important that the costume design and performance were as successful as the lighting experiment. The methodology used is a fusion of theoretical and practical and could have interesting application in further research in design.

Producing coloured stripes in Fair Isle knit creates complex colour interactions where changing one colour in a design can dramatically change the viewer's perception of the pattern. This can be explained through established colour and pattern theory and the most interesting effects occur when colour theory interacts with pattern theory to cause figural ambiguity or to disrupt the Gestalt principles "belongingness" in pattern (Kanizsa 1979).

2. METHOD

A series of garment pieces were knitted with the same Fair Isle pattern, in one of six colour ways. The pattern was created from an amalgamation of traditional Fair Isle patterns observed at the Shetland Museum. When produced in two colours it was perceived as an all over pattern with clear figure/ground separation. Initial colour investigation was based on a twelve hue subtractive colour wheel, however this was limiting in terms of design and intuitive colour choices were made. 14 colours were used in the investigation. Each colour way of the fabric used six colours, three in the figural areas and three in the background. Following traditional Fair Isle design methodology only two colours occur in any one course (row), the same striping sequence was maintained in all fabrics (Staremore 1988).

All yarns used were 100% 4/0.6 Nm wool from the King Cole Super Merino range and were solid dyed. Fabrics produced using one end of yarn were produced on a Brother KH850 6 gauge knitting machine, stitch quality 10. Fabrics produced using four ends of yarn were hand knitted using 20 mm needles.

To investigate the effect of scale on changes in pattern perception the pattern was produced in three scales, ×1, ×4 and ×8, using two production methods. Scale was increased by A, increasing the number of stitches in a colour area and B, by creating bigger stitches.

In the case of method A, the texture of the fabric was maintained however the pattern appears pixelated. In the case of method B, the pattern areas maintain the same stitch relationship however the cover factor is reduced and the fabric appears more open and textured. Fabrics were viewed at 1 m and 4 m.

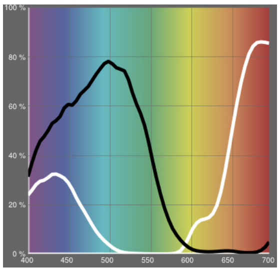

Figure 1: Graph of the pass bands of the blue (black line) and purple (white line) filters.

Colour change was produced through the use of coloured filters designed for stage lighting. Two filters were selected, Lee Filters 049 Medium Purple and Lee Filters 115 Peacock Blue. The purple filter removed much of the green spectrum and the blue filter removed much of the red spectrum (Figure 1). The light source was either 850w at approximately 3m or 30w at approximately 0.5m. The performance took place in a black space with no additional lighting.

Movements were choreographed for one performer using a textile design methodology that reflected the repetition of small elements in a Fair Isle pattern which together result in complex pattern. The movements also echoed the dramatic colour changes that occurred when the incident lighting was changed.

3. RESULTS AND DISCUSSION

Adding coloured stripes to the two coloured pattern resulted in four main categories of perceptual pattern. Broad, medium and narrow stripes and the all over pattern were observed. Coloured lighting could be used to change the category of perceptual pattern observed in a fabric. This is demonstrated in colour-way five (Figure 2, left), which can be perceived in daylight as a medium width tonal stripe, where the red diamond and cross appear as a clear figure on the close toned background of gold and yellow/green but the dark purple and fuchsia figural elements have less contrast to and so merge with the dark green background. Under the blue lighting conditions, where the red spectrum is removed, the red, dark purple and fuchsia appear much darker then the ground and the increased contrast improves the figure ground articulation so the pattern is perceived as an all-over with a feint tonal stripe in the background. Further examples of change in the category of perceptual pattern observed were noted.

Figure 2: Left colour-way five in daylight and blue light;
right colour-way three in blue and purple light.

Where the scale of pattern was increased by using a thicker yarn to create larger stitches the overall texture of the fabric was changed. At a viewing distance of 1m colour-way one (Figure 3, left), knitted at x4 using four ends of yarn had a very textural appearance. The centre of the knitted loops appeared as dark spaces and there was a lot of tonal variation in one hue. The border region between contiguous colour regions was diffused, particularly at diagonal and horizontal borders. At a viewing distance of 4 m visual acuity was reduced and the textural effect was reduced resulting in a sharper gradient at the border region.

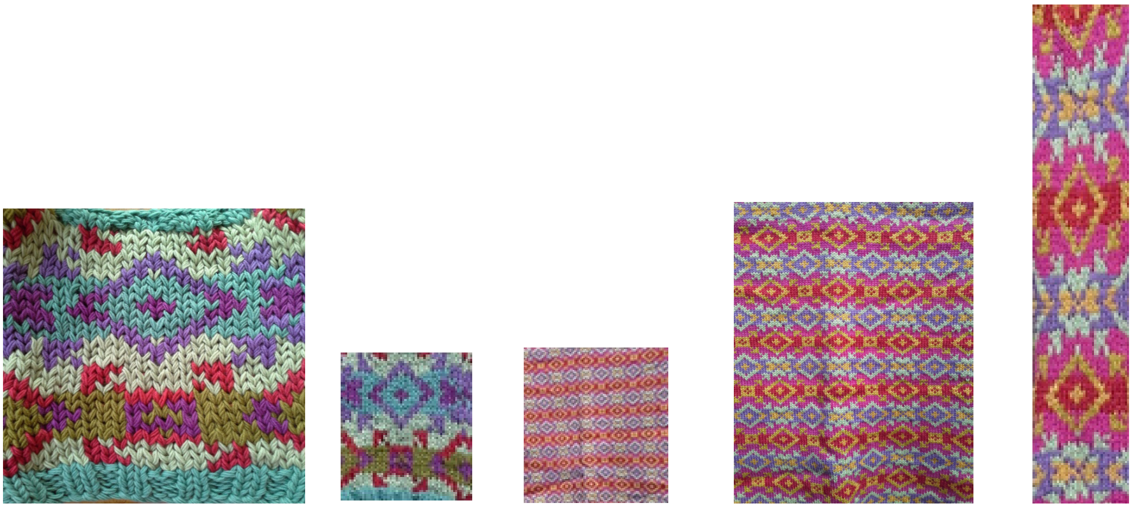

Figure 3: Left colour-way one in daylight viewed at 1 m and 4 m; right colour-way two ×1 in daylight viewed at 4m and 1m and colour-way two x4 in daylight viewed at 1 m.

In some cases the same colour change viewed at different distances produced different perceptual effects. In colour-way two (Figure 3, right) the x1 version demonstrated clear figural mint green diamonds at 4m viewing distance where the mint green had greater tonal contrast to the background whereas at 1m viewing distance the yellow and yellow/green diamond was visually more dominant and demonstrated greater hue difference to the background. At a viewing distance of 4 m the ×4 version of colour-way two was visually similar to the ×1 version viewed at 1 m.

The garment produced in colour-way three (Figure 2, right) was knitted at ×8 and only a partial repeat of the pattern was seen. The most obvious part is the left side of a diamond with a cross within it. Under blue light the central region of the diamond and cross were seen as yellow with the outer regions seen as dark purple. The contrast between the two regions served to segregate the two areas. Under purple light the diamond and cross were both perceived as close pink hues and as the Gestalt law of similarity states that similarity confers belongingness, the figural area was perceived as a cross within a clear diamond. Figure 2 (right) also demonstrated metamerism. The area to the left of the lower part of the cross appeared identical to the rest of the background in blue light, when viewed in violet light it appeared much darker than the rest of the ground. This is due to yarn from a different dye lot being used for this portion of the fabric and was not evident until viewed under different lighting conditions.

Although movement confers belongingness of objects in this case movement had little effect on the amount of change observed under different lighting conditions. Movement would only have an impact if the performer's costume and the backdrop were designed so that the costume was produced at a smaller scale then the backdrop but positioned at the correct distance in front of the backdrop the two fabrics would appear as one. In this instance movement would help identify the area of the performer. As the costumes were of varying colour ways and scales movement was not needed to identify the area of the performer. However the performance was important to communicate the research to a wide audience.

4. CONCLUSIONS

Colour Movements successfully demonstrated that it was possible to alter the perceptual pattern of a knitted fabric using coloured lighting. Scale, viewing distance and fabric texture all had an effect on pattern perception. These variables, and the effect of metarmerism resulted in an inability to predict results accurately and an empirical approach was necessary. The use of photography to record findings resulted in inaccuracies in colour reproduction and also in a change in scale of patterns which affected the ability of the photograph to accurately demonstrate perceptual pattern change caused by scale and viewing distance. Movement did not affect pattern perception in this case. The experiment was conducted as a performance as a method of conveying results to a wide audience however findings could be verified by more controlled experiments.

ACKNOWLEDGEMENTS

Thanks to Stephen Westland for his help and advice during this research.

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Evaluation of Colour Effects on Knitted Fabrics using Marl Yarns

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ABSTRACT

Marl yarn, consists of combining two or more coloured yarns, has been commonly used by knit designers for creating innovative knitwear over decades. It is observed that different types of yarn parameters and knitting techniques can lead to a variety of colour effects (or, often, referred to as marl effects). However, there is relatively little literature discussing the formation of such marl effects in details. Therefore, exploring and unifying standard of marl effects is valuable as it could help knit designers to present their ideas faithfully and the fashion industry to diversify knitted fashion for the growing needs in the market. This study is aimed to investigate the relationship of yarn parameters and knitting techniques with marl effects. Four factors – yarn colours, yarn type, knitting machine gauge, and knitting structure – have been considered. In a psychophysical experiment, a set of 36 knitted samples were assessed according to the degree of marl effect. The results allow a better understanding on how to prepare knited fabrics to achieve different degrees of marl effect. This understanding would particularly be useful for knit designers to achieve their predetermined requirements and could also contribute towards quality control.

1. INTRODUCTION

Marl yarn has been commonly used by knit designers for creating innovative knitwear over decades. Textile Terms and Definitions defined marl yarn as a group of yarns that containing two or more different coloured single ends twisted together (Textile Institute 2002). The appearance of a knitted fabric composed of marl yarn using different types of yarn, knitting parameters and knitting techniques can lead to a variety of colour effects (or more often referred to as marl effects). Whilst knit designers often have predetermined requirements for a given marl effect in order to meet their knitwear design needs for the market sectors, there is relatively little literature discussing the formation of such marl effects in details. Figure 1 shows examples of knitted fabrics with different degrees of marl effects. It is suggested that high degree of marl effect corresponds to two (or more) colours of a textile sample being evenly distributed in a dotted manner.

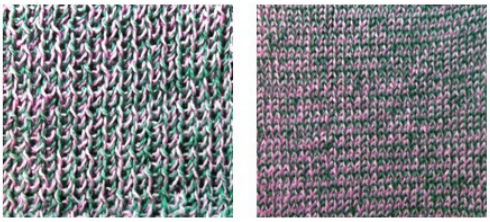


Figure 1: Examples of knitted fabrics with different degrees of marl effects.

This study is aimed to investigate the marl effects of knitted samples produced by different knitting parameters. This would allow better understanding for knit designers to achieve their predetermined requirements. In addition, this could contribute towards quality control in which predictable visual results of marl effect can be applied to manufacturing and supply chain to providing a situation of predictable outputs (Romano and Vinelli 2001).

2. METHOD

2.1 Sample Preparation

Table 1 listed the four yarn and knitting parameters that were considered in the study: (a) yarn type, (b) yarn colour, (c) knitting machine gauge size and, (d) knitting structure. The yarns are all with the same count and have been twisted under the same condition of 100 turns per metre and in Z direction. The spectral reflectance factors were measured for each of the eight yarns at 10nm intervals in the visible spectrum to allow the calculation of CIE tristimulus values. In total 12 pairs of two-colour marl yarns were prepared and a set of 36 samples (6 colour pairs ´ 3 gauge sizes ´ 2 knitting structures) was knitted by combining different parameters systematically.

Table 1. Various yarn and knitting parameters.

Yarn type	Worsted, acrylic
Yarn colour	Worsted: light blue, blue, purple, ivory Acrylic: ice green, dark blue, brown, ginger
knitting machine gauge size	5, 7, 10
knitting structure	Single jersey, 1 × 1 rib

2.2 Psychophysical Experiment

The samples were cropped to a size of 9 × 9 cm and mounted onto black card. A ranking method was proposed for the visual assessment. The experiment was carried out in a darkened room and the samples were presented in a viewing cabinet illuminated by a light source approximating the D65 illuminant. Ten observers with normal (or corrected-to-normal) visual acuity and normal colour vision participated in the experiment. The experiment conisisted of two stages. In the first stage, 6 groups each containing 6 samples in turn were viewed by observers. The observers were asked to rank the samples in order of their degree of marl effect (i.e. two colours of a textile sample are evenly distributed in a dotted manner). The rank orders were converted to interval-scale Z values using Torgerson's Categorical Scaling method (Bartleson 1984; Torgerson 1962). In the second stage, 6 samples each with the highest degree of marl effect, according to the Z value, within its group were ranked by the same group of observers. The rank orders were converted to interval-scale Z values in the same manner.

3. RESULTS AND DISCUSSION

Figure 2 shows an example of a set of 6 samples in the order of their degree of marl effect obtained in the first stage of example. Table 2 summarises the final results obtained from the visual assessment. It shows the yarn and knitting parameters of the 6 samples that are deemed to be of highest degree of marl effect.

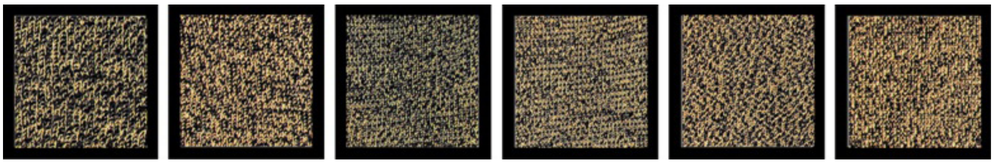
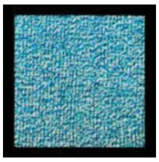
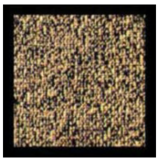
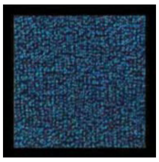
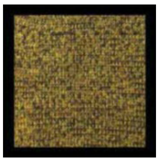
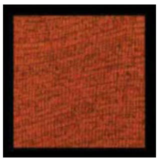
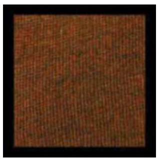


Figure 2: A set of 6 samples in the order of degree of marl effect (left to right: lowest to highest) obtained in the first stage of experiment.

Table 2. Yarn and knitting parameters of the 6 samples with highest degree of marl effect.

		Yarn parameters		Knitting parameters	
ranking order (degree of marl effect)	sample	colours	type	gauge size	structure
1		light blue × blue	acrylic	10	1 × 1 rib
2		ivory × purple	acrylic	10	1 × 1 rib
3		blue × purple	acrylic	7	1 × 1 rib
4		ice green × dark blue	worsted	7	single jersey
5		ginger × brown	worsted	10	single jersey
6		brown × dark blue	worsted	10	single jersey

The results indicate that fabrics produced by a larger gauge knitting machine (size 7 or 10) tend to have a higher degree of marl effect. It is noted that the smoothness of acrylic yarns allows stronger marl effect whereas the hairiness of worsted yarn inhibits the effect. The impact of knitting structure seems to be insignificant. Table 3 shows the CIELAB colour differences of the two yarns for each of the 6 samples. In general, samples comprise of two yarns with large colour difference are deemed to have stronger marl effect. Table 3 also shows the corresponding CIELAB lightness and chroma differences. It is evident that lightness difference has made a bigger contribution to the marl effect compared with chroma difference.

Table 3. CIELAB lightness (L), chroma (C_{ab}*) and colour differences.*

ranking	colours	ΔE_{ab}	ΔL^*	ΔC_{ab}^*
1	light blue ´ blue	35.23	32.91	-12.34
2	ivory ´ purple	77.17	65.90	-8.86
3	blue ´ purple	32.92	22.23	5.71
4	ice green ´ dark blue	23.37	19.76	2.14
5	ginger ´ brown	18.99	14.51	11.88
6	brown ´ dark blue	20.24	-2.90	8.65

5. CONCLUSIONS

This study illustrates that the degree of marl effect of knitted fabrics is driven by the yarn and knitting parameters. The results show that yarn type, yarn colour (difference) and the size of knitting machine gauge enable a more significant contribution on marl effect. The findings of this study allow a better understanding on how to prepare the knitted fabrics to achieve different degree of marl effect. These can help knit designers to effectively produce knitwear according to their predetermined requirements and provide better quality control with the scope of the samples used for this study.

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Class A Color Classification for Light Sources used in General Illumination

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ABSTRACT

Consumers who care about color expect electric light sources used for general illumination to provide consistently “white” light that reveals “true” object colors. Presently, the metrics used by the lighting industry, color rendering index (CRI) and correlated color temperature (CCT) poorly meet the expectations of consumers. CRI is poorly correlated with the ability of a light source to provide “true” colors and CCT does not guarantee that illumination from the source will look “white” or even that illumination from two of the same CCT will appear the same. Proposed here is the Class A color designation for sources of general illumination for the consumer market that would serve as an industry seal of approval. Light sources with this designation would provide “white” light that “looks the same” and would provide “true” object colors. More specifically, light sources having the Class A color label (Figure 1) would (a) have a chromaticity on the line of minimum tint, (b) have narrow chromaticity tolerances, and (c) meet the two-metric (CRI≥80; 80≤GAI≤100) criterion for good color rendering.

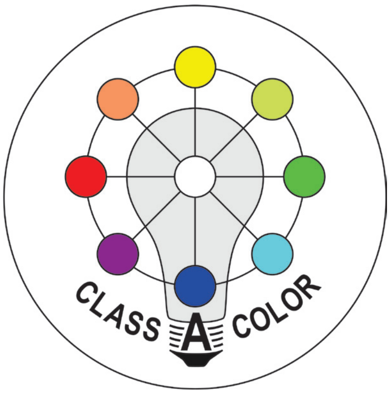

Figure 1. Schematic of the proposed seal of approval for Class A color lamps.

1. BACKGROUND

Most domestic lighting systems in the United States utilize Edison, screw-base sockets designed to accommodate common incandescent lamps. As consumers have become more attuned to energy efficiency many would like to replace their conventional incandescent lamp with more efficacious technologies equipped with screw bases that fit their existing sockets. In the 1980s, screw-base compact fluorescent lamps (CFLs) were offered to consumers as an energy efficient replacement for incandescent lamps. Despite governmental promotions, subsidies and rebates, CFLs have had limited penetration in the consumer market place (EPRI 1992). Among the various identified barriers to market penetration, the CFL was not widely embraced because of its poor color qualities even though they met industry standards. Consumers complained about the greenish light emitted by CFLs and the poor rendering of skin and other natural objects like fruits and vegetables when illuminated by CFLs.

In recent years light emitting diode (LED) screw-base sources have been offered to consumers as energy efficient replacements for incandescent lamps. Based upon the disquiet generated among consumers for “energy efficient lighting,” manufacturers of LED sources are concerned with the color qualities of these new light sources (Sandahl et al. 2006). This concern has led to wide interest among manufactures and specialists in examining the color metrics currently used by the industry. The lighting industry describes the color qualities of light sources used for general illumination in terms of two metrics, correlated color temperature (CCT) and color rendering index (CRI). CCT is a temperature metric, in units of kelvin (K), intended to describe the apparent “tint” of the illumination; “warm” sources (like incandescent lamps) have CCTs between approximately 2700 K and 3000 K while “cool” sources have CCTs between 5000 K and 6500 K. All sources of a given CCT designation are expected to have the same apparent “tint” so manufacturers have self-imposed color tolerances as an implicit part of the CCT designation (ANSI 2001, 2011). CRI is a metric intended to represent how similar object hues appear when illuminated by an electric light source in comparison to their appearance under a reference source, daylight or incandescent, of the same CCT (CIE 1995). Unfortunately, CCT and CRI are not, by themselves, particularly useful metrics for describing the color qualities important to consumers. For example, one would expect a light source with a high CRI value to be preferred over one with a low CRI value. Several studies have shown, however, that color preferences are not well correlated with CRI (Narendran and Deng 2002; Smet et al. 2011). Also, a recent study showed that for simulated residential applications people are less likely to prefer “warm” illumination from traditional incandescent lamp than “white” illumination of the same CCT (Rea and Freyssinier 2012).

The two metrics used by the lighting industry to communicate color qualities, CCT and CRI, also represent a non-technical problem for helping to transform the residential lighting market from incandescent sources to more energy efficient LED sources. CCT and CRI are not understood among non-specialists which may be an ironic benefit to market transformation because both are poor metrics for predicting user preferences. Most consumers do not care about metrics *per se*. Rather, they would like some assurance that they will not be disappointed with the color qualities of energy efficienct light sources when they take them home. Seals of approval are common in industries where consumers need assurances that products will perform as expected (EPA 2013; Hong et al. 2002; Waide and Tanishima 2006).

Proposed here (and elsewhere, e.g., Freyssinier and Rea 2012) for consideration by the lighting industry is a *Class A color* designation for light sources used in domestic applications. A carton label like the one shown in Figure 1 would serve as a consumer seal of approval for color quality from manufactured sources used in general illumination applications. To meet the *Class A color* designation, a light source is expected to (a) provide illumination with minimal tint (i.e., be “white”), (b) have an appearance consistent with other *Class A color* light sources, and (c) provide good color rendering. The *Class A color* designation should not only deliver the color benefits expected by consumers, it should be readily understood by consumers as delivering those benefits.

Several color metrics underlie the *Class A color* designation. Two metrics are used to assure consumers they are purchasing a “white” source of illumination and that the light emitted by all sources with the *Class A color* designation will appear similar when placed side-by-side. Figure 2(a) shows the empirically established line of minimum tint in chromaticity space for six CCTs between 2700 K and 6500 K (Rea and Freyssinier 2013a). A theoretical interpretation of the “white” line has also been developed (Rea and Freyssinier 2013b). Chromaticity tolerance zones for the six “white” sources are also illustrated in Figure 2(a).

Each of these tolerance trapezoids are approximately the same area in chromaticity space as a 4-step Macadam ellipse.

Two additional metrics are included to assure consumers that the light source provides general illumination with good color rendering. Gamut Area Index (GAI) serves as an adjunct measure to the well-established and traditional color rendering metric, CRI. Computational details for both GAI and CRI can be found in several references (Rea and Freyssinier-Nova 2008; Rea and Freyssinier 2010), but, briefly, GAI is a simple measure of hue saturation provided by the illumination, whereas CRI is a measure of hue consistency provided by the illumination with respect to reference sources. Sources of illumination that have high values of CRI (CRI ≥ 80) and high (but not too high) values of GAI (80 ≤ GAI ≤ 100) have been shown in several human factors experiments to be predictive of user acceptance (Rea and Freyssinier-Nova 2008; Rea and Freyssinier 2010, 2012b). Figure 2(b) provides GAI and CRI values for several screw-base sources that might be used in domestic applications.

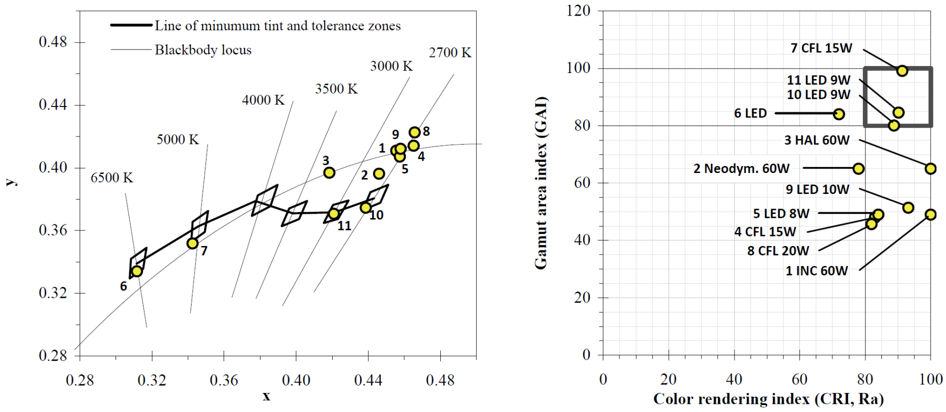

Figure 2. Class A color lighting recommendations for (a) "white" illumination (thick line) of prescribed chromaticity tolerance (rectangles) and (b) "good color rendering" illumination (thick line) of prescribed CRI and GAI (CRI ≥ 80 and 80 ≤ GAI ≤ 100). Also shown are the CRI and GAI values of several screw-base lamps that may be used in domestic lighting.

SUMMARY

The proposed *Class A color* seal of approval provides consumers with assurances of good, consistent color quality for general illumination. Those assurances are based upon research where sources meeting that designation are predictive of user acceptance for general illumination. By bundling a number of color quality metrics together, the industry does not have to spend a lot of resources on educating consumers about the benefits provided. A *Class A color* seal of approval should help reduce bariers implementation of more energy efficient lighting technologies by providing consumers with products that meet their expectations of good color qualities.

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Reconstruction of CIE Standard Illuminants with an LED-based Spectrally Tuneable Light Source

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ABSTRACT

Solid-state lighting is reaching a really good position on the market and replacing traditional light sources. For this reason, a LED-based spectrally tunable source with high spectral resolution has been developed. The aim of this light source is the generation of spectra of CIE standard illuminants (D65, D50, A, E, F2, F11 and HP1) in the visible range (400-700nm) by means of 31 spectral channels. First, Gauss's equations were applied for finding the weighting values for each LED. This method shows very good results in terms of goodness of fit coefficient (GFC) and root-mean square error (RMSE). In addition, the colorimetric properties, such as correlated colour temperature (CCT), colour rendering indexes (Ra and Rb) and the colorimetric coordinates in the CIE-xy system are quite similar to CIE standard illuminants. Secondly, a minimization routine designed for offering transferable (positive) weights to the light source was applied. The fitting and colorimetric parameters are not as good as in Gauss's equations but, despite that, they are experimentally better. In conclusion, a minimization method which is able to simulate spectra of standard illuminants by means of a LED-based light source has been developed but it needs further work to reach higher levels of accuracy.

1. INTRODUCTION

LED technology has been growing very fast in last years and, nowadays, is one of the branches of optics with a higher prediction of development. This work is focused on one of the most versatile applications: generation of CIE standard illuminants. The main advantage of generating standard illuminants by using a LED-based light source lies on the fact that it allows to reproduce different illuminants with only one source. Generally, recent researches apply minimization methods in order to adjust as maximum as possible the generated spectrum by LEDs to the spectrum of the illuminant (Park et al. 2009, Mackiewicz 2012). These methods started being used as an alternative to lengthy convergence procedures (Fryc et al. 2005).

Consequently, the model for reconstructing illuminants that we propose it is placed inside minimization procedures but, in this case, we use a light source with 31 spectral bands in the visible range (400-700nm), more than usual in this kind of devices. For this reason, we expect to reach better adjustment than others works that use fewer channels.

2. METHOD

The first prototype of the light source is composed of 62 LEDs, two for each channel. Peak wavelengths are spread between 400 and 700nm, with a mean gap of 10.06nm and a mean

FWHM of 22.51nm (Figure 1). This spectral characterization was performed by the PR-655 tele-spectroradiometer of Photo Research, Inc.

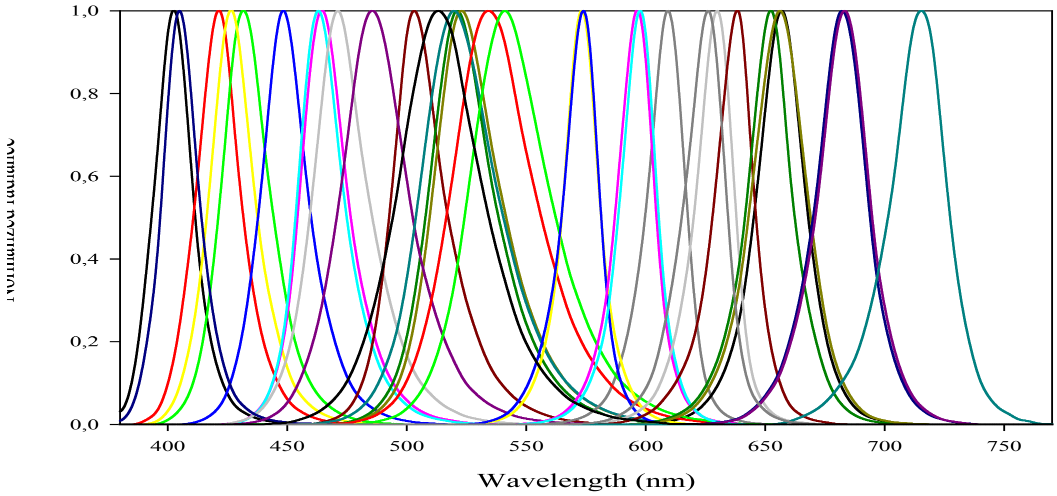

Figure 1. Spectral power distribution with normalized spectral radiance.

After this previous evaluation, we proceed to the development of the mathematical model that would allow us to know the intensity needed from each LED for reconstructing the followings illuminants: D65, D50, A, E, F2, F11 and HP1. The result of this method should be a weighting matrix that relates the spectrum of standard illuminant to the set of LED spectra, both expressed by radiance:

$$I_m = p_n L_{m,n}, \qquad \text{(Eq. 1)}$$

where I_m represents standard illuminant spectrum, $L_{m,n}$ contains spectra of the 31 LEDs and p_n is the weighting matrix that encompasses the weights of each LED which are used to match target spectrum. The spectral resolution that set for the reconstruction was 1nm, in this way, the model should simulate the spectrum of each illuminant over 301 wavelengths (m) and 31 channels (n).

First of all, equation 1 was theoretically solved by normal or Gauss equations due to that $L_{m,n}$ is not an square matrix:

$$p = (L^T L)^{-1} L^T I, \qquad \text{(Ec. 2)}$$

Unfortunately, this technique solves this system of equation without taking into account that the weight of an LED cannot be negative, therefore another method was applied. As we said previously, this new method is classified as a minimization routine; especially, the Matlab's (version 7.11) function *fmincon* was applied. Its goal is to minimize the distance between target spectrum (SPD_illum_i) and the one generated by LEDs (SPD_LEDs_i):

$$f = \sum_{i=400}^{700} \left(SPD\_illum_i - SPD\_LEDs_i \right)^2 \qquad \text{(Eq. 3)}$$

Thanks to this method, positive weighting values were obtained between 0 and 1.

Quantitative evaluation of the reconstructions was realised through goodness of fit coefficient (GFC), root-mean-square error (RMSE), correlated colour temperature (CCT), colour rendering indexes (Ra and Rb) and chromatic coordinates CIE-xy.

3. RESULTS AND DISCUSSION

Figure 2 shows four comparisons between of the generated spectra and the real ones. In addition, in Table 1 there are CCT, Ra, Rb, CIE-xy, GFC and RMSE values for D65, A, E and F2 illuminants.

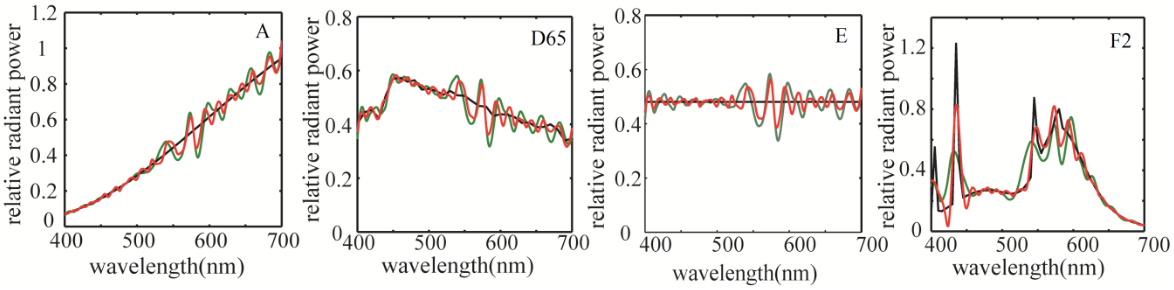

Figure 2. Comparison between the generated spectra (green line: Gauss's equations method; red line: minimization routine) and the real ones (black line).

Table 1. CCT, Ra, Rb, CIE-xy, GFC and RMSE parameters.

		CCT (K)	Ra	Rb	x	y	GFC	RMSE
CIE standards	D65	6505	99.55	99.50	0.3127	0.3293	-	-
	A	2864	99.47	99.23	0.4472	0.4077	-	-
	E	5457	95.31	93.84	0.3333	0.3338	-	-
	F2	4230	64	50.61	0.3721	0.3751	-	-
Gauss's equations	D65	6557	99.06	98.89	0.3118	0.3286	0.9984	2.6466
	A	2867	98.66	98.37	0.4467	0.4072	0.9980	3.4059
	E	5496	94.39	92.71	0.3325	0.3331	0.9983	2.7809
	F2	4261	63.48	51.32	0.3708	0.3751	0.9846	7.0262
Minimization routine	D65	6615	98.32	98.04	0.3108	0.3281	0.9966	3.8852
	A	2875	97.31	96.89	0.4461	0.4069	0.9957	4.9892
	E	5541	93.46	91.65	0.3315	0.3325	0.9964	4.0655
	F2	4423	70.07	59.08	0.3649	0.3726	0.9543	12.0390

Theoretical model offers more accurate reconstructions in both fitting and colorimetric values, as it can be seen in Figure 2 and Table 1, but experimentally unacceptable. Despite the fitting achieved by the minimization routine is not as accurate as the theoretical method, the obtained weights for each LED are totally transferable to the light source. The best reconstructions were found for D65, D50, A and E standard illuminants.

The spectral range where fitting is worse is the one placed between 550 and 600nm, the well-known *green gap*. This phenomenon is due to the fact that, nowadays, LED technology is not able to generate higher values of radiance like it does in other spectral regions.

4. CONCLUSIONS

In this work, a minimization routine able to reproduce the spectrum of standard illuminants based on an LED-based spectrally tuneable light source has been developed but further work is needed to reach higher levels of accuracy. Moreover, new LEDs in the green region of the visible spectrum (500-600nm) will be searched in order to increase the spectral sampling in this zone. Consequently, the performance of the algorithm will be improved, which is considered a solid and applicable method to any set of quasi-monochromatic light sources (LEDs or any other future technology).

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Spectral Distribution of Daylight in Tehran, Iran

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ABSTRACT

In this research, the dimensional property of received daylight in Tehran is investigated in the visible spectrum of electromagnetic radiation. The measurement site was located in the central zone of Tehran metropolitan area. The measurements were carried out within a period of 9 months, i.e. from September to May 2011, from early in the morning to late in the evening under very different weather conditions including clear sky, partly and mostly cloudy, misty, overcast, dusty and industrial pollution environment. The measurements were also continued in snow and rainfall weather. Totally, 12396 daylight spectra were measured and used for spectral analysis. The collected data were analyzed colorimetrically as well as spectrally. In the color domain, the results showed that the chromaticity of Tehran daylight spectra is significantly more reddish in comparison to those reported in literatures. In fact, some measurements were extended to the reddish part of chromaticity diagram while such extension has not been reported by previous measurements in other regions. The principal component analysis technique was used to study the spectral characteristics of dataset. Unlike the previous reports, the global spectral irradiance functions in Tehran cannot be accurately fitted over the visible range by using only a few basis vectors, i.e. 5 to 6 eigenvectors. In fact, the first 12 most important eigenvectors of the spectral dataset were required for accurate spectral recovery of the daylight spectra. Based on results, 97% of the spectral information could be reconstructed by using 12 basis functions with an appropriate goodness-fitting coefficient (GFC) greater than 0.9999. However, 3% of spectral information still needs more eigenvectors to be recovered sufficiently.

1. INTRODUCTION

Study of the spectral power distribution (SPD) of sunlight has been an important issue in many scientific disciplines, applications and industries. The spectral behavior of daylight depends on several parameters such as location, time and the weather condition. The light absorbing materials such as ozone, water vapor and air particles also alter the spectral distribution of daylight at different wavelengths (McDonald 1997). By ignoring the chromatic adaptation phenomenon, any changes in the spectral power distribution of the light source could have a great influence on the resultant color and the sun plays a major role in this case as the most important resource for human visual evaluation.

The spectral and colorimetric behaviors of daylight have been studied in different regions over the world and the strong statistical tool, i.e. principal component analysis method, was employed for the interpretation of collected spectra. It was reported that, because of the high correlation between the sunlight spectral, the spectral emission of daylight could be successfully defined in significantly reduced spaces. According to literature, 3 to 8 basis are needed to adequately explain the spectral behavior of sun lights (Hernández 2001).

It was reported that 8 eigenvectors could reasonably recover the Granada spectra. It was also claimed that the 99% of spectra in Colorado daylight could be expressed by 3 eigenvectors when the spectra were limited to 350 to 700 nm and 8 eigenvectors were needed if the spectral range extended to 400 to 2200 nm (Pan 2005). Judd recovered 622 spectra with linear combination of the first three eigenvectors (Judd 1964). Sastri also showed that 187 spectra of Delhi daylight could be reconstructed with the first four eigenvectors (Sastri 1968).

In this study, we measured the spectral power distribution of daylight in the central region of Tehran metropolitan. The colorimetric specification of collected data are investigated by the variation of the chromaticity coordinates of samples while, the PCA is employed to interpret the spectral characteristics of collected lights (Tzeng 2005).

2. METHOD

The spectral radiances across the sky dome were measured by using an X-Rite i1 Pro spectroradiameter. The wavelength measurement was in the range of 380 to 780 nm with 10 nm interval. Device was fixed in a desired viewing direction, i.e. the i1 pro's detector was focused upward to receive the downwards lights. The measurement site was in the central zoon of Tehran with the longitude and latitude of 51°42N, 35°7W and 1206 m altitude The measurements were performed over a period of 9 months from September to May 2011 in different weather conditions, including clear sky, partly cloudy, cloudy, dark and foggy, rainy and snowy skies.

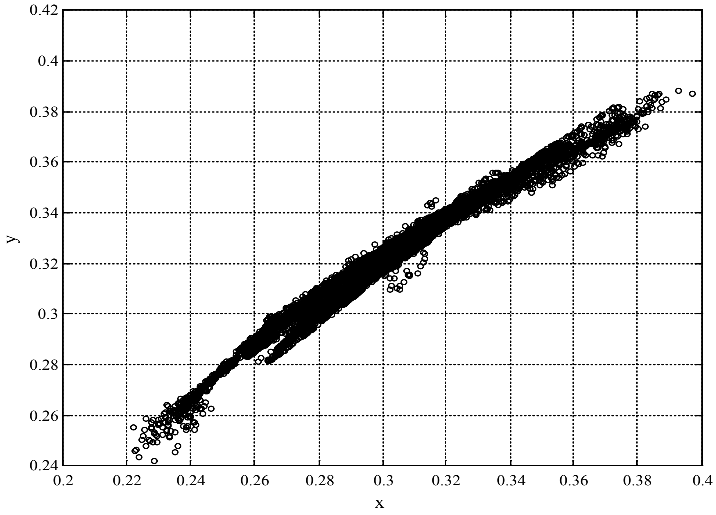

Figure 1: CIE 1931 chromaticities of 12396 Tehran daylight spectra.

3. RESULTS AND DISCUSSION

Figure (1) shows the CIE 1931 chromaticities of 12396 Tehran daylight spectra. To compare the results with the other locations, the CIE chromaticities of 2600 daylight spectra that were measured in Granada (Spain) are also shown in Figure (2).

As the figures show, the colors of Tehran daylight spectra have shifted to the orange and red region of the CIE locus and the x values of samples are between 0.23 to 0.4. As Figure 2 shows, the chromaticity coordinates of Granada daylight spectra are mostly scattered in the green side of the CIE locus and the x values of samples stand between 0.23-0.35.

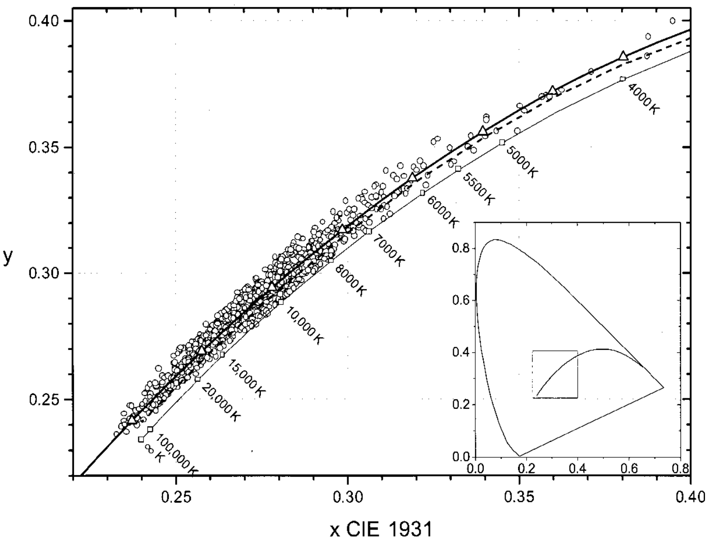

Figure 2: CIE 1931 chromaticities of 2600 Granada daylight spectra.

To study the spectral behavior of dataset, the first 12 most important eigenvectors were extracted. Figure 3 shows the spectral power distribution of proposed bases.

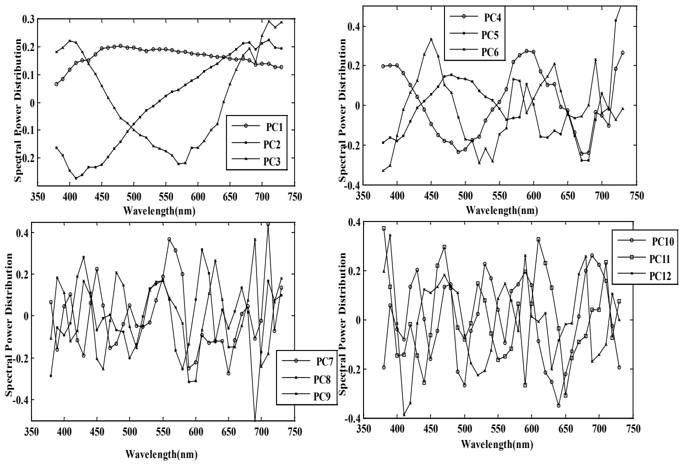

Figure 3: The first 12 eigenvectors of dataset.

Different reduced subspaces were employed for the compression of collected spectral data and the adequacy of desired spaces were evaluated by the value of goodness-of-fit coefficient (GFC) between the actual and the reconstructed radiance spectra. The percentages of spectra that satisfy the desired criteria, i.e. GFC≥0.995 for acceptable, GFC≥0.999 for good and GFC≥0.9999 for excellent recovery are reported in Table 1. The table also shows the results of recovery for Granada SPDs (Hernández 2001). As the table shows, the Granada daylight spectra show smoother distribution in comparison to those obtained in Tehran. According to results, about 8 eigenvectors could reasonably recover the Granada spectra while application of 12 bases does not yield a convincingly good-excellent results for Tehran daylight spectra.

Table 1. Comparison between GFC values of Tehran and Granada.

GFC						
# Eigenvectors	Spectra with GFC≥0.995		Spectra with GFC≥0.999		Spectra with GFC≥0.9999	
	Tehran	Granada	Tehran	Granada	Tehran	Granada
1	36.2925	NA	11.8308	NA	1.7051	NA
2	92.1734	95.2	77.4441	78	34.6163	3.8
3	96.2226	99.8	90.8419	97.4	61.0005	29.3
4	97.6221	100	95.5466	99.5	73.3044	61.5
5	97.7025	100	95.6486	99.9	87.1894	91.5
6	99.4562	100	98.3931	100	94.5544	97.2
7	99.2635	100	98.2923	100	94.8769	99.1
8	99.2397	100	98.4148	100	96.4334	99.4
9	99.1771	NA	98.5317	NA	96.4585	NA
10	99.2255	NA	98.6043	NA	96.5069	NA
11	99.3466	NA	98.6931	NA	96.5715	NA
12	99.4191	NA	98.7495	NA	96.7166	NA

*Not Available

4. CONCLUSIONS

The colorimetric and spectral properties of Tehran daylight spectra were studied. The chromaticities of Tehran spectra tended to be more reddish appearance in comparison to the other parts of the world, e.g. Granada, Spain. Besides, the collected spectra exhibited higher dimensional property in contrast with those reported form Granada. However, application of 12 bases does not yield a convincingly good-excellent results for Tehran daylight spectra. With implementation of 12 bases, 96.72% of spectra were excellently recovered while still about 0.5% of spectra were not acceptably reconstructed.

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Colour Rendering of Solid-State Sources of Light under Mesopic Conditions

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ABSTRACT

Several approaches to the quantification of colour rendition properties of light sources under the conditions of mesopic vision were considered. The CIE general colour rendering index and statistical metric, which yields the percentage of a large number of colours rendered with high fidelity and different distortions, were rescaled with the reduced colour discrimination ability of human vision under low adaptation luminances taken into account. The results of the assessment of the colour rendition properties of different light sources, such as common phosphor converted (pc) light-emitting diodes (LEDs), RGB LED cluster, dichromatic "fire-light" LED, and high-pressure sodium (HPS) lamp, are presented for adaptation luminances relevant to street lighting (0.1-2 cd/m^2).

1. INTRODUCTION

Solid-state lighting technology allows for the versatile tailoring of the spectral power distribution (SPD) of light sources in order to meet the needs of various lighting applications. In particular, the SPDs of LEDs for street lighting, which is relevant to the conditions of mesopic vision, can be optimised in terms of high mesopic luminous efficacy and low circadian hazard (Žukauskas et al. 2012). Besides, mesopic light sources must ensure sufficient colour rendition, which is important for visual performance in illuminated outdoor environments (Fotios et al. 2005). However, under low luminance conditions, quantifying colour rendition properties of light sources is to be considered with the reduced colour discrimination ability of human vision taken into account.

2. METHOD

In order to quantify the colour rendition properties of light sources for mesopic conditions, we introduced two approaches. One approach is based on the CIE general colour rendering index, R_a, which measures colour differences within the CIE 1964 uniform colour space for 8 test colour samples (CIE 1995). Another approach is based on the advanced statistical metric, which sorts 1269 test colour samples by the colour shifts in respect of three-step MacAdam ellipses and luminance discrimination threshold (Žukauskas et al. 2009; Lebedenko and Vaicekauskas 2013). The statistical metric yields the percentage of colours that are rendered with high fidelity or with increased/reduced chroma, and/or with distorted hue and lightness. In both approaches, the mesopic effect on colour discrimination was taken into account through the rescaling of the colour space by a factor, k_{mes}, which is the ratio of just perceivable colour differences at mesopic and photopic conditions, respectively. The colour space rescaling factor derived from the mean size of the MacAdam ellipses and luminance discrimination thresholds (Brown 1951; Pridmore and Melgosa 2005) is shown in Table 1 for adaptation luminances, L, typical of street lighting standards. The rescaling factor is normalized to unity at a photopic luminance of 48 cd/m^2 originally used by MacAdam (1942).

Table 1. Colour space rescaling factor as a function of adaptation luminance.

Adaptation luminance (cd/m^2)	0.1	0.2	0.3	0.5	0.75	1.0	1.5	2.0
Color space rescaling factor	6.25	4.44	3.85	3.23	2.81	2.54	2.19	1.96

For the rescaled CIE 1964 colour space, the colour shifts are reduced by a factor of $k_{\mathrm{mes}}(L)$. This results in that the CIE general colour rendering index converts to the mesopic general colour rendering index with a larger value as follows:

$$R_{\mathrm{a,mes}} = 100 - k_{\mathrm{mes}}^{-1}(L)(100 - R_{\mathrm{a}}) \quad . \tag{2}$$

Similarly in the statistical metric, the size of MacAdam ellipses and luminance discrimination threshold increase by a factor $k_{\mathrm{mes}}(L)$ and the colour shift vectors are to be re-sorted. This results in a larger percentage of test colour samples that are rendered almost indistinguishably from those under a reference source (Colour Fidelity Index, CFI) at an expense of the percentage of test colour samples that are rendered with perceptually noticeable increased chroma (Colour Saturation Index, CSI), reduced chroma (Colour Dulling Index, CDI), distorted hue (Hue Distortion Index, HDI), and distorted luminance (Luminance Distortion Index, LDI).

3. RESULTS AND DISCUSSION

The above two approaches were applied for assessing some solid-state sources of light considered for outdoor lighting and having different correlated colour temperatures (CCTs), different colour rendition properties, and different circadian action factor, a_{cv} (Gall and Bieske 2004). Also, the assessment was performed for HPS lamp, which presently is widely used in street lighting.

The photopic characteristics of the light sources are presented in Table 2. The daylight pc LED is a typical colour dulling source with rather high circadian action; the warm white pc LED and RGB LED cluster are high-fidelity and colour-saturating sources, respectively, with moderate circadian action; and the firelight pc (blue-orange) LED (Žukauskas et al. 2012) and HPS lamp are colour dulling sources with low circadian action. Besides, hues are severely distorted by daylight pc LED and RGB LED cluster, whereas high lightness distortions is a characteristic of RGB LED cluster, firelight pc LED and HPS lamp.

Table 2. Characteristics of the assessed light sources under photopic conditions.

Light source	CCT (K)	R_{a}	CFI (%)	CSI (%)	CDI (%)	HDI (%)	LDI (%)	a_{cv} biolm/lm
Daylight pc LED	6042	71	17	4	53	50	45	0.74
Warm white pc LED	3510	89	62	2	14	17	17	0.53
RGB LED cluster	3000	41	11	77	1	53	61	0.43
Firelight pc LED	2000	40	9	1	77	37	62	0.10
HPS lamp	1906	13	9	0	83	38	68	0.12

Figure 1 displays the SPDs of the five sources (a-e) and the variation of the colour rendition characteristics with adaptation luminance in the mesopic range relevant to street lighting (0.1-2 cd/m^2) (f-j). The warm white pc LED is seen to retain high-fidelity colour rendition within the entire range of luminances. With decreasing luminance, all other sources are gradually losing the ability to distort chroma, hue and lightness. The daylight pc LED, RGB LED cluster, firelight pc LED, and HPS lamp show a crossover to high-fidelity regime (CFI > 50%, $R_{\mathrm{a,mes}}$ > 80) when the luminance is reduced below 1.2, 0.25, 0.3, and 0.17 cd/m^2, respectively. The daylight pc LED, RGB LED cluster, and firelight pc LED have moderate colour fidelity (CFI >25%, $R_{\mathrm{a,mes}}$ >70) in the entire range of luminances. For HPS lamp, such moderate colour fidelity is attained only for L < 1 cd/m^2.

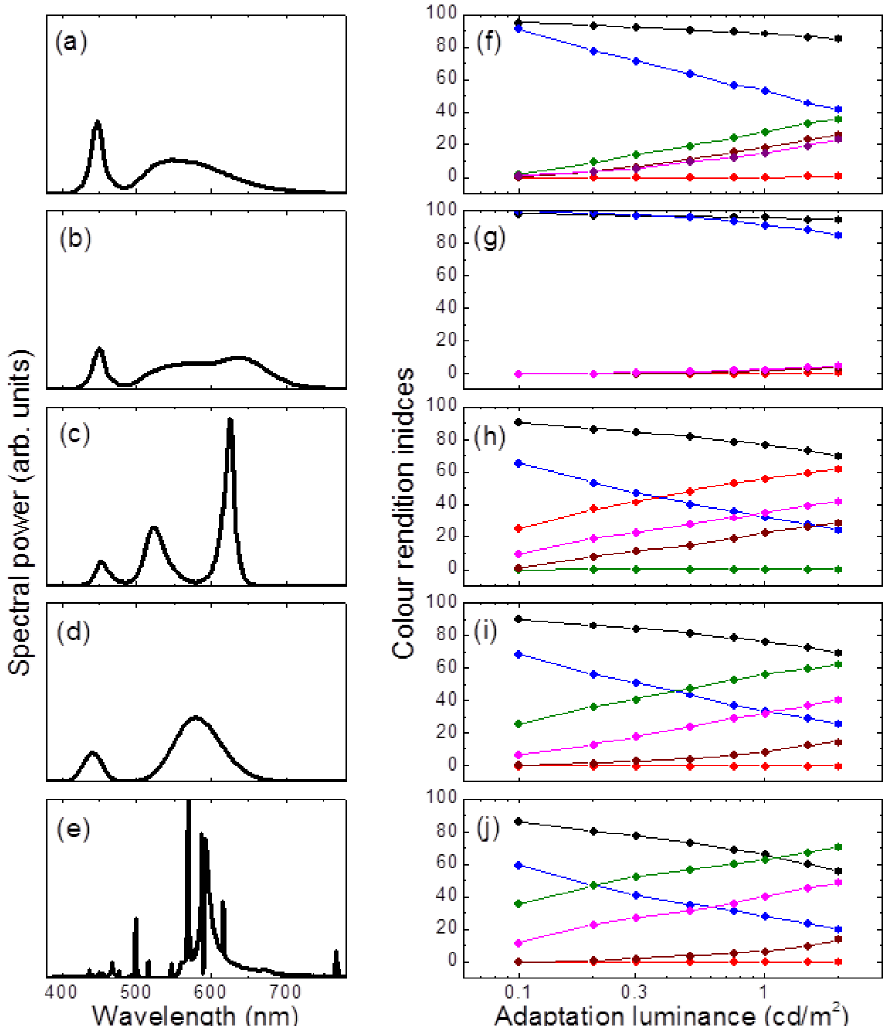

Figure 1: SPDs of daylight pc LED (a), warm white pc LED (b), RGB LED cluster (c), firelight pc LED (d), and HPS lamp (e). Corresponding variation of colour rendition indices with adaptation luminance (f-j): $R_{a,mes}$, CFI, CSI, CDI, HDI, and LDI (black, blue, red, green, wine, and magenta points and lines, respectively).

4. CONCLUSIONS

The results of the assessment have shown that many light sources that have poor colour rendition properties under photopic conditions can provide with an appropriate colour quality of lighting under mesopic conditions. In particular, the colour rendition properties of dichromatic low-CCT (firelight) pc LED with extremely low circadian hazard are considerably improved with reduced adaptation luminance. In the entire range of luminances relevant to street lighting, such LEDs have moderate colour fidelity and render a reduced number of colours with perceptually noticeable chroma reduction and hue distortion. On the other hand, trichromatic warm white pc LEDs were found to have redundant colour fidelity under mesopic conditions. For many outdoor lighting applications, these LEDs can be replaced by less sophisticated (dichromatic) and cheaper ones.

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Spectral Opponency in Human Circadian Phototransduction: Implications for Lighting Practice

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ABSTRACT

Regulation of circadian functions by light in mammals is mediated through the retina by intrinsically photosensitive retinal ganglion cells (ipRGCs) containing the photopigment melanopsin as well as distal photoreceptors, rods and cones. Utilizing conventional retinal neurophysiology and incorporating all photoreceptors, a model of human circadian phototransduction was proposed in 2005 and with minor refinements for pre-retinal absorption in 2012. This model incorporates a spectral opponent, blue versus yellow (b-y), retinal mechanism that implies a non-linear response by the circadian system to some types of polychromatic light stimuli. Three experiments were conducted to test whether there was evidence for a subadditive response to polychromatic light by the human circadian system, as measured by acute melatonin suppression. Subadditivity was demonstrated in all three studies suggesting that the human circadian system may respond to color information.

1. INTRODUCTION

All mammals exhibit daily oscillatory responses in physiology and behavior that are known as circadian rhythms. Light on the retina is the primary stimulus used by both diurnal and nocturnal mammals to entrain their circadian rhythms to their local position on Earth. A robust marker of circadian time is the daily rhythm of melatonin concentrations in blood, saliva or other body fluids; melatonin levels are low during the day and high at night. Retinal light exposure during the night can suppress melatonin synthesis. Using nocturnal melatonin suppression, Brainard et al. (2001) and Thapan et al. (2001) independently measured the spectral sensitivity of human circadian phototransduction to narrow-band light stimuli.

Starting in the 1990s, Foster and colleagues (Lucas et al. 1999) and later Berson and colleagues (Berson et al. 2002) attempted to understand the circadian phototransduction mechanisms in mouse retina. In 2002, Berson's group identified an intrinsically photosensitive retinal ganglion cell (ipRGC) that was central to light regulation of circadian rhythms. Subsequent research demonstrated that rods and cones also participate in circadian rhythm entrainment (Hattar et al. 2003). Neurons in the outer layers of the retina provide vertical and lateral connections between the distal photoreceptors and the more proximal ganglion cells, and form the first step in spectral opponent color vision in humans and other diurnal mammals. It is reasonable to hypothesize that the human circadian system might exhibit spectral opponent behavior. Subadditivity is a characteristic of the spectral opponent color channels whereby the net response of these channels to polychromatic light cannot be predicted from summing responses to the fractional amounts of the component spectra. A model of human circadian phototransduction was published in 2005 incorporating input from the spectral opponent, b-y channel (Rea et al. 2005). The model was constrained by the known photoreceptors, including the ipRGCs, conventional retinal neurophysiology and empirical data on light-induced nocturnal melatonin suppression in humans. The modeled spectral sensitivities to narrow-band and to polychromatic sources are shown in Figure 1. Three tests of subadditivity served as partial validations of the more complete model.

2. THREE EXPERIMENTS

2.1 Experiment 1 (Figueiro et al. 2004)

Using a counterbalanced design, four subjects were exposed on different nights to one hour of light from two sources, narrowband short-wavelength LEDs (l_{max} = 470 nm) producing 29 mW/cm^2 at the cornea and a polychromatic clear mercury (Hg) lamp producing 170 mW/cm^2. The clear Hg source has only three major emission lines, at 436 nm, 546 nm and 578 nm, in the visible spectrum. The shortest wavelength in the discrete Hg emission spectrum should stimulate the "blue" side of the b-y channel and the longer two wavelengths should stimulate the "yellow" side. The 470-nm LEDs should stimulate only the "blue" side of the b-y spectral opponent channel. Melatonin concentrations in plasma were measured before and after the light exposures to calculate nocturnal melatonin suppression. Effective light stimulus magnitudes for the two sources were calculated using a spectral efficiency function derived from combined data from Brainard et al. (2001) and Thapan et al. (2001) and an assumption of additivity such that all radiant power generated by the two lights could be weighted by the combined efficiency function and then summed. Nocturnal melatonin suppression to 1530 effective units of light from the Hg lamp was compared to 740 effective units of light from the LEDs. Consistent with the subadditivity hypothesis, there was significantly less nocturnal melatonin suppression from the Hg lamp than from the LEDs, even though the Hg lamp produced twice as many effective units of light as the LEDs.

2.2 Experiment 2 (Figueiro et al. 2005)

Again using a counterbalanced design, four subjects participated in a two light-level by two light-spectrum experimental design. Unfiltered light from a clear Hg source was presented at low (450 lx) and at high (1050 lx) light levels on separate nights. A low-pass spectral filter was applied to the Hg spectrum for two light levels such that retinal irradiance from the 436-nm spectral emission line was approximately equal for the filtered and unfiltered Hg source. Consistent with the subadditivity hypothesis, the unfiltered Hg source resulted in significantly lower nocturnal melatonin suppression than the filtered Hg source, even though the unfiltered light produced much greater total retinal irradiance. By including the yellow-stimulating 546-nm and 578-nm emission lines in the unfiltered Hg source, the circadian system response to the 436-nm emission line was diminished compared to the 436-nm emission alone.

2.3 Experiment 3 (Figueiro et al. 2008)

To determine whether subadditivity was the result of spectral opponent mechanisms in the retina, three sets of light stimuli were presented dichoptically to 10 subjects in a counterbalanced design. For the first set, a short-wavelength (blue) light stimulus from narrow-band LEDs (l_{max} = 450 nm, 7.7 mW/cm^2) was presented to the left eye and a long-wavelength (green) light stimulus from narrow-band LEDs (l_{max} = 525 nm, 21.1 mW/cm^2) was presented to the right eye. For the second set, the 525-nm light stimulus was presented to the left eye and the 450-nm light stimulus to the right eye. In the third set, half the irradiances from the 525-nm light stimulus and from the 450-nm light stimulus were combined and presented to both eyes. Nocturnal melatonin suppression was the same for the first and second sets of light stimuli, but was significantly less for the third set. Thus, subadditivty is a feature of the retinal mechanisms as proposed in the model of human circadian phototransduction.

All three studies demonstrated that the human circadian system's response to polychromatic light sources cannot be predicted from an action spectrum based upon system responses to narrow-band stimuli. Subadditivity is a phenomenon associated with well-established spectral opponent retinal mechanisms in the human retina. The model of human circadian phototransduction incorporates a b-y spectral opponent process and as such implies that the circadian system may respond to color information in the environment. Two studies have made similar conjectures, one with rabbit (Nuboer et al. 1983) and one with fish (Pauers et al. 2012), but a color response by the human circadian system has not been demonstrated.

3. SUMMARY

A model of human circadian phototransduction was developed for predicting circadian system responses to retinal light exposures (Rea et al. 2005, 2012). Subadditivity is an inherent feature of the model whereby a simple action spectrum based upon circadian system responses to narrow-band stimuli cannot be used to predict system responses to all polychromatic light stimuli. This model has been incorporated into a field device for quantifying personal, daily light exposures (Figueiro et al. 2012). The daily light-dark exposure patterns characterized by the model of circadian phototransduction have been used to quantify circadian entrainment and disruption in several populations (e.g., Miller et al. 2010). The ability to quantify circadian light exposures with a calibrated device offers great promise for developing better light schemes for schools, offices and factories as well as for prescribing precise doses of light for clinical applications (e.g., sleep consolidation for persons with Alzheimer's disease).

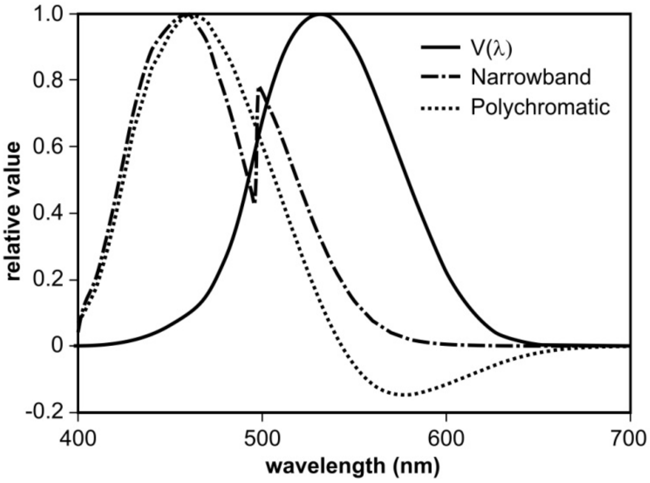

Figure 1: The photopic luminous efficiency function (V(λ)) which forms the basis of all lighting standards (Commission Internationale de l'Éclairage 1994) together with the spectral sensitivity of the human circadian system to narrow-band and polychromatic sources based upon the model of circadian phototransduction (Rea et al. 2005, 2012).

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A Study of Atmosphere Perception of Dynamic Colored Light

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ABSTRACT

A psychophysical experiment was carried out to investigate the impact of dynamic lighting physical parameters on the atmosphere perception. The experiment was conducted in a purposely built LED lighting lab, where the lights can be spatially and dynamically changed, and colorimetric specifications such as SPD, CCT, CIE xy, CIELAB values can be controlled. In this study, the influence of chroma and changes of speed was investigated. Twenty native Chinese observers participated in the experiment, each assessing the environment under dynamic lighting conditions using 21 atmosphere terms. 21 scales can be grouped into four categories: *coziness, liveliness*, *tenseness and detachment,* which were consistent with results under static lighting environment. *Living room-like* atmosphere evaluation is consistent with *coziness* and office-like atmosphere was highly correlated with *detachment*. Both chroma and speed have significant influence on the atmosphere perception. A higher saturated LED light would lead to less *tense*, more *cosy*, more *lively* and less *detached*. By increasing the speed, it will generate more *tense*, less *cosy* and less *detached* atmosphere. Medium speed (8s) offers the most *lively* and preferred atmosphere. A more saturated and a slower speed will produce more *living room-like* environment, but it seems that such dynamic lighting is not suitable for *office-like* environment.

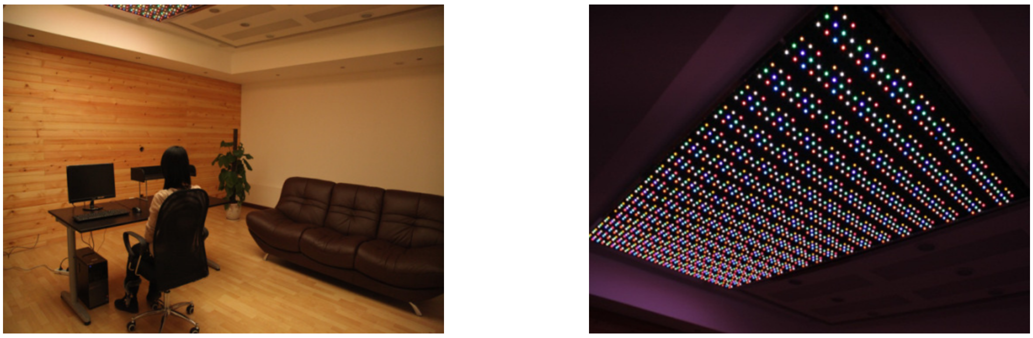
1. INTRODUCTION

Light plays an essential part in human life. It has an effect on visibility, health and well-being and can influence our affective state. With the advance of LED technology, lighting systems can enable not only full control over both the luminance and chromaticity, but also the creation of fully dynamic lighting environment. Thus, LED based lighting systems can be used to design more complex and attractive lighting environment.

Literature indicates that lighting physical parameters like color temperature, luminance affect people's emotions, mood, preference and cognition. However, contradictory results have been found on this topic. These conflict results can be explained by the fact that emotions are influenced by many environmental and non-environmental factors which relate to a person's mental state such as stress happy events in the real life. Atmosphere differs from emotion and mood in the sense that it is not an affective state, but it is the experience of the surrounding in relation to ourselves. Vogels *et al.* developed a questionnaire to assess and quantify the perceived atmosphere of an environment. It has been shown that atmosphere can be quantified in a four-dimensional affective space: coziness, liveliness, tenseness, and detachment. However, the previous atmosphere perception studies were carried out under static light environment. One of the major features of LED lighting system is their dynamic properties. In this study, psychophysical experiments were carried out to explore atmosphere dimensions under dynamic lighting and to investigate the physical parameters of speed, saturation of dynamic lighting on the atmosphere perception.

2. METHOD

The experiment was carried out in the lighting lab of Zhejiang University, decorated as a multi-purpose room, as shown in Figure 1a. The light source was an LED array of 3 × 1.5 m (L × W) including 11 kinds of LED and more than 1700 LEDs, as shown in Figure 1(b). Software was developed to control luminance levels of 11 different kinds of LED.



a. Experimental condition *b. LED array*

Figure 1. Experimental setup.

2.1 Stimuli

In this study, six lighting conditions were created. Control parameters of lights are 1) 72 lights ranged from CIELAB hue angle of 0° to 360° at 5° interval), 2) two CIELAB C^*_{ab} values at 25 and 45, 3) three speed values at 2, 8 and 16s. The specification is given in Table I. The mean color difference ΔE^*_{ab} between target and measured was 1.83 units. All the colors were measured by a PhotoResearch PR655 SpectraScan Spectroradiometer in this study.

2.2 Participants and Procedure

Twenty participants (including 10 male and 10 female) took part in the experiment, with an average age of 23.4 (SD=2.3). Each passed the Ishihara test. They are students at Zhejiang University and had no experience for performing visual assessments. The participants were required to assess atmosphere of the room under different dynamic light conditions by answering a questionnaire which consists of 21 terms to describe the atmosphere studied. The categorical judgment method was used to scale each atmosphere perception in 7 categories from 1) the most positive to 7) the most negative feelings such as most and least cosy respectively. Table II lists the 18 terms used in Vogels *et al*'s study, which were divided into four dimensions: *coziness, liveliness, tenseness, detachment*. The 18 terms were chosen from those highly correlated with the four dimensions. In addition to the atmosphere perceptions, '*beautiful*' and appropriateness atmosphere for *Living rooms-like* and *Office-like* were also included. This is intended to explore the perception on preference and particular environment, respectively.

Table I. The physical parameters used in the dynamic light.

Variables	Levels	Values
C^*_{ab}	Low	45
	High	25
Speed	Slow	16s
	Medium	8s
	Fast	2s

Table II. The 18 atmosphere terms grouped in four categories.

Coziness	Liveliness	Tenseness	Detachment
Cosy safe Relaxed Pleasant Hospitable Tranquil	Lively Stimulating Inspiring	Tense Hostile Uncomfortable Oppressive Threatening Horrible	Formal Chilly Spatial

3. RESULTS AND DISCUSSION

The underlying dimensions of dynamic light in this study were extracted by factor analysis.

Extraction method applied here was the principal component analysis, together with Varimax rotation method. Table III lists four main factors extracted (accounting for 67% variance) from all data. They are *coziness*, *liveliness, tenseness* and *detachment,* which was the same as the results of Vogels *et al.* except that *pleasant* were found to be fallen into different categories and that spatial, safe and hospitable were not correlated with all the four dimensions. Factor analysis results means that both dynamic and static light have the same four atmosphere dimensions: *coziness, liveliness, tenseness, detachment. Beautiful* was found in *liveliness* dimension which means that lively atmosphere were more preferred. *Living room-like* evaluation was consistent with *Coziness*. *Office-like* was located in *Detachment* dimension.

The differences between the levels of each experimental factor were analyzed using the method of multivariate analysis of variance (MANOVA). Table VI gives an overview of the effects of the dynamic settings. The significant differences between levels are indicated by the *p* values. The impact of physical changes of dynamic lightings on atmosphere dimensions was described by the mean factor score across participants for each dimension. For example, S>M>F means that slow speed scored highest and fast speed scored lowest. A higher saturated LED light would lead to less *tense*, more *cosy*, more *lively* and less *detached*. By increasing the speed, it will generate more *tense*, less *cosy* and less *detached* atmosphere. Medium speed (8s) offers the most *lively* and preferred atmosphere. A more saturated and a slower speed will produce more *living room-like* environment, but it seems that such dynamic lighting is not suitable for *office-like* environment. Table VI also shows that chroma and speed have significant interaction effects on all four atmosphere dimensions.

Table III. Four main factors extracted by factor analysis.

Coziness	**Liveliness**	**Tenseness**	**Detachment**
Cosy Living room-like Tranquil Relaxed	Lively Stimulating Inspiring Beautiful Pleasant	Horrible Threatening Oppressive uncomfortable Horrible Tense	Office-like Formal Chilly

Table VI. An overview of the effects of the dynamic settings.

	Coziness	**Liveliness**	**Tenseness**	**Detachment**
Speed (slow, medium, fast)	P=0.032 S>M>F	P=0.021 S<M>F	P<0.01 S<M=F	P<0.01 S>M>F
Chroma (high, low)	P<0.01 H>L	P=0.014 H>L	P=0.061 H=L	P<0.01 H<L
Chroma*Speed	P<0.01	P<0.01	P<0.01	P<0.01

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High Color-rendering Tunable Light Source Fufilling the ENERGY STAR Requirments by 4-color LEDs

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ABSTRACT

The dynamic lighting using only 4-color LED set to fulfill the eight nominal CCTs of the Energy Star plus two extra spectra 9000K and 12000K each with color rendering indexes greater than 96 is presented. It is based on finding each spectrum with optimal synthesis coefficients for the four LEDs to maximize the general color rendering index and to keep the chromaticity coordinates located in the tolence zone. This dynamic lighting is not only using for general lighting such as smart lighting but also possible for alleviating afternoon sleepiness with less energy consumption and mood converting for major depressive disorder (MDD).

1. INTRODUCTION

Using multi-color LEDs to imitate the CIE standard illuminants and blackbody radiators used in some measurement intruments, the selection of optimal LEDs is based on minimizing the mean-squared-error between the spectral power distribution (SPD) of the CIE standard illuminats and the synthesized illuminants (Wu 2012, Hu 2008). In general, it requires more LEDs, such 12-color LEDs. The purpose of this is to synthesize a correct SPD of a standard illuminant. However, the correctness of the synthesized SPD is not important compared to high CRI of the synthesized SPD for general lighting uses. Besides the less LEDs used, the better for color mixing. Thus it is suggested that the dynamic lighting is color tunable and with less color LEDs used but with high CRI of the illumination.

For the purpose, instead of minimizing the mean-squared-error between the SPD of the CIE standard illuminats and blackbody radiators, the algorithm for a selected 4-color LED set to maximize the color rendering indexes of the eight nominal CCTs of the Energy Star plus two extra spectra with 9000K and 12000K is presented. It is based on how to find the optimal synthesis coefficients for the four LEDs to maximize the CRI and to keep the chromaticity coordinates located in the tolence zone. In order to so, the color difference between the standard illuminant and the synthesized illuminant on computing R_a is simplified, and then the Nelder-Mead algorithm to synthesize coefficients of the ten CCTs and the CRI values is applied.

This dynamic lighting with high CRI for each of the emitted light is not only using for general lighting such as smart lighting but also possible for alleviating afternoon sleepiness with less energy consumption and mood converting for major depressive disorder (MDD).

2. OPTIMAL RECONSTRUCTION OF COLOR RENDERING INDEX

The special colour rendering indexes R_i for each of the test colours are obtained as R_i=100-ΔE_i and ΔE_i is given as

$$\Delta \mathrm{E_i} = \sqrt{(\mathrm{W_{s,i}} - \mathrm{W_{r,i}})^2 + (\mathrm{U_{s,i}} - \mathrm{U_{r,i}})^2 + (\mathrm{V_{s,i}} - \mathrm{V_{r,i}})^2} \qquad (1)$$

where

$$\Delta \mathrm{W_i} = 25\left(\mathrm{Y_{s,i}}^{\frac{1}{3}} - \mathrm{Y_{r,i}}^{\frac{1}{3}}\right)$$

$$\Delta \mathrm{U_i} = 13\left[\mathrm{W_{s,i}}\left(\mathrm{u_{s,i}} - \mathrm{u_s}\right) - \mathrm{W_{r,i}}\left(\mathrm{u_{r,i}} - \mathrm{u_r}\right)\right]$$

$$\Delta \mathrm{V_i} = 13\left[\mathrm{W_{s,i}}\left(\mathrm{v_{s,i}} - \mathrm{v_s}\right) - \mathrm{W_{r,i}}\left(\mathrm{v_{r,i}} - \mathrm{v_r}\right)\right] \qquad (2)$$

The suffixes s and r denote the standard illuminant and the reconstructed illuminant. Two preamble steps to simplify Eq.(2). There are

1. In general, assume $\mathrm{Y_s} \approx \mathrm{Y_r} = 100$ when we calculated the CRI of light source.
2. Assume, where coefficient a is a constant. Therefore Eq.(2) is written as

$$\Delta \mathrm{U_i} = 13\mathrm{W_{r,i}}\left[\mathrm{a}\left(\mathrm{u_{s,i}} - \mathrm{u_s}\right) - \left(\mathrm{u_{r,i}} - \mathrm{u_r}\right)\right]$$

$$\Delta \mathrm{V_i} = 13\mathrm{W_{r,i}}\left[\mathrm{a}\left(\mathrm{v_{s,i}} - \mathrm{v_s}\right) - \left(\mathrm{v_{r,i}} - \mathrm{v_r}\right)\right],$$

where a≈ 1 and $\Delta \mathrm{U_i} \approx 13\mathrm{W_{r,i}}(\Delta \mathrm{u_i} - \Delta \mathrm{u})$, $\boldsymbol{\Delta \mathrm{V_i} \approx 13\mathrm{W_{r,i}}(\Delta \mathrm{v_i} - \Delta \mathrm{v})}$

Under the chromatic adaptation consideration we assume that $\mathrm{u_s} = \mathrm{u_r}$ and $\mathrm{v_s} = \mathrm{v_r}$ that makes $\Delta u = \Delta v = 0$ then $\mathrm{R_a} = \left(\sum_{i=1}^{8} R_i\right)/8$ is related to the function as $\mathbf{f} = \sum_{\mathbf{i=1}}^{\mathbf{8}}(\Delta\, \mathbf{u_i} + \Delta \mathbf{v_i})$

The synthesis coefficients of the ten CCTs are obtained by using Nelder-Mead algorithm, and the CRI values for different CCT of light by the 4-color LED lighting are shown in Table 1. Figure 1 shown the synthesiaed SPDs of the ten CCTs with DUV<0.06. red circles mean the synthesized SPDs.

Table 1 CRI values for different CCT of light by the 4-color LED lighting.

CCT	2700K	3000K	3500K	4000K	4500K	5000K	5700K	6500K	9000K	12000K
CRI	98.3	98.1	97.5	97.6	97.3	97.1	97.0	96.5	96.3	96.1

3. THE DYNAMIC LIGHTING FOR MEDIATING NOON DROWSINESS AND MOOD

Many people have experienced afternoon drowsiness especially right after lunch. The arousal levels induced by different color temperature of illuminations are interpreted by the alpha attenuation coefficient (AAC) (Curcio 2001). ΔAAC denotes the AAC difference compared with baseline. The experimental procedure applied the dynamic lighting to alleviating the post-lunch dip is shown in Figure 2. The experiments of arousal level affected by different correlated color temperature (CCT)-fixed lighting such as 6500K and 12000K, denoted by L1 and L2, respectively, and dynamical CCT-varying lighting, namely, the CCT changed gradually from 2300K to 6500K, from 6500K to 2300K, from 6500K to 12000K, and from 12000K to 6500K, denoted by L3, L4, L5, L6 respectively, are conducted with 15 subjects from 13:00 to 15:30. The illuminance is 500 lx at eye level. Since higher light intensity induces higher ΔAAC, how high the intensity of L1 is to have ΔAAC significantly higher than 500 lx L1? According this experiment, the ΔAAC of L1 with 800 lx is not significantly higher than that of L1 with 500 lx. Since the ΔAAC of L6 is significantly higher than that of L1 which is commonly used in office (Hu 2012), low intensity dynamic light, such as L_6, is suggested, instead of high intensity L_1 for energy saving point of view.

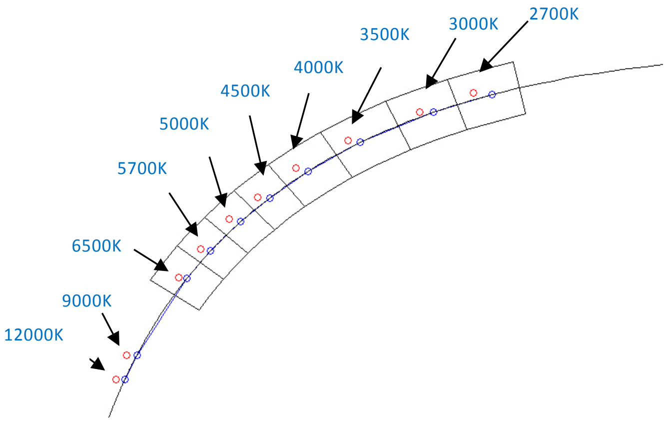

Figure 1: CIE chromaticity diagram in uv domain Showing the synthesiaed SPDs of the ten CCTs with DUV<0.06. red circles mean the synthesized SPDs.

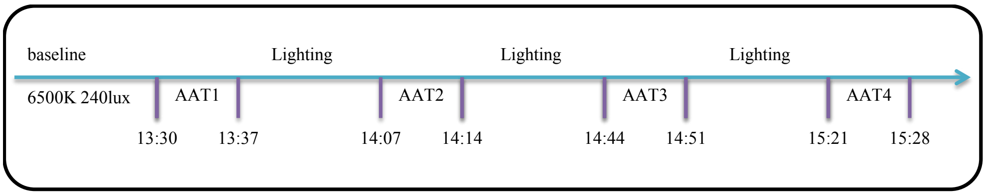

Figure 2: *The experimental procedure. Alpha attenuation tests (*AAT*S)* *of EEG* is *measured in every 30 minutes.*

Not only judged by ΔAAC variations, a mood conversion for the dynamic lights or the static lights is investigated. The positive or negative valence is given by α= ln(averaged alpha band power of left hemispheric part of brain) - ln(averaged alpha band power of right hemispheric part of brain), where ln denotes nature logarithm. If α> 0 means negative valence while α< 0 means positive valence (Tomarken 1992). Therefore, light exposure to have a person whose mood from negative valence to positive valence may be another purpose of choosing lights.

The valence status may be converted after the exposure of different types of lights, such as from negative valence to positive valence, denoted by N→P, or positive valence to negative valence, denoted by P→N. We define the mood conversion ratio as

$$R_{N\to P} = M_{A2} + M_{A3} + M_{A4} / N_{A1} + N_{A2} + N_{A3},$$

where $R_{N\to P}$ means the percentage of the subjects from negative valence converted to positive valence after light exposure. N_{A1}, N_{A2}, N_{A3} are the number of the subjects classified to be negative valence by EEG measurement at AAT1, AAT2, AAT3, respectively while M_{A2}, M_{A3}, M_{A4} are the number of the subjects being classified to negative valence at AAT1, AAT2, AAT3 and converted to positive valence at AAT2, AAT3, AAT4, respectively after light exposure. So $R_{N\to P}$ is required to be as higher as possible in order to staying positive valence. Similarly, the other mood conversion ratio is defined by

$$R_{P\to N} = L_{A2} + L_{A3} + L_{A4} / P_{A1} + P_{A2} + P_{A3},$$

So, $R_{P\to N}$ is required to be as lower as possible in order not to staying negative valence. A merit index is defined as $\delta = R_{N\to P} - R_{P\to N}$. Thus, a light with high δ means it has high potential of remaining in positive valence.

The values of $R_{N\to P}$, $R_{P\to N}$, δ of different lights are shown in Table 2. From this table, the dynamic lights have higher δ than the static lights. Thus in general, the dynamic lights are superior to the static lights. Since L_6 has the highest δ, it is the best choice among the six lights not only for alleviating afternoon sleepiness but also for maintaining positive mood.

Table 2. $R_{N\to P}$ *and* $R_{P\to N}$ *of the static lights and the dynamic lights.*

	$R_{N\to P}$	$R_{P\to N}$	δ
L_1	23%	25%	-2%
L_2	25%	22%	3%
L_3	70%	54%	16%
L_4	77%	65%	12%
L_5	54%	39%	16%
L_6	75%	54%	21%

4. CONCLUSION

The study used the 4-color LEDs to synthesize coefficients of the ten CCTs and the CRI values which derived the best color rendering index with acceptable color difference. Another purpose in present study is defined new index for choosing lights. According to this index, the dynamic lights are able to convert negative valence to positive valence. So, the dynamic lights have better performance regarding this point of view and possible for reducing the risk of major depressive disorder. However, more clinical studies for the dynamic light applied to light therapy are needed. Based on these, the dynamic lighting can be easily realized by multi-color LED unit and is possible to replace the static lighting we are using nowadays.

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A Study on Appropriate Illuminance and Color Temperature for Reading (Focused on visual age of 25 years and under)

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ABSTRACT

In this study, targeting Koreans whose ‘visual ages’ were under the age of 25, the range of appropriate illumination per color temperature was derived and compared with the illumination standards of IESNA and KS. And also evaluations of readability, comfort, and preference were performed. As results, the illumination standard of 150 lx which was indicated from IESNA turned out to be dark in brightness for reading. This trend was consistent throughout all ranges of color temperature. In addition, as a result of the analysis to identify the range of appropriate brightness for reading at individual color temperature ranges, 5000K of color temperature corresponds to 300 – 400 lx, 4000K to 400 – 600 lx, and 3200K to 600 – 1000 lx. Readability, at all ranges of color temperature, becomes easier as the illumination is higher. As for comfort and preference, with the illumination of 400 lx or less, the color temperature of 5000K was observed to be the highest while 4000K was assessed to be the highest with 600 lx or more.

1. INTRODUCTION

The Illuminating Engineering Society of North America (IES) recently presented, in the 10th Edition of Lighting Handbook, the horizontal and vertical illuminations varying with the ages of worker (visual age) in each of characterized space. And the handbook also mentioned considerations of uniformity and daylight as well as vast reflection. In contrast, the current Korean KS illumination standard (KS A 3011) was established by citing the illuminations of foreign standards as it was, and it only defines minimum-medium-maximum of horizontal range of illumination. The KS standard does not deal with an appropriate range of illumination standard suitable for individual ages of Asians whose eye structures are significantly different from those of the Westerners in terms of the physiology anatomy of eyes. In addition, both IESNA and Korean KS standards do suggest only illumination but not standards pertaining to a range of color temperature.

Therefore, this study, as a preliminary experiment, attempted to derive both the scope of illumination and the range of color temperature suitable for variability of Asians’ visual ages during eye’s work of reading. For this experiment, only Koreans whose visual ages were under the age of 25 were selected as subjects. And also, as indicating the illumination standards of both IESNA and KS associated with reading, this study evaluated brightness, readability, comfort, and preference and interpreted the results by comparing the individual illumination standards.

2. METHOD

The experiment was conducted excluding the impact of daylight and artificial light around the experimental test bed of which the study room was composed. The subjects comprised of total 20 Koreans whose ages ranged from 18- to 23-year-old and their corrected visual acuity was all above 1.0 with no dyschromatopsia. The subjects participated in two to three times of pre-training and pre-test in advance for better understanding of this experiment, the correct visual assessment of lighting conditions, and a standard of their subjective judgments.

2.1 Experimental Method

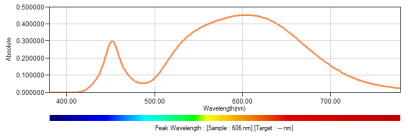
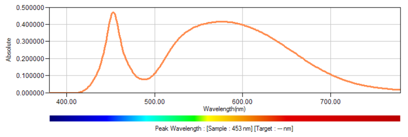
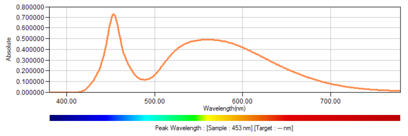
In this study A4 size white paper printed with 10-point size black letters was placed on a desk along with a stand light, and the background illumination was 0 lx. And a subject was asked to read at a distance of about 30cm from the white paper at a 45-degree angle for about 1 minute, as shown in Fig. 1. After reading, the subject was required to assess the brightness perceived during the reading, easiness of reading, comfort, and preference using the five step value level method [very: 5 points, moderate ('appropriate' in case of brightness): 3 points, never: 1 point].

Figure 1: The figure of the subjective evaluation.

2.2 Experimental Variable

The light source of the stand lighting used in the experiment is the LED whose color temperature and illumination are divided into 100 steps so as to be adjusted for their degree. The LED stand of lighting has the implementable range of color temperature of about 3000K to 5500K and in this study, 3200K, 4000K, 5000K were selected as experimental variables. In addition, in terms of illumination used in this experiment, the illuminations during reading in a residential space were determined to be 150, 300, 400, and 1000 lx after taking into account combination of the U.S. IESNA and KS illumination standard. The KS illumination standard exhibits the range of illumination from the perspectives of bedroom, study room and living room of a residential space and their illumination degrees are 300-400-600, 600-1000-1500 and 300-400-600 lx, respectively. And also the IESNA illumination standard classifies the reading activity in a residential area into a category called "Reading and Writing" and presents its required illumination. In this category, the "print media' section requires 150 lx for the age of 15 and less when reading a document with 8 to 10 font size. As to measurement of physical quantities lighting, the color light meter (Minolta, CL-200), the illumination light meter (Minolta, T-10), and the spectral radiation luminance meter (Minolta, CS-1000A) were used for measurement of color temperature, illumination, and the spectral distribution of the light source as well as the color rendering index, respectively. The physical properties and spectral distribution of the measured light source are shown in Table 1.

Table 1: Physical properties and spectral distribution of measured light source.

Color Temperatures (K)	General Color Rendering Index (Ra)	Color coordinates		Spectral Distribution
		x	y	
3175 K	79	0.4318	0.4053	
4011 K	78	0.3842	0.3832	
5017 K	75	0.3478	0.3656	

3. RESULTS AND DISCUSSION

The results from the evaluation of brightness indicated that, with a basis of Koreans with the visual age of 25 or less, the U.S. IESNA illumination standard of 150 lx when reading was dark for reading in all ranges of color temperature. And the range of illumination that was characterized and extracted as an appropriate brightness for reading significantly varied with color temperature. It was observed that as the color temperature was the lower, the higher illumination was required. In order words, the color temperature of 5000K corresponds to the illumination of 300 - 400 lx as a range of appropriate brightness, 4000K to 400 - 600 lx, and 3200K to 600 - 1000 lx. It was proposed that at the same illumination, the higher color temperature correlated with the brighter perception.

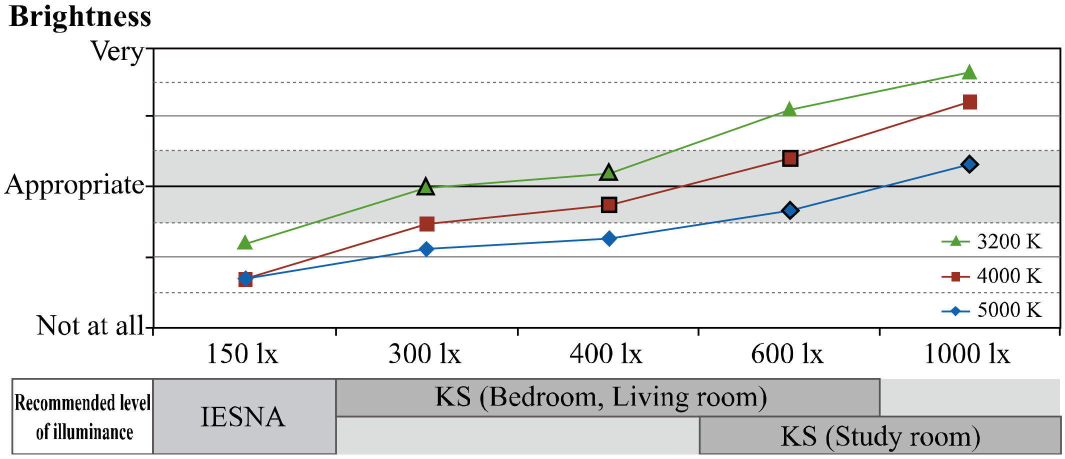
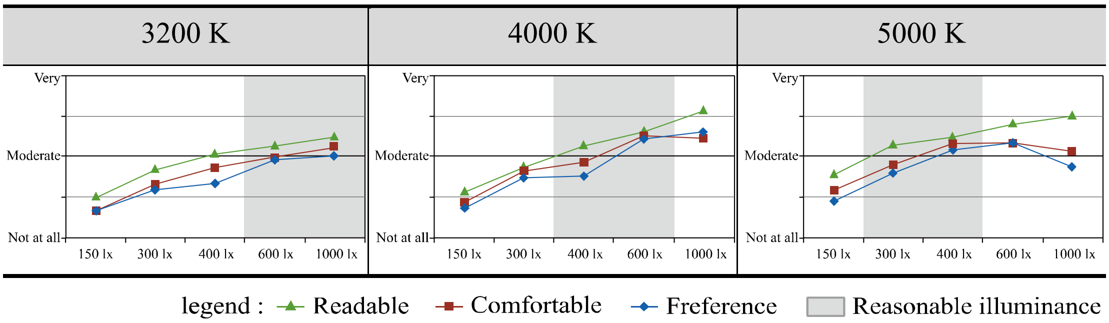


Figure 2: Results from the evaluation of appropriate brightness.

In readability, as the illumination is the higher, the readability is the easier. This pattern remained consistent throughout all ranges of color temperature. And as to evaluation of comfort and preference, presenting similar trends, comfort and preference were observed to be the highest within the range of the appropriate illumination in each color temperature range. The color temperature was investigated from the viewpoints of the comfort and preference, and as results 3200K of color temperature was evaluated to be the lowest in general in terms of comfort and preference. And at the illumination of 400 lx or below, 5000K of color temperature ranked the highest from the perspectives of comfort and preference while at 600 lx or above, 4000K was reported to be the highest.

Table 2: Results of assessment of readibility, comfort and preference by color temperature.



4. CONCLUSIONS

In this study, aiming at Koreans with the 'visual age' of 25 or less, the range of the appropriate illumination per color temperature when reading was derived and assessments of readability, comfort, and preferences were carried out. As results, when color temperature was the lower, the reading required the higher illumination. And also low color temperatures were not preferred in general. In addition, the range of preferred color temperature varied with illuminations. These results are expected in the future to be utilized as fundamental physical properties for designing of the stand of lighting for reading.

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Using LED Technology to Build up Museum Lighting Environment

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ABSTRACT

In 1941, Kruithof proposed a method to achieve the "pleasantness" effect based on a plot of correlated color temperature (CCT) against illumination level for indoor lighting design, in which a pleasing region was identified. This paper describes an experiment to verify the method using modern LED sources.

In this study, six original paintings were reproduced by hand-painting by artists including three categories: oil paintings, watercolors and oriental paintings. There are two paintings for each category including one indoor and the other outdoor scenes. Thirty observers took part in the experiment. A light replicator, including 16 narrow band LEDs was used. Fifteen sets of illuminants were generated using a light replicator, including 5 CCTs (2700, 3500, 4000, 5000, 6500 K), and 3 illumination levels (50, 150 and 300 lx). A category judgment method was used to scale 11 visual attributes, which fell into two categories: physics of lighting including colorful, bright, clear, and psychological perception on painting including warm, relax, soft, pleasant, natural, active, old, comfort. The results showed that these scales can be divided into two components: warmth and visibility which are associated with CCTs and illuminance level of the light source respectively.

Keywords: LED, museum lighting, kruithof rule

1. INTRODUCTION

Due to the advantages of LED light sources such as low energy consumption and long life, it is inevitable to develop new LED light source for museum applications. The research found that at a higher CCT, the perception of brightness, glare and contrast will increase, but comfort and pleasure will decrease (Viénot, 2009). However, the experimental results were uncertain whether the comfort and pleasure will increase at lower CCT conditions. Note that their experiment did not use real art work. The results showed that at 200 lux, 3600K work best to reach the most pleasant effect with real painting. But they also found that the 3000K and 5300K can reach similar perception. It should be noted the research was carried out with incandescent light source (Sculleo, 2004). Simulated light sources for display fine art materials, and found a source including three LEDs at 450 nm, 530 nm and 610 nm gave the best performance, but this research was based on computation without the verification using real sources (Berns, 2011).

It has been evidence to show that some LED mixtures will accelerate damage more rapidly on natural yellow dyes and less damage-activation spectra of most dyes and pigments. Because so much is piled on to narrow bands in LEDs, the possibility of the so called "hole burning" effect will occur (Druzik, 2010). The relationship between wavelength and color change for blue pigments (International Organization for Standardization (ISO) blue wool standard grades 1-3) was used to established to test radiation damage. However, it is less straightforward. Also, the radiation in the blue region is not necessarily the most damaging for the other colorants (Saunders, 1994).

2. METHOD

Six fine art paintings were collected at Taipei Fine Arts Museum. These were then reproduced with hand-painting by the artists. They are divided into three categories: oil paintings, watercolors, oriental paintings. In each category, an indoor and an outdoor scene are included. In total, 30 observers took part in the experiment, 15 males and 15 females. Also, half of the observers were science and engineering students and, the other half art and design students.

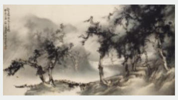
	Oriental painting	Water color	Oil painting
Indoor scene	 Artist's Mother at Fifty 1959 by LIANG Shiow-Chung	 Portrait of Miss Sun 1952 by LI Che-Fan	 Still Life 1988 by KOO Chung-Kuang
Outdoor scene	 Lonely Boat 1984 by OU Haonian	 East Gate 1981 by LI Che-Fan	 Street Scene on a Summer Day 1927 by CHEN Cheng-Po

Figure 1. Test paintings (in part) using in this study (collected by Taipei Fine Arts Museum)

With Telelumen multispectral lighting system, 16-narrow band LEDs, was used in the light replicator to simulate 15 sets of the SPD of CIE light reference sources, including the CCTs at 2700K, 3500K, 4000K, 5000K, 6500K, and illumination levels at 50 lx, 150 lx, 300 lx for each CCT. A Konica Minolta CL-200A illuminance meter was used for the experiment. In the visual assessment, each observer scaled each painting using 11 perception attributes via a categorical judgment method. They are presented in word pairs including colorful/dull, bright/dark, clear/blur, warm/cold, relax/tense, soft/hard, pleasant/unpleasant, natural/unnatural, active/passive, comfortable/uncomfortable, modern/classical. These were chosen to typically describe the visual perception to view fine art paintings.

Each observer was asked to sit in front of a lighting cabinet. For each experimental condition, the observers were asked to rate the paintings using a 6-categoy scales in Chinese word. The sequence of 20 experimental conditions was randomised.

3. RESULTS AND DISCUSSION

The aim of the study was to investigate visual impression of paintings induced by lighting conditions, i.e. to investigate the variables of gender, illuminance level and CCT to have an impact on visual perception and these variables interacted with each other, the analysis of variance (ANOVA) were conducted. As shown in Table 1, there are significant interactions between illuminance and CCTs. According to the experimental data preferred by the art and design students is 5000K at 300 lx, and the science and engineering students is 4000K at 300 lx. Male preference is 4000K at 300lx, and female prefers 5000K at 300lx. All observer groups prefer the highest illuminance level (300 lx) with CCTs ranged from 4000K to 5000K.

Table 1 (left) 3-way ANOVA for visual impressions of the experimental light induced by CCT, Illuminance, Painting, Gender and Specialty. (right) Component loadings for the 11 semantic scales.

Item	F-value	p-value
CCT	27.780	***.000***
Illuminance	655.829	***.000***
Painting	16.796	***.000***
CCT * Illuminance	7.183	***.000***
CCT * Gender	3.127	***.002***
Illuminance * Painting	3.458	***.000***
Painting * Gender * Specialty	3.373	***.005***

Item	Visibility	Warm
Pleasant	**.980**	.174
Comfortable	**.973**	.165
Colorful	**.967**	.222
Bright	**.949**	-.241
Clear	**.925**	-.359
Natural	**.895**	.373
Active	**.841**	.514
Relax	**.712**	.676
Soft	.115	**.992**
Classical	.234	**.968**
Warm	.301	**.935**

In addition, Principal Component Analysis (PCA) was also used to classify the 20 experimental conditions and create a semantic map where the interrelationships between these experimental conditions are revealed. It was found that all 11 perceptions are divided into two components: "visibility" and "warmth". The detailed results are given in Table 2 and Figure 2. The two principal components, accounting for 97.5% of the total variance. The "warmth" factor was found to correlate closely with classical/modern, soft/hard, and warm/cool. Meanwhile, the "visibility" was highly correlated with pleasant, natural, active, comfortable, colorful, bright, clear and relax. In Figure 2, the three perceptions in relation to warmth are most deviate from bright and clear perceptions. This implies that these are highly associated with physical parameters of CCT and illumination levels, respectively.

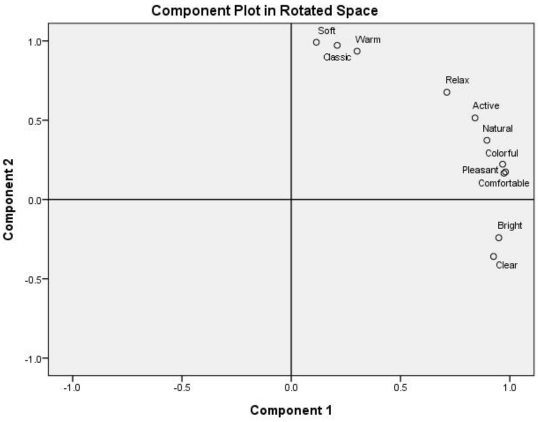


Figure 2. The component plot for the 11 semantic scales.

4. CONCLUSIONS

This study is aimed to investigate the impact of lighting conditions on the visual impression of a simulated museum exhibition environment. The ANOVA results show that the higher illuminance level, the more pleasant observer will be. The results can be recommended for the museum fine art exhibition when white LEDs are introduced. In addition to the low-power characteristics, and capability to control the color temperature and illumination properties to achieve visual aesthetic, comfort and pleasure.

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A Study on the Usage of Both White LEDs and Daylight in Art Galleries

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ABSTRACT

LED lighting systems have been recently introduced in the field of museum displays. Their controllability of colour and intensity have great advantages in using them together with daylighting, which varies from moment to moment. However, there is not enough information available to know what is the acceptable range of the balance between LEDs and daylighting. In this study we focuses on white LEDs using phosphors stimulated by violet LEDs (CCS Inc. "Natural Light LED") which emit light with better spectral distribution and are higher at colour rendering. The appropriate balance between white LEDs and daylighting to obtain the good appearance of artworks has been examined.

1. INTRODUCTION

The exhibition space in museum can be more attractive by adopting daylight. However, dealing with daylight in museum lighting environment that should be tightly controlled is not an easy task. Light-induced damages to exhibits and the effect to visibility under the daylighting conditions which vary from moment to moment have to be due considered. LED lighting has been expected as one of the next generation exhibition lightings for its ease of intensity and color modulating. The combination of daylight and LEDs may allow exquisite controls in museum lightings. In this study we focuses on white LEDs using phosphors stimulated by violet LEDs (CCS Inc. "Natural Light LED") which emit light with better spectral distribution and are higher at colour rendering. The appropriate balance between white LEDs and daylighting to obtain the good appearance of artworks has been examined.

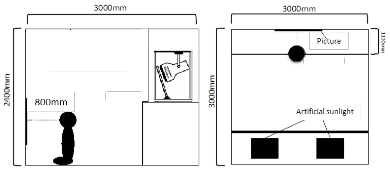
2. METHOD

Firstly, the appearance under both natural daylight and artificial sunlight (SERIC Ltd.) has been compared (Experiment 1) to examine whether this artificial sunlight can be used as a substitute for natural daylight in the following experiment. Secondly, the appropriate balance for art appreciation in museums is examined using both white LEDs and artificial sunlight at the same time (Experiment 2). All experiments have been done in a mockup model, and oil painting copies were used for the subjective evaluation.

2.1 Experiment 1

The purpose of this experiment is to compare the appearance of paintings under both natural daylight and artificial sunlight (SOLAX-2000: SERIC Ltd). This artificial sunlight is using a xenon lamp and exhibits smooth curves of spectral distribution like natural daylight.

Figures 1 and 2 show the floor plan (right) and section (left) of the mock-up room for the experiment using natural daylight and artificial sunlight respectively. The floor, ceiling and walls of the rooms are painted with a matt neutral grey paint of which reflectance value is 0.6. As to the lighting conditions of natural daylight, colour temperature levels are 6500 and 10000K, and illuminance on the paintings are set to be 50 and 200 lux. As to the artificial sunlight, correlated color temperature levels are 2700, 6500 and 10000K, and illuminance on the paintings are set to be 50, 100 and 200lux. Figure 2 shows the spectral power distribution of natural daylight and artificial sunlight at 5000K.



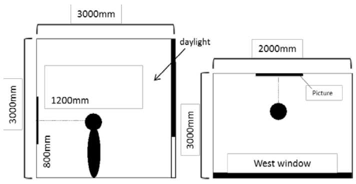


Figure 1: Mock-up room: Natural daylight. *Figure 2: Mock-up room: Artificial sunlight.*

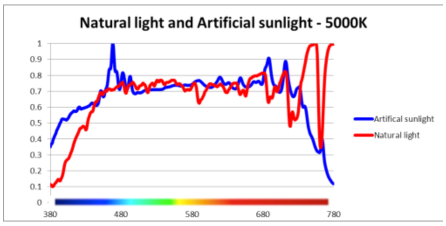


Figure 3: Spectral power distribution of natural daylight and artificial sunlight.

Two copies of oil paintings are used for the subjective evaluation (see Figure 4). The size is 530 mm wide × 455 mm high. Picture A is "*Madonna of the Meadow"* written by Giovanni Bellini and picture B is "*Squares with Concentric Circles*" written by Wassily Kandinsky. The subjects, 10 for each condition, are architectural students aged around 20. Subjects are asked to evaluate each of the paintings after one minute adaptation to every lighting condition. For the evaluations of the painting nine scales are used (see Table 1).

Table 1: Scales for the evaluation.

	Scales
1	colorful − drab
2	easy detail discrimination − difficult detail clarity
3	too much light on the painting
4	exhilarating − dressing
5	moist − dry
6	feel depth − flat
7	preferable − unpreferable
8	warm − cool
9	natural − unnatural

Figure 4: Picture A (left) and Picture B (right).

2.2 Experiment 2

Figure 5 shows the floor plan (right) and section (left) of the mock-up room for the experiment. The floor, ceiling and walls of the rooms are painted with a matt neutral grey paint of which reflectance value is 0.6. As to the lighting conditions of artificial sunlight, correlated colour temperature levels are 2700, 5000 and 10000K. As to the white LEDs, correlated colour temperature levels are 2700, 4000, 5000 and 10000K. Illuminance on the paintings is set to be 200lux, and the ratio of illuminance by white LEDs to illuminance by artificial sunlight is controlled for 0.25, 0.5 and 0.75. Table 2 shows the colour temperature and CRI Ra of each lighting conditions. CRI Ra values of the total light with 10000K CCT are less than other lighting conditions, therefore, the evaluation of the appearances under 10000K CCT will be excluded in the following analysis. Figure 7 shows an example of luminance distribution on the wall.

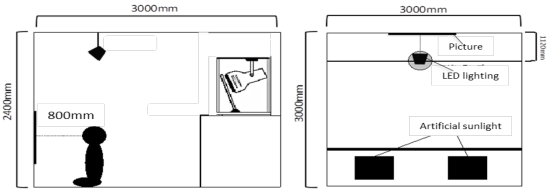


Figure 5: Mock-up room.

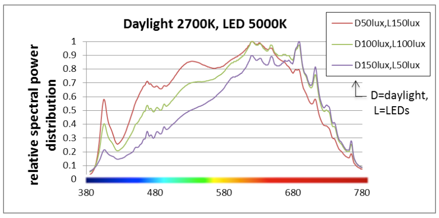


Figure 6: Example of spectral power distribution.

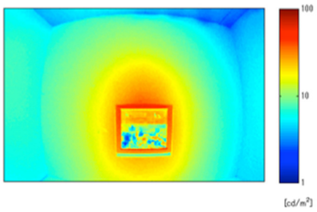


Figure 7: Example of luminance distribution.

Figure 8: picture C (left) and D (right).

Table 2: Example of lighting conditions with Ra level.

Daylight [CCT, Painting Illuminance]	LED [CCT, Painting Illuminance]	Total [CCT]	Ra	Daylight [CCT, Painting Illuminance]	LED [CCT, Painting Illuminance]	Total [CCT]	Ra
2700K, 50lux	2700K, 150lux	2700K	98	10000K, 50lux	5000K, 150lux	5600K	97
2700K,100lux	2700K,100lux	2700K	98	10000K, 100lux	5000K, 100lux	6700K	95
2700K,150lux	2700K,50lux	2700K	98	10000K, 150lux	5000K, 50lux	7900K	93

Two copies of oil paintings are used for the subjective evaluation (See Figure 8). Picture C is *"Jardin à Sainte-Adresse"* written by Claude Monet and picture D is "*Gabrielle with Jean Renoir and a girl*" written by Pierre-Auguste Renoir. The subjects, 10 for each condition, are architectural students aged around 20. For the evaluations of the paintings nine scales are also used in this experiment.

3. RESULTS AND DISCUSSION

3.1 Experiment 1

Figure 9 shows the average values of the evaluations as to 'preference', 'too much light on the painting' and 'colourfulness'. The appearances under natural daylight and artificial sunlight are almost the same; therefore, it is reasonable to assume that this artificial sunlight may be used as a substitute for natural daylight in the following experiment.

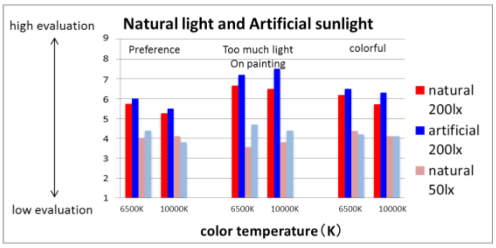


Figure 9: Appearances under natural daylight and artificial sunlight.

3.2 Experiment 2

Figure 10 shows the relationship of colour temperature of the total light to preference of the appearances (Left: Painting C, Right: Painting D). Figure 11 shows the relation of the absolute value of Mired difference between LEDs and sunlight to preference of the appearances (Left: Painting C, Right: Painting D). The results of the evaluation are a bit different between two paintings, but in both paintings the evaluations of the preference have a peak at about 3500~4000K. As to the Mired differences, there is a tendency that the paintings preference increases until the absolute value of mired differences reaches approximately 100: above this value the tendencies are different between the two paintings. Therefore in the usage of both spotlight and daylight, these results indicate that colour temperature around 3500 to 4000K is preferable, but at the same time, observers prefer the slight differences of colour temperature between daylight and LED spotlights.

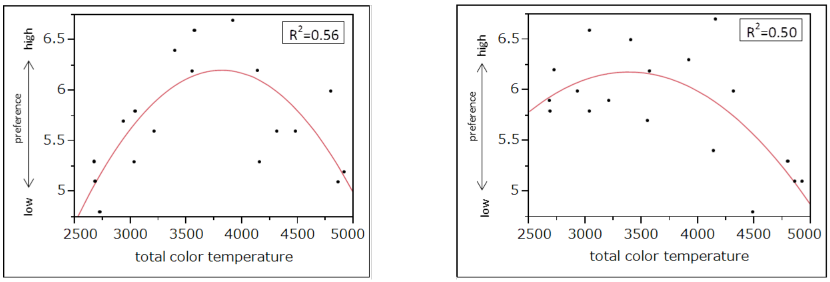


Figure 10: The relation of colour temperature of the composite light to preference (left: Painting C, right: Painting D).

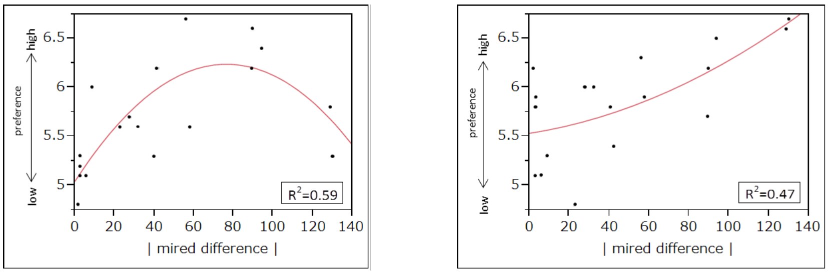


Figure 11: The relation of absolute value of Mired difference to preference (left: Painting C, right: Painting D).

4. CONCLUSIONS

The results are as follows: 1. As to the composite light of daylight and LED spotlight, colour temperature around 3500 to 4000K is preferable. 2. There is a tendency that observers prefer the slight differences of colour temperature between daylight and LED spotlights.

In this experiment, the daylight conditions around 3500-4000K were not examined, therefore, continuous surveys are necessary to make sure whether differences of colour temperature between daylight and LED spotlights are necessary for preferable appearances when the colour temperature of daylight is around 3500-4000K.

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A Study on the Impact of Spectral Characteristics of Filters on Multispectral Image Acquisition

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ABSTRACT

In every aspect, filter design plays an important role in an image acquisition system based on a single image sensor and a colour filter array (CFA) mounted onto the sensor. Complementary CFAs are used by some colour cameras in the interest of higher sensitivity, which motivated us to employ filters of wide pass bands in the effort to adapt CFA for multispectral image acquisition. In this context, filter design has an effect on the accuracy of spectrum reconstruction in addition to other aspects. The results show that wider bandwiths in general result in more faithful spectrum reconstruction and higher signal-to-noise performance.

1. INTRODUCTION

The success gained by colour filter array (CFA) based single-sensor colour imaging systems has awakened particular interest from the academia and the industries in extending the colour filter array into multispectral domain by integrating more than three types of filters into one filter array, which results in a multispectral filter array (MSFA).

In general, development of a MSFA based multispectral imaging system involves filter design, mosaic tessellation and demosaicking. Spectral characteristics of filters make a direct impact on spectrum reconstruction from the multispectral sensor response. Further filters of wider bandwidth may reduce the incoming radiant power absorbed and reflected by the filters thus boosting the sensitvitity and improving the efficiency of energy use. In addition, it may also increase the spectral overlap between filters hence increasing the correlation between channels and offering benefits to modern demosaicking algorithms taking advantage of inter-channel correlation. Following our previous research (Wang *et al.* 2013), we focus in this work on the impact of spectral characteristics of filters on the accuracy of spectrum reconstruction in the context of a multispectral image acquisition system.

The following parts of the article begins by an introducion of filter design in Section 2 followed by a description of three spectrum reconstruction methods in Section 3. Section 4 explains the procedures and conditions of the experiments, and demonstrate the results, which leads to the conclusions drawn in Section 5.

2. DESIGN OF FILTERS

The most common CFA design is known as Bayer filter mosaic (Bayer 1976). Since then the pattern has been employed in its original state, and a spectrum of modified arrangements have been proposed. Among the derivatives of Bayer mosaic, some possess complementary colour filters in comparison to the primary colour filters utilised in the original patent, in the interest of higher sensitivity (Parulski 1985). Further, two distinct types of filter design, namely narrow-band and broad-band, are commonly seen in the multispectral capture (Imai *et al.* 2000). The spectral transmittances of the filter mosaic exert direct influence on the responsivity of an imaging system which in turn has an effect on system sensitivity, signal-to-noise performance as well as accuracy of spectral reconstruction.

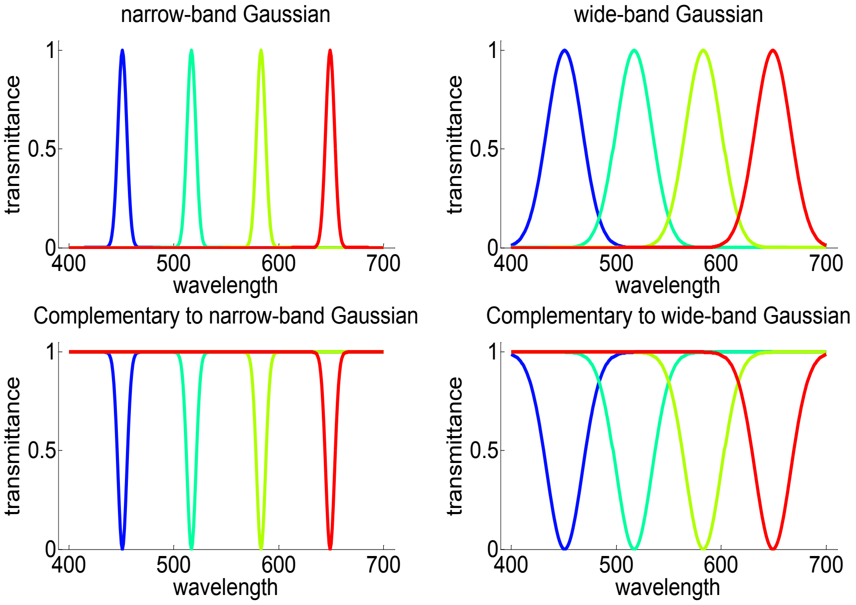

Figure 1: An example of filter design.

Inspired by the aforementioned facts, we chose four types of bandwidths. Figure 1 illustrates an example set of filters designed for a four-band multispectral acquisition system. The two graphs in the upper row show narrow-band and broad-band transmittances with FWHM (Full Width at half maximum) of 10 nm and 40nm respectively. The two graphs in the lower row present filter sets complementary to the corresponding sets in the upper row.

3. SPECTRUM RECONSTRUCTION FROM MULTISPECTRAL MEASUREMENTS

Spectrum reconstruction is an inverse problem aimed at an estimation of spectra of high dimension from the corresponding multispectral measurements of lower dimension. In concrete terms, a multispectral capture process can be described in a linear form as

$$\mathbf{R=QS}, \qquad (1)$$

where refers to the multispectral responses of dimension , correspondes to system responsivities of dimension , and is the incoming spectra of dimension , is the number of spectral bands captured by the system, is number of spectral components of incident spectra, and is the number of spectra.

Spectrum reconstruction aims at an estimation of from . (1) is solvable if is known and invertible, however it is not true in the case of spectrum reconstruction. Nevertheless it can be estimated by means of training where a collection of training spectra and corresponding responses are utilised to derive an approximation of . Three representative methods based on different principles were experimented with to this end.

The method of linear least squares attempts to solve (1) by means of pseudoinverse which leads to (2).

$$\mathbf{S}' = \mathbf{S}_t\mathbf{R}_t^{+}\mathbf{R} \ , \tag{2}$$

,

where is an estimation of and is a right pseudoinverse of :

Imai and Berns (1999) propose to employ PCA (principal component analysis) to anlyse the training spectra, which gives rise to (3)

$$\mathbf{S}^{'} = \mathbf{W}(\mathbf{S}_t^T\mathbf{W})^T\mathbf{R}_t^{+}\mathbf{R}, \tag{3}$$

where is of dimension consisting of *m* most significant eigenvectors of the training spectra by means of PCA. The parameter *m* is determined so that the RMSE (root mean square error) between and is minimised.

Wiener estimation is yet another method taking noise into consideration in the following manner,

$$\mathbf{S}^{'} = \mathbf{S}_t\boldsymbol{S}_t^T\mathbf{Q}^T(\mathbf{Q}\mathbf{S}_t\mathbf{S}_t^{'}\mathbf{Q}^T + \mathbf{N})^{-1}\mathbf{R}, \tag{4}$$

where N is a term reflecting additive noise intrinsic to the system in form of $\sigma^2\mathbf{I}$ with σ^2 being the variance of noise and being the identity matrix.

4. EXPERIMENTAL SETUP AND RESULTS

48 hyperspectral image sets were used in this study. 16 of them are from Foster *et al.* (2006) consists of a mixture of rural scenes, and another 32 are from the CAVE project (Yasuma *et al.* 2008) including a wide variety of real-world materials and objects and artificial replicas. For the ease of processing and comparison, all images were interpolated to cover the range between 400 nm and 700 nm with an interval of 1 nm. The number of filters studied ranges from 3 to 9. A framework that simulates the key elements of a multispectral imaging system was built as a testbed. Images were rendered with the illuminant of CIE D65. Evaluation of the performance was carried out by means of the avaerage RMSE evaluated from normalised spectra. The amplitude of noise was determined so that the maximum SNR achieved by a perfect diffuser is 50 dB and the variance is 20% of the level of noise.

The results obtained with the three methods illustrate similar tendencies, therefore results obtained with method 1 is shown only in Figure 2. Clearly the complementary filter sets outperform the primary filter sets. Filters complementary to the narrow-band primary filter set possess wider pass band than their wide-band counterparts. Nevertheless the inverse relationship between the performance and the bandwidths seems not entirely true, as indicated by the dotted line and the dash-dotted line.

5. CONCLUSIONS

We tested the performance of three spectrum construction methods with four types of filter designs. It verifies our hypotheses that filters of wider pass bands benefit multispectral acquisition in terms of higher accuracy as well as higher SNRs especially in low light conditions. The results merit closer examination and further theoretical analyses. And preliminary experiments have shown that wider filter bandwidths increases degree of overlap between filters therefore increasing the inter-channel correlation on which modern demosaicking algorithms rely.

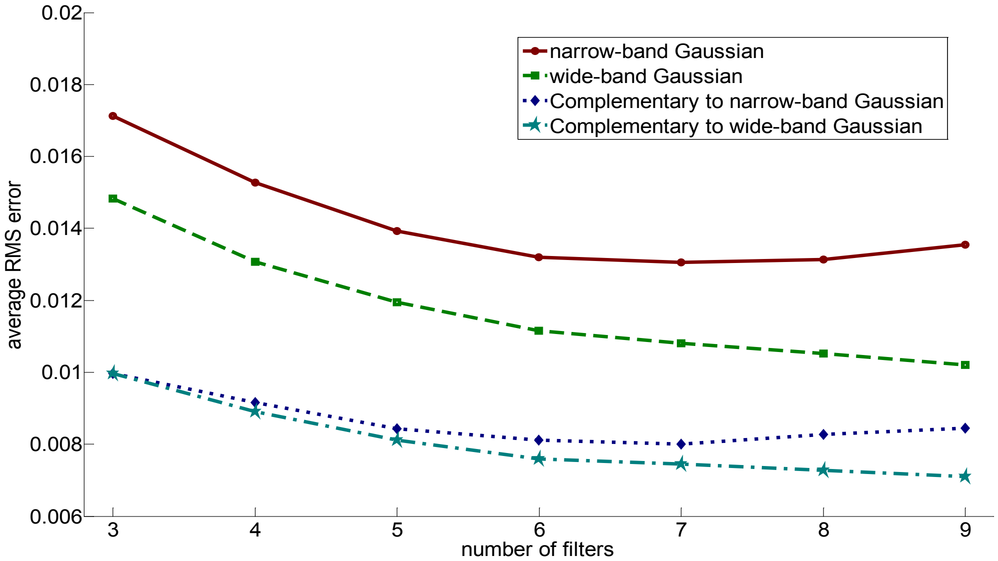

Figure 2: Results obtained with Least Squares Method.

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Texture Effect on Color Difference Evaluation by Spectrophotometric and Multi-spectral Imaging Measurement

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ABSTRACT

One of the most important parameters which influence the color appearance of a textile fabric is its surface texture. The texture effect has significant impact on color quality control. The influence of surface texture of fabric samples on color differences measured by a spectrophotometer and a multi-spectral digital imaging color measurement system was investigated in this paper. 105 physical textile samples were knitted with 21 texture structures distributed in 5 different color centers. The CMC color difference between the jersey sample set as the standard and 20 other texture samples was evaluated by using spectrophotometer and imaging system. The texture level was represented by the histogram, which indicated that an increasing of complexity of the texture would cause an increase in imaging color difference. The results revealed that the average color difference value obtained from imaging system was consistently higher than that from spectrophotometer by 0.2 CMC (2:1) units. This effect is dependent on the color centers and type of texture structures of the samples.

1. INTRODUCTION

The parametric effect of texture on color differences has been investigated by simulated textures generated on CRT displays such as those published previously by Xin et al. (2005), Xu et al. (2002) and Montag and Berns (1999). Some other studies including Shao et al. (2006), Kandi et al. (2008) and Kandi (2011) have been published in which the influence of texture on color differences was done through the measurements by spectrophotometer. However, a systematic approach for analyzing the texture effect of textile samples has not been thoroughly studied. In this study, an in-house developed multi-spectral digital imaging color measurement system, namely ICM, was used to measure the colors of texture samples. The spectrophotometer and ICM results for texture color samples were examined using CMC color difference formula in terms of color difference, lightness, chroma and hue differences.

2. EXPERIMENT

2.1 Textured Sample Preparation

105 physical textile samples were knitted by a Shima Seiki Knitting Machine with 5 color centers including grey, red, yellow, green and blue. Each color yarn was knitted with one single jersey, defined as the standard sample and 20 different textures widely used in knitwear as shown in Figure 1. The CIELAB values of the standard sample of each color center under the D65 illuminant and the 1964 standard colorimetric observer are given in Table 1.

Table 1. The CIELAB values of the five color centers. For each color, the first row was measured by CE7000A and the second one by ICM.

Color	L*	a*	b*	C*	h
Grey	59.180	0.560	1.217	1.340	65.278
	56.530	0.600	1.190	1.330	63.320
Red	42.233	36.032	22.744	42.610	32.261
	39.560	35.810	23.220	42.680	32.960
Yellow	83.759	-5.438	47.571	47.881	96.522
	81.680	-5.280	48.540	48.820	96.210
Green	53.554	-32.332	-0.696	32.340	181.233
	50.710	-32.540	-1.160	32.560	182.040
Blue	33.764	4.116	-28.959	29.250	278.090
	30.880	3.970	-28.780	29.060	277.860

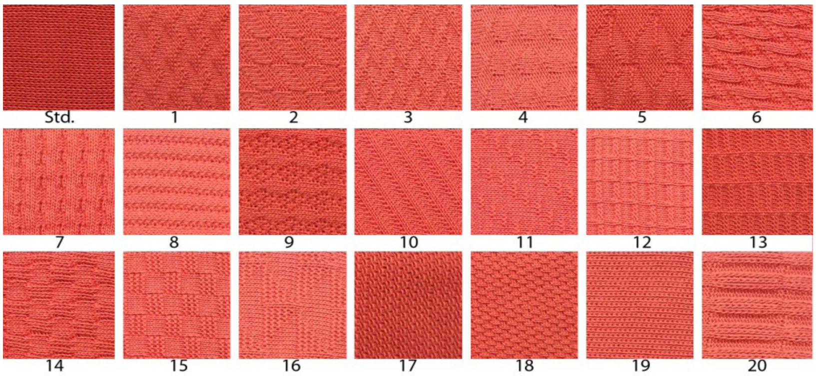

Figure 1: The standard sample and 20 differently knitted texture structures.

2.2 Instrumental Color Measurement by Spectrophotometer and Imaging System

In spectrophotometric approach, the colors of the texture samples were measured using Gretag Macbeth CE7000A spectrophotometer in SCI mode with D/8 geometry. In imaging approach, the images of the samples were captured by an in-house developed multi-spectral imaging system using a high-grade digital monochrome CCD camera and 16 narrow band filters from 400 to 700 nm with 20 nm interval. The measured color of the sample is computed by averaging each pixel of the image. The instrumental color differences between the standard sample and other texture samples are analyzed and the effects of surface texture on color measurement are evaluated.

3. RESULTS AND DISCUSSION

3.1 Texture Effect on Spectrophotometric and Imaging Color Difference Evaluation

The histogram of texture images in the L channel for the minimum and maximum ΔE measured by ICM at five color centers compared with their respective standard samples are presented in Figure 2. It is shown that the shape of the histograms varies with different texture structures in which texture pairs with the lowest and highest color differences appear the narrowest and widest respectively. It indicates that an increasing of complexity of the texture would cause an increase in imaging color difference. Therefore, the structural difference played an important role in color difference measurement.

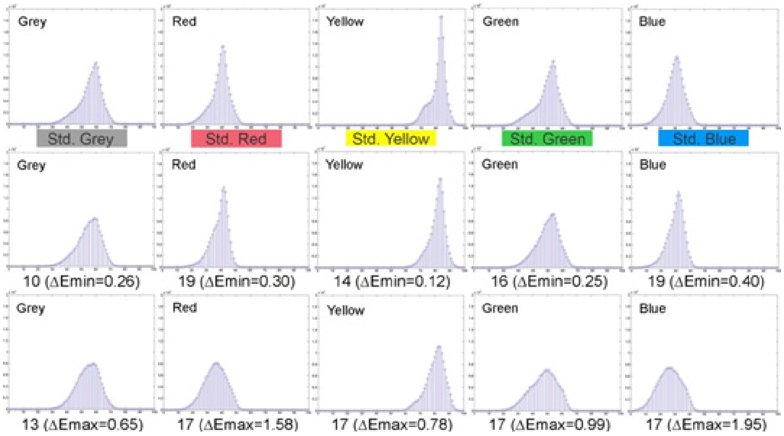

Figure 2: Histograms of texture images in the L channel on the five color centers.

The results of the color difference, lightness, chroma and hue differences between the standard and 20 texture samples measured by CE7000A and ICM are illustrated in Figure 3. It is clearly seen from Figure 3 that the contours of the two plots are similar except that the area plotted by ICM is larger than that of CE7000A. Blue texture pairs for CE7000A and ICM evaluation exhibit the highest color differences of 1.32 and 1.95 CMC (2:1) units at Texture No.17 respectively. In contrast, grey and yellow texture pairs for CE7000A and ICM evaluation show the lowest color differences of 0.093 and 0.12 CMC (2:1) units at Texture No.10 and 14 respectively. Due to inter-reflection within physical texture samples, color has an impact on color difference measurement of texture samples in which bright color (i.e. yellow) shows weaker texture effect than that of dark color (i.e. blue). It also reveals that the average color difference of imaging system is consistently higher than that of spectrophotometer by 0.2 CMC (2:1) units. This is largely due to the averaging effect of the spectrophotometer over a given aperture area. Furthermore, a multispectral imaging system captures both color information and spatial information at each pixel location. Hence, ICM evaluation implies a higher degree of parametric texture effect.

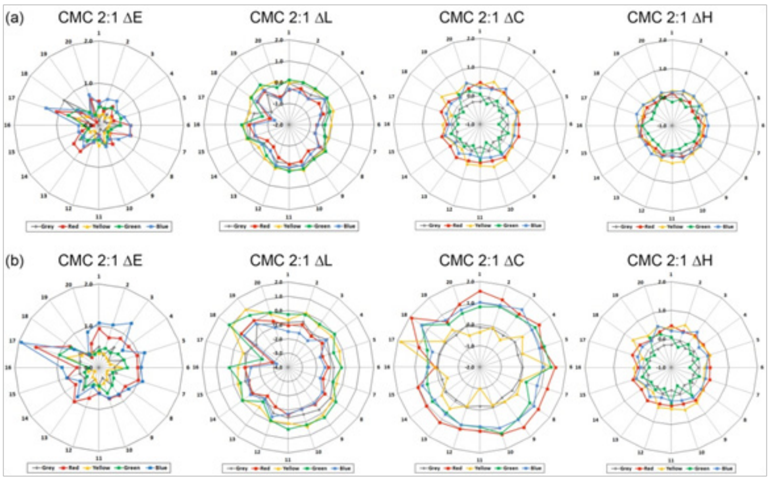

Figure 3: The CMC 2:1 color difference, lightness difference, chroma difference and hue difference distributions for the 20 different texture samples compared with jersey sample at five color centers measured by (a) CE7000A spectrophotometer and (b) ICM system.

Figure 3 apparently shows that color differences measured by CE7000A and ICM are contributed not only by lightness but also chroma and hue differences. In comparison with the standard sample, majority of texture samples appear darker and more saturated with relatively insignificant hue change. This result demonstrates that the influence of texture on color difference evaluation depends on the color center and texture structure of the sample.

4. CONCLUSIONS

In this study, the parametric effect of surface texture has been investigated viz. spectrophotometric and imaging measurement. It was found that blue center induced the highest color difference while grey and yellow centers induced the lowest color difference. It is evident that texture has a significant impact on lightness, chroma and hue attributes. Histogram analysis indicated that imaging color difference increased when the texture increased in complexity. Therefore, the results from different measuring methods depend greatly on the structures of the samples in which the multispectral one indicates a higher parametric effect of texture than that of the sphere-type spectrophotometer.

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An Estimation Method of Spectral Reflectance from a Multi-band Image using Genetic Programming

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ABSTRACT

The measurement of spectral reflectance conducted using a multi-band cameras are implemented in estimations from several images, which are captured through multiple filters. Therefore, the measurement of a spectral video using multi-band cameras is difficult. To resolve these, we propose a multi-band camera system that uses a special optical element in real time. We also present a method for estimating the spectral distribution from a 12-band image captured using the multi-band camera system. The reconstruction of spectral distribution curves is an inverse problem, one in which even a tiny variation in the input data completely distorts the expected results. Thus, a robust reconstruction operator is required. As a result, many learning-based algorithms have been proposed. In this paper, we present a robust method that utilizes cartesian genetic programming (CGP). CGP is one of the representations using a graph based genetic programming (GP). The proposed method achieves the construction of unknown functions that convert the 12-band sensor values into spectral distribution based upon CGP. The proposed method is then applied to 24 colors of a color chart image, and spectral distributions are obtained. The accuracies of the proposed method are confirmed by comparing the results with conventional methods.

1. INTRODUCTION

In this paper, we present a method for estimating the spectral distribution from a 12-band image captured using a single-shot 12-band camera system. Spectral reflectance is an important property of an object. Therefore, it is important to calculate the spectral reflectance in color reproductions and higher-order representations of a visual system. Many studies have been conducted on spectral-based color reproduction systems that require a method of estimating spectral reflectance. Previous studies have shown that the color reproduction of natural reflecting objects is realized by using six to ten bands with high accuracy (Yamaguchi *et al.* 2002; Uchiyama *et al.* 2004). Wiener estimation, multiple regression analysis, and principal component analysis, etc. methods have proposed as linear conversion from low dimensional images to spectral reflectance (Vrhel and Trussell 1992; Tsumura *et al.* 1999). Genetic algorithms (GA) is exploited to achieve spectral estimation by select a linear combination of a small number of basis functions (Schettini and Zuffi 2007).

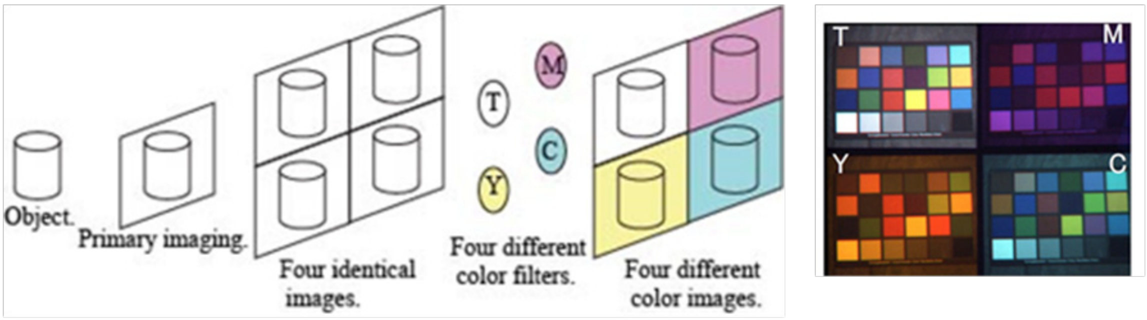
The proposed estimating method is based upon cartesian genetic programming (CGP). Genetic programming (GP) is a programming model that uses a biological evolution model to handle a complex problem (Koza 1992). GP evolves computer programs, which are usually tree structure, and searches a desired program using GA. GP techniques have been applied to the automatic construction of information-processing algorithms (Koza 1992). They have also often been applied to function-identification problems. Conversely, a graph can adequately describe various programs to simple structure. One of the representations using a graph based GP is CGP. CGP was developed from a representation that was used for the evolution of digital circuits and represents a program as a graph (Miller and Thomson 2000).

2. METHOD

The proposed method achieves the construction of unknown functions that convert the 12-band sensor values into spectral distribution that consists of 81 values at 5 nm intervals from 380 nm to 780 nm based upon CGP.

2.1 Multi-band camera system

We propose a multi-band camera system that uses a special optical element in real time. A single-shot 12-band camera system is realized by using a color camera, four different color filters, and an optical element. Figure 1 shows the structure of the multi-band camera system and an example of captured images. First, the optical element divides an input image into four identical images. Second, four color filters which are cyan, magenta, yellow, and transparence transform each image. Then, integrated combination of four different color images is captured as an image. Finally, 12-band sensor values are obtained from the combined image at the same time.



(a) The structure of the camera system. *(b) A captured image.*

Figure 1: The multi-band camera system.

2.2 Cartesian genetic programming

The proposed method adopts CGP to an evolutionary method. CGP uses genotype-phenotype mapping that the feed-forward network structure is encoded in the form of a linear string. This string is mapped into phenotype of an index graph. The genotype is a fixed length representation and consists of a string that encodes the node functional ID and connections of each node in the network. However, the number of nodes in the phenotype can vary in a restricted manner, as not all the nodes encoded in the genotype have to be connected. This allows the existence of inactive nodes.

2.3 Settings of construction method

We apply CGP to the problem of automatic construct functions that convert the 12-band sensor values into 81 values of spectral distribution.

We prepare simple arithmetic operators as the functions of the nodes, e.g., four arithmetic operations, mean, exponential, power, square root, threshold function, piecewise linear function, sigmoid function, absolute value, constant value, and so on. The proposed method is expected to construct a complex conversion function using a combination of these nodes.

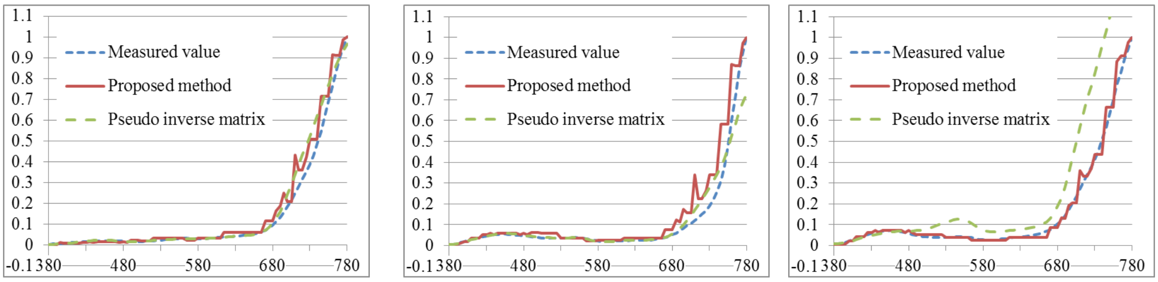
The fitness function of CGP is described as follows:

$$F = -\sum_{0}^{n}\sum_{0}^{81}|V_o - V_t| \qquad (1)$$

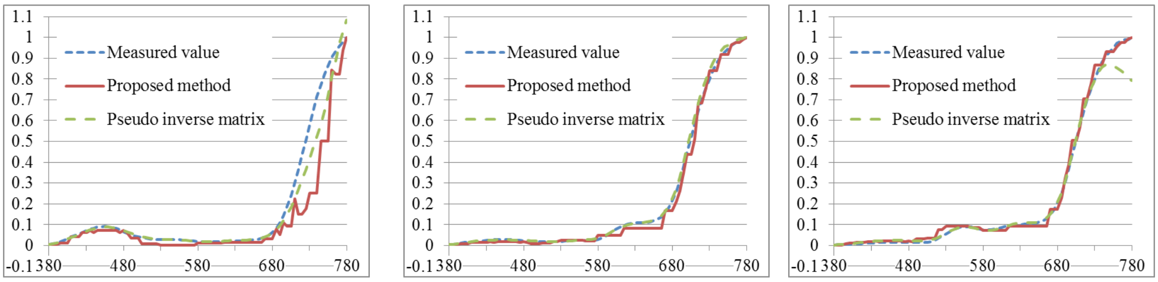
where Vo is the output value, Vt is the training data, and n is the number of training data. The higher the numerical value indicates better performance.

Table 1. Mean squared errors of the experiment.

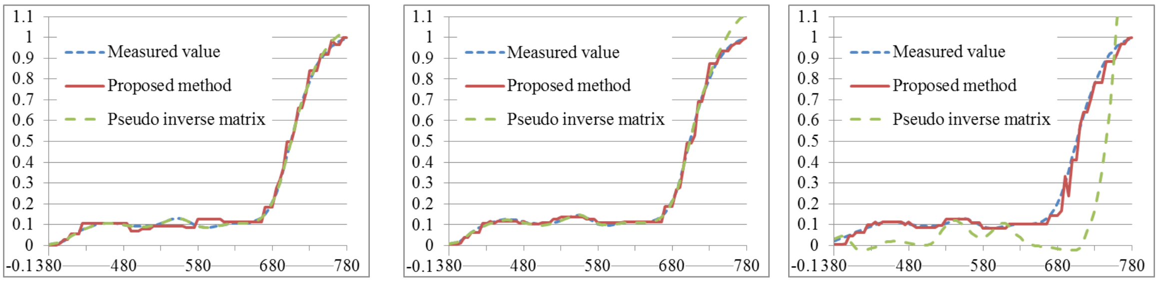
	Proposed method	Pseudo inverse matrix
Average	1.60E-03	6.94E-03
Maximum	1.38E-02	6.54E-02
Minimum	3.02E-04	7.42E-05



(a) No.1 Dark Skin. *(b) No.3 Blue Sly.* *(c) No.5 Blue Flower.*



(d) No.8 Purplish Blue. *(e) No.9 Moderate Red.* *(f) No.12 Orange Yellow.*



(g) No.19 White. *(h) No.20 Neutral.* *(i) No.24 Black.*

Figure 2: The graphs of relative spectral distributions.

3. EXPERIMENT AND DISCUSSION

The training data that we used in the experiment are 24 colors from X-Rite ColorChecker that is illuminated by a 6400K halogen lamp. Additionally, the effectiveness of a method of pseudo inverse matrix and CGP are compared. Table 1 shows the mean squared errors of the experiment, and the examples of the output relative spectral distributions are shown in figure 2. The proposed method has higher accuracy on the average and the maximum. It is however worse in the minimum case that input color is Purplish Blue (#8). From the figure 2 (i), the obtained convert function is particularly effective when the necessary calculation is not linear. However, the spectral distributions that output from proposed method have many gyrations.

4. CONCLUSIONS

In this paper, we propose a method for estimating the spectral distribution from a 12-band image captured using a single-shot 12-band camera system based upon CGP. The robustness and the reliability of the proposed method has confirmed by comparing the results with a method of pseudo inverse matrix. From the experimental results, the obtained convert function is effective in estimating complicated distribution. We are, however, recognizing that the smoothness of the output should be considered when calculating the fitness function.

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Characterization of a Liquid-Crystal Tunable Filter Based Hyperspectral Camera

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ABSTRACT

The present study investigates the influence of pixel dependent spectral responsivity on colour measurements. Examplarily measurements of a white LED are shown to evaluate whether the pixel dependent spectral responsivity should be considered or not.

1. INTRODUCTION

Hyperspectral Cameras (HSCs) generally consist of an optical imaging system, some variation of an electrically tunable filter, in addition to a detector array. The tunable bandpass shaped transmission of the electrically tunable filter in conjunction with the imaging system, enables the spatially resolved reconstruction of spectra. A spectrum is sequentially sampled by varying what is referred to as nominal wavelength, which characterizes the position of the bandpass of the tunable filter. In our investigation we use a Liquid-Crystal Tunable Filter (LCTF) whose banpass shaped transmission can be displaced in 1 nm increments over the working range of the LCTF (400-720 nm). The measurement with a HSC can be modelled as a transformation of object radiance into a grey-scale value, where the transformation is described by the spectral responsivity. A sampled value of the spectrum is reconstructed as the ratio of the response of the system to the integral of spectral responsivity of a nominal wavelength of the filter, where the bounds of integration are chosen to include all wavelengths in which the integrants are not zero. Dividing the camera responses by the integral of spectral responsivitiy of a nominal wavelength can be understood as normalisation of the camera responses. The sampled value has to be assigned to a wavelength, which generally is assigned to the centroid wavelength of the nominal spectral responsivity. This is often referred to as wavelength calibration. There are different modes in which a HSC can be operated. One way is in the fashion of a scanning spectrometer where spectra are highly sampled. Every camera response of a channel corresponds to a sampled value of a spectrum. Another way is to operate the HSC as a Multispectral Camera (MSC). This is achieved by reducing the amount of channels which are used to reconstruct spectra; this is sometimes reasonable because it is time consuming to highly sample a spectrum. The low dimensional responses of the camera are used to estimate a high dimensional spectrum, utilizing a priori knowledge about the set of spectra which has to be expected in a specific application and the spectral responsivitiy of the HSC. The performance of true MSCs is usually optimized for a specific application whereas HSCs, because of their ability to highly sample spectra, can be used for a broader range of applications. The spectral responsivity is needed for all the different modes of reconstructing spectra which has been discussed above. Due to the fact that a HSC is an imaging system and the transmission of the LCTF is dependent on the incident angle, the spectral responsivity is dependent on pixel position; therefore the spectral sampling referred to each pixel would be different as well. Note that this effect is also apparent when using interference filters. The component of the HSC system which affects the dependence of spectral responsivity on pixel position the most is the focal length of the lens used. The use of a LCTF with an aperture of 20 mm restricts us, because of vignetting, to use a lens with a minimum of 50 mm focal length. In the following we consider this worst case.

2. MEASURING SPECTRAL RESPONSIVITY

To estimate the influence of pixel dependent spectral responsivitiy two approaches were used, whereas the first step of both approaches is to correct every channel for vignetting (even though this is only necessary for the second approach). The first approach is to take into account the pixel dependent spectral responsivity by measuring it for different positions on the detector array and applying those to reconstruct the spectra. The second approach is to consider the spectral responsivity to be pixel independent in spectral shape but distinct in their integral values (geometrical extend); therefore the so called vignetting has to be corrected before measuring the spectral responsivity. In the second approach we only have to measure the spectral responsivity for a region on the optical axis (OA). For estimating spectral responsivity we evaluated the so called indirect approach where the responses of the camera to a known set of spectra are determined to find a transform which allows us to predict camera responses of a channel for a huge variety of spectra. This transform is the spectral responsivitiy, if the set of spectra has a high enough effective dimension. In our case we used overall 100 filters which are placed in front of a high-power Lambertian light source. Barely half of these filters are bandpass shaped filters which have compared to a monochromator a much higher FWHM. The other half are roscolux filters with a broadband spectral transmission. This should ensure the high dimensionality of the set of spectra. To estimate the spectral responsivity, we used the Wiener-Inverse (WI) (Pratt and Mancill 1976), however instead of modelling the covariance matrix of spectral responsivity by a first-order Markov process we formed a covariance matrix by utilizing a priori knowledge about the spectral shape of the transmission of the LCTF, which is Gaussian shaped (Peralta, Pons and Campos 2010). To estimate the SNR we repeatedly compared the measured camera responses to simulated camera responses utilizing the successively estimated spectral responsivities, starting with a first estimate of the SNR. As criterion for automated SNR estimation we used the Pearson correlation coefficient (maximum). We compared the results of the indirect approach with the results obtained by the direct approach (monochromator measurements) and found both to be virtually identical, except for some side lobes in case of the indirect approach. For that reason we decided to present hereinafter only the results of the direct approach. To study the dependency of spectral responsivity on pixel position we chose the so called "near extended-source" geometry (Nicodemus and Zissis 1962).

3. DEPENDENCIES OF SPECTRAL RESPONSIVITY

We measured the spectral responsivities of 17 channels of the HSC which are almost equally spaced over the visible spectral range with a 20 nm pitch. In the following we nevertheless present only the results of the channels at 400 nm, 500 nm, 600 nm and 700 nm (Figure 1). We compare the measured spectral responsivities for three areas on the detector array; one region is at the OA and the others are located at the outer most edges of the detector array. The spectral responsivity was measured under constant ambient conditions at 25° C.

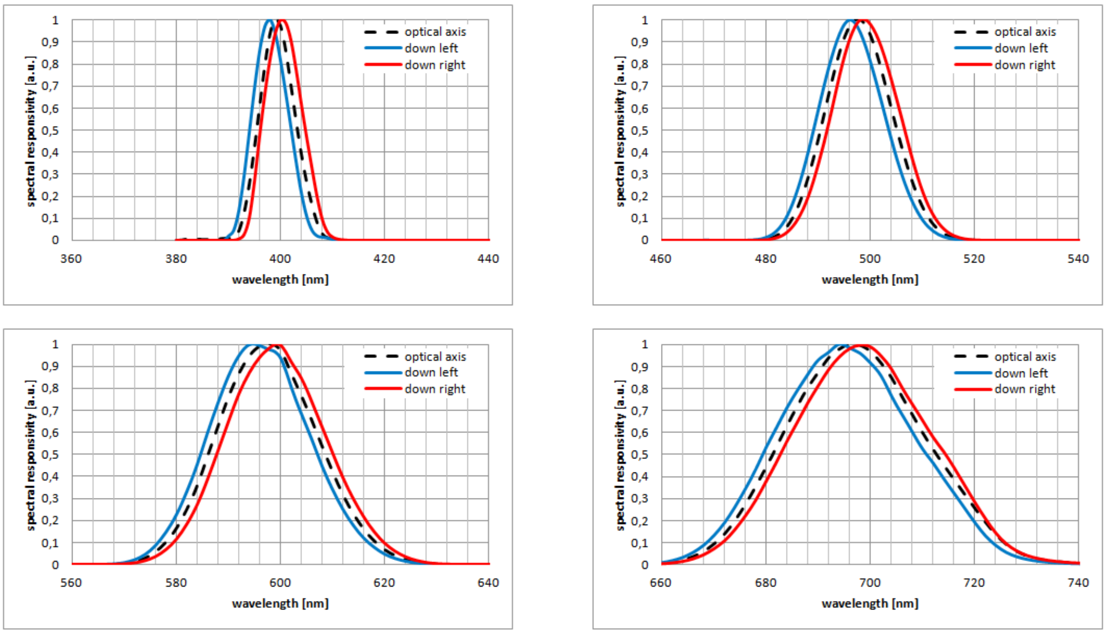

Figure 1: Spatial dependence of spectral responsivity (normalized).

4. MEASUREMENT RESULTS

To evaluate whether it is necessary to consider the pixel dependent spectral responsivity or not, we measured a white LED spectrum by using the 17 channels which have been characterized in the previous paragraph. The white LED was successively placed in the positions of the FOV of the camera which correspond to the above described positions, for which the spectral responsivity of the HSC has been estimated. We compare two approaches: one approach is to use a pixel dependent spectral responsivity and the other is to use a single spectral responsivitiy for all measurements, independently of the pixel position. To reconstruct the spectrum we compare the results of interpolating the sampled values (triangle-shaped marks in Figure 2 and 3) with a cubic spline (SI) and the results of using the WI (Figure 2 and 3). All results are compared to spectrometer measurements. Because HSCs are often used to estimate CIExy coordinates we chose the MacAdam ellipse as a criterion to decide whether the dependence of spectral responsivity on pixel position should be considered or not. If the CIExy coordinates of the HSC measurements all lay inside of the 1-step ellipse, there is no need to consider the pixel dependent spectral responsivity, because no colour difference might be recognized by a human observer (Figure 4).

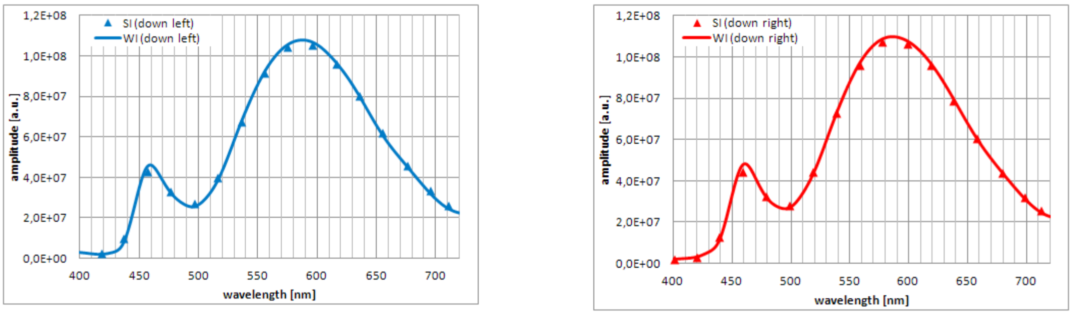

Figure 2: (left) reconstructed spectra for the down left area, (right) the down right area - considering the pixel dependent spectral responsivity.

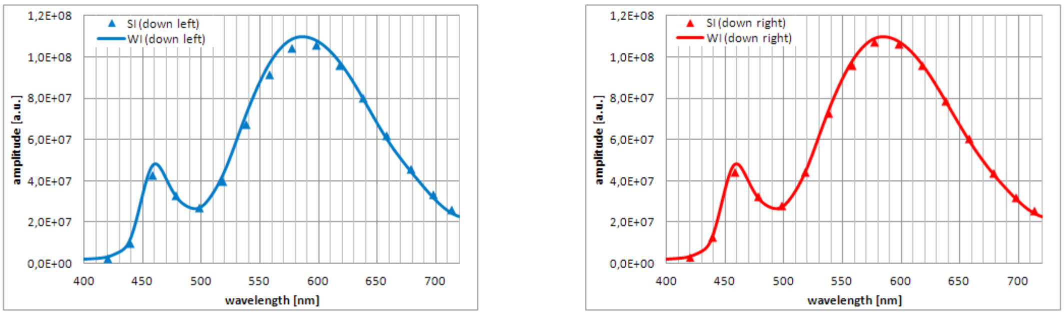

Figure 3: (left) reconstructed spectra for the down left area, (right) the down right area - neglecting the pixel dependence of spectral responsivity.

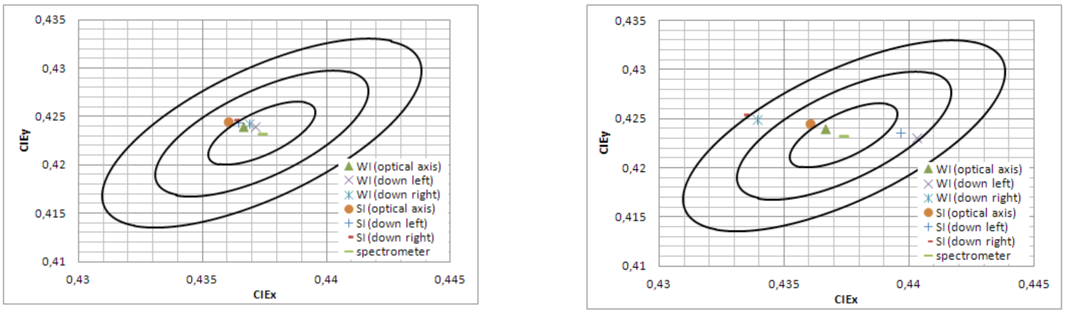

Figure 4: (left) considering the pixel dependent spectral responsivity, (right) neglecting the pixel dependence of spectral responsivity.

Because of the pixel dependent spectral responsivity (Figure 1) the samples (triangle-shaped marks) in Figure 2 are either shifted to the blue or to the red of the VIS. Neglecting this shift leads to increasing distortions in the reconstructed spectrum (Figure 3). As can be seen from Figure 4 there is a need for considering the pixel dependent spectral responsivity for reconstructing spectra for colorimetric purposes.

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Skin Feature Estimation Using a Filter-based Multispectral Imaging System

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ABSTRACT

A simple approach for estimating camera sensitivites by multiple LED illuminations is proposed first. Afterward, a filter-based multi-spectral imaging system was optimized for estimating spectral reflectances of human skin. The system perfermed well in both virtual test using ISO SOCS database and in real test with a calibrated camera.

1. INTRODUCTION

Skin appearance is very important for diagnosing pigmented skin lesions such as melanin spots, burn scars and skin cancers. It also is potentially useful to cosmetic and plastic applications. However, to measure the appearance of skin surface is a difficult task as it depends on many variables. The aim of the present study is to optimize a filter-based multi-spectral imaging system (FMSIS) for skin feature estimation. It used two RGB tri-band digital cameras with one specially designed color filter to enhance the accuracy of skin spectral reconstruction. A six-channel multispectral skin image can be taken in only one shot by using a half mirror (i.e., a beam splitter) with the two cameras. The multispectral data is further analyzed by principal component analysis (PCA). The advantages of the system are it provides a fast, low-cost, high-resolution, portable, user-friendly, non-contact and accurate skin color measurement.

2. METHOD

The present study used a PCA-based method introduced by Imai and Berns (1999) to estimate spectral reflectances of human skin. The skin spectra in ISO/TR 16066:2003 standard object color spectra database (SOCS) were used to generate the principal components (i.e., eigenvectors). The method needs corresponding camera signals of each skin color sample to generate a matrix to transfer camera signals to the corresponding eigenvalues. However, it's not possible to have real camera signals of the SOCS samples. Therefore, we need to build virtual cameras to generate the signals. To use real cameras with the matrix and eigenvectors, spectral sensitivity functions (SSF) of the real cameras must be estimated first. The first part of this paper therefore is to propose a method which uses a 16-band LED light source with a white balance card to estimate the SSF for building the virtual cameras. The second part is the spectral reconstruction of human skin based on the PCA method using the SOCS samples. A Gaussian filter was introduced to optimize the results. A real-world sample is estimated in the end of the paper for verification.

3. RESULTS AND DISCUSSION

3.1 Recovering Camera Sensitivities Using Multiple LED-Illuminations

Many methods have been proposed to recover camera spectral sensitivities using common targets (e.g., ColorChecker, IT8.7/2 etc.). Most of them regarded it as a constrained least square problem (Finlayson *et. al.*, 1998). The constraints are based on assumptions on the properties of common camera sensitivities, such as smoothness, positivity, roundedness or unimodality. Furthermore, many methods require additional parameters (weighting factors) to control the importance of these assumptions compared to the residual error (Cheung *et. al.*, 2005). As multi-spectral LED illuminations are available for color imaging in recent years, Urban (2010) used a constrained maximum-a-posteriori approach to recover the camera sensitivities using 6 different LEDs.

In this study, a Canon 5D Mark II (5D2) was used to capture an X-rite ColorChecker White Balance target under 16 different LED illuminations generated by Telelumen Light Replicator. The spectral powers of the 16-channel LEDs are shown in Figure 1(a). The camera sensitivities were commonly assumed as 2-parameter Gaussian functions. However, we found using 4-parameter Gaussian functions which have been widely used in fuzzy logic study as a membership function are slightly better in the curve estimation. We optimized the parameters (peak position and sigmoidal parameter for left and right sides of the Gaussian functions) iteratively to minimize sum of squared error between the camera RGB values and the spectral predictions. The optimal functions are shown in figure 1(b). Its color accuracy tested by the 24 colors in ColorChecker chart under 6 representative CIE standard illuminants are shown in Table 1.

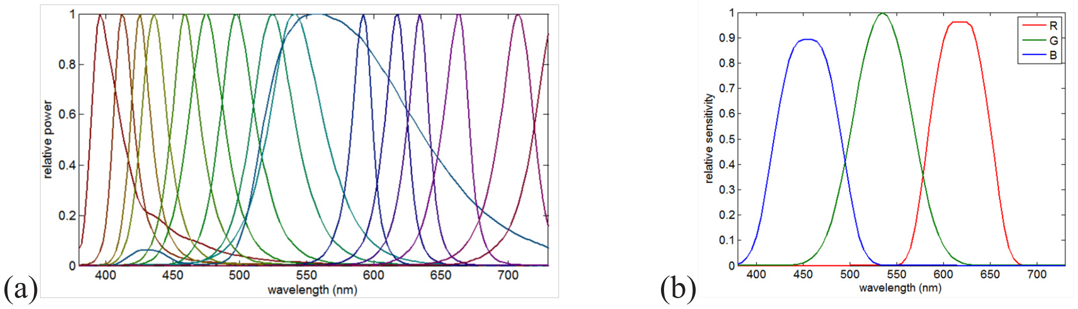

Figure 1: (a) Spectral powers of the 16-channel LEDs in the Telelumen Light Replicator. (b) 5D2 camera sensitivities estimated by the proposed method.

Table 1. Color accuracy of 2- and 4-parameter Gaussian approaches (Unit: CIEDE2000)

	mean ΔE00						max ΔE00					
Gaussian	D65	D50	A	F2	F8	F11	D65	D50	A	F2	F8	F11
2-parameter	1.19	1.15	1.13	1.25	1.47	1.18	4.27	4.84	5.09	4.17	5.96	4.30
4-parameter	1.28	1.16	1.08	1.30	1.63	1.26	3.92	4.38	4.61	3.98	5.62	3.91

3.2 Spectral Estimation of Human Skin

Figure 2 illustrates the workflow of the spectral estimation of human skin. To test the model justly, we divided the SOCS human skin spectrum data into two sets: training set (with odd index numbers) and test set (with even index numbers). Each set contains 4,285 spectral samples. In the training phase, the PCA was used to extract first n-level basis functions (v) from the training set (R), and then calculated eigenvalues (a) of each sample by a pseudo-inverse method (Imai and Berns, 1999). On the other hand, the training spectra (R) were multiplied by the spectral power of the D65 illumination (E) and the 5D2 camera sensitivity functions (derived in the previous section) to generate virtual camera responses (d). The relationship between the camera responses and the eigenvalues (a) can be described by an n-by-k linear matrix (A) which can be derived from a least-squared regression, where k represents the number of color channels for all cameras.

In the test phase, the virtual camera responses (d') were generated by the test spectra (R') multiplied by the illumination (E) and the camera sensitivity functions. The camera responses then converted to the corresponding eigenvalues (a'). The skin spectral reflectances were finally reconstructed by (v·a').

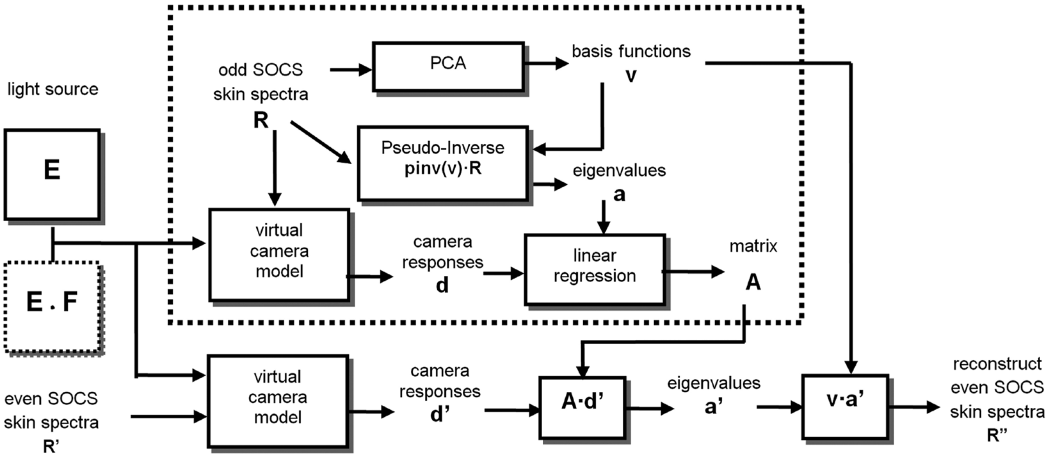

Figure 2: Workflow of the skin spectral estimation.

The spectral resolution of the test was 400 to 700nm in 10 nm intervals. In the training phase, first 6 basis functions (eigenvectors) can interpret 99.91% information from (R). Table 2 upper rows list the spectral accuracy of the test set under the 6 representative CIE standard illuminants using a signal virtual camera (i.e., k=3). RMSE(%) is the root-mean-squared-error of the skin spectral reflectances. As can be seen, the maximum errors do not reduced by increasing the number of basis functions (n). To reduce the maximum errors, second camera with a Gaussian color filter was introduced. In Figure 2 left dotted box, the incoming light spectrum of the second camera can be regarded as the spectral power of D65 illumination (E) multiplied by the spectral transparency of Gaussian color filter (F). We found the peak wavelength of the optimal Gaussian is 590 nm and the half spectral width is about 80 nm. As can be seen in the lower rows of Table 2, the maximum errors reduced sharply by introducing the second camera (i.e., k=6) with the optimal Gaussian color filter. The reason could be that the filter enhances the spectral differences around the 590 nm which is the turning point of a typical skin spectrum.

3.3 Verification

A real skin image was taken by the 5D2 (k=3) and the spectral reflectance was estimated by the above approach (with odd SOCS samples) as Figure 3. The result is acceptable and it can be further enhanced by adding one more camera with the optimal Gaussian color filter.

Table 2. The CIEDE2000 color difference and RMSE of skin spectral estimation using 3-channel (upper) and 6-channel (lower) camera responses.

		mean DE00							max DE00						
k	n	D65	D50	A	F2	F8	F11	RMSE	D65	D50	A	F2	F8	F11	RMSE
3	6	0.99	1.07	0.72	1.28	0.89	1.19	0.97	6.48	7.32	6.49	10.17	6.45	7.48	3.19
	7	0.97	1.02	0.47	1.10	0.85	1.02	0.74	6.62	7.10	6.34	9.84	6.12	7.33	3.18
	8	0.95	0.98	0.45	1.09	0.82	0.98	0.70	6.54	7.26	6.35	10.05	6.27	7.52	3.14
	9	0.94	0.98	0.45	1.08	0.82	0.98	0.70	6.54	7.26	6.35	10.06	6.27	7.53	3.14
6	6	0.29	0.47	0.28	0.67	0.29	0.73	0.73	0.73	1.00	1.71	1.00	0.50	1.20	1.44
	7	0.41	0.46	0.17	0.45	0.40	0.46	0.40	0.99	1.12	1.44	0.79	0.65	1.11	1.39
	8	0.26	0.31	0.12	0.33	0.26	0.33	0.33	0.83	0.96	1.31	0.63	0.50	0.98	1.33
	9	0.25	0.31	0.12	0.32	0.25	0.33	0.33	0.82	0.95	1.30	0.62	0.49	0.97	1.32

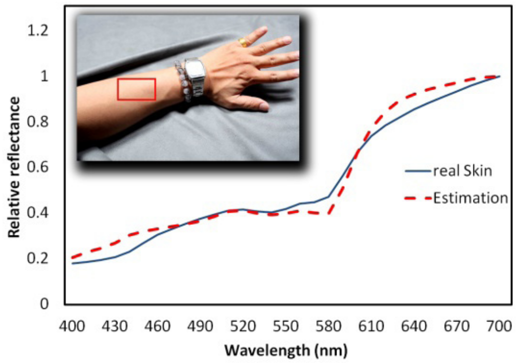

Figure 3: An example of the skin spectral estimation using a single camera.

4. CONCLUSIONS

In this paper, multiple LED illuminations were used for estimating a camera's spectral responses for skin spectral estimation. A filter-based multi-spectral imaging system was optimized using two cameras with one Gaussian color filter to accurately estimate the spectral reflectances of human skin. More applications based on it will be explored next.

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Estimation of Spectral Reflectance from Six-band Images based on Partial Least-squares Regression

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ABSTRACT

This paper reports experimental results of estimating spectral reflectance from six-band images based on partial least-squares (PLS) regression. PLS regression is a statistical method that bears some relation to principal components regression; instead of finding hyper-planes of minimum variance between the response and independent variables, it finds a linear regression model by projecting the predicted variables and the observable variables to a new space. Experimental results show that the PLS method is superior to the Wiener estimation method in terms of spectral and colorimetric error metrics, and that the PLS method can work well even when the number of color channels is six.

1. INTRODUCTION

The purpose of this paper is to evaluate PLS-based estimation of spectral reflectance in six-band images. PLS regression is a statistical method that bears some relation to principal components regression; instead of finding hyper-planes of minimum variance between the response and independent variables, it finds a linear regression model by projecting the predicted variables and the observable variables to a new space. PLS is implemented in an iterative manner. Shen et al. (2010) have applied this technique to the estimation of spectral reflectance from 16-band images. Their system, as well as general multispectral camera systems (Tominaga 1996; Burns and Berns 1996; Tominaga and Okajima 2000; Helling et al. 2004), consists of a monochrome camera and some narrow band-pass filters, and an image of each band is captured time sequentially, which makes it impossible to obtain multispectral images of a moving object or an object under a varying illumination condition such as in an outdoor scene. To overcome this problem, several types of six-band video systems have been developed (Ohsawa et al. 2004; Tsuchida et al. 2010; Shrestha et al. 2011; Hashimoto 2008). This shows that six-band system is seen as a practical multispectral image capturing system at this time.

2. PARTIAL LEAST-SQUARES-BASED REFLECTANCE ESTIMATION

Suppose that the continuous visible spectrum (from 410 nm to 780 nm) is uniformly sampled at N, and the number of color channels is C. The camera signal   is described as

$$\mathrm{u{=}Hr + n,} \tag{1}$$

where $\mathbf{u} \in R^{C\times 1}$. $\mathbf{H} \in R^{C\times N}$, $\mathbf{r} \in R^{N\times 1}$, and $\mathbf{n} \in R^{C\times 1}$ denote the system function of the camera, spectral reflectance of the target object, and noise, respectively. Under assumption of linear system, the spectral reflectance is estimated as

$$\hat{\mathbf{r}} = \mathbf{Wu}\,. \tag{2}$$

The matrix $\mathbf{W}$ is calculated based on Partial Least Squares in this paper.

Let K be the number of training samples. We can construct reflectance matrix $\mathbf{R} \in R^{N\times K}$ and response matrix $\mathbf{U} \in R^{C\times K}$, and then calculate the transform matrix as

$$\mathbf{W} = \mathbf{RU}^{+}, \tag{3}$$

where superscript $+$ denotes the matrix pseudo-inverse. To deal with the nonlinearity due to non-Gaussian data distribution, a two-order polynomial response vector $\tilde{u} \in R^{J\times 1}$ is defined as

$$\tilde{u} = [1, u_1, \cdots, u_c, u_1^2, u_1 u_2, u_2^2, u_2 u_3, \cdots, u_2 u_c, \cdots, u_{c-1} u_c, u_c^2]^T, \tag{4}$$

where $u_c (1 \le c \le C)$ is the cth element of $\mathbf{u}$. By defining the polynomial response matrix as $\tilde{\mathbf{U}} = [\tilde{u}(1)\ \tilde{u}(2)\ \cdots, \tilde{u}(K)] \in R^{J\times K}$, the transform matrix $\mathbf{W}$ can be solved as

$$\mathbf{W} = \mathbf{R}\tilde{\mathbf{U}}^{+}. \tag{5}$$

The polynomial response matrix $\tilde{\mathbf{U}}$ can be decomposed into a score matrix $\mathbf{T} \in R^{K\times L}$ and a loading matrix $\mathbf{P}$, with L being the number of PLS components, as

$$\tilde{\mathbf{U}}^T = \mathbf{TP}^T + \mathbf{E}, \tag{6}$$

where $\mathbf{E} \in R^{K\times J}$ is a residual matrix. Similarity, $\mathbf{R}$ can also be decomposed into a score matrix $\mathbf{D} \in R^{K\times L}$ and a loading matrix $\mathbf{Q} \in R^{N\times L}$ as

$$\mathbf{R}^T = \mathbf{DQ}^T + \mathbf{F}, \tag{7}$$

where $\mathbf{F} \in R^{K\times N}$ is a residual matrix.

The goal of PLS is to extract the common structure between $\tilde{\mathbf{U}}$ and $\mathbf{R}^T$ by searching a projection such that the covariance between the score matrices $\mathbf{T}$ and $\mathbf{D}$ is maximized. In matrix form, this relationship is written as

$$\mathrm{D=TB}, \tag{8}$$

where $\mathbf{B} \in R^{L\times L}$ is the diagonal regression matrix.

The PLS algorithm is carried out in an iterative manner. To obtain an orthogonal score matrix $\mathbf{T}$, a weight matrix $\mathbf{G} \in R^{J\times L}$ is introduced in the iterative procedure. Let j be the iteration index, and $\mathbf{g}$, $\mathbf{t}$, $\mathbf{q}$, and $\mathbf{d}$ be the jth column vectors of matrices $\mathbf{G}$, $\mathbf{T}$, $\mathbf{Q}$, and $\mathbf{D}$, respectively. Before starting the iteration, let $\mathbf{E} = \mathbf{U}^T$ and $\mathbf{F} = \mathbf{R}^T$. Matrices $\mathbf{E}$ and $\mathbf{F}$ are then column centered and normalized so that each variable has zero mean and unit variance. Let $j = 1$ and $\mathbf{d}$ be any column of $\mathbf{F}$ then compute Eqs.(9)-(12) iteratively:

$$\mathbf{g} = \frac{\mathbf{E}^T\mathbf{d}}{\left\|\mathbf{E}^T\mathbf{d}\right\|}, \tag{9}$$

$$\mathrm{t=Eg}, \tag{10}$$

$$\mathbf{q} = \frac{\mathbf{F}^T\mathbf{t}}{\left\|\mathbf{F}^T\mathbf{t}\right\|}, \tag{11}$$

$$\mathrm{d{=}Fq}, \tag{12}$$

where $\|\cdot\|$ denotes the Euclidean norm. If $\mathbf{t}$ has not converged, return to Eq. (9), otherwise compute the value of b, which is the j th diagonal element of matrix $\mathbf{B}$, as $b = \mathbf{d}^T\mathbf{t}/\mathbf{t}^T\mathbf{t}$, and compute the factor loading, which is the j th column vector of $\mathbf{P}$, as $\mathbf{p} = \mathbf{E}^T\mathbf{t}/\mathbf{t}^T\mathbf{t}$.

The residual matrices $\mathbf{E}$ and $\mathbf{F}$ needed for the next iteration are calculated as

$$\mathbf{E} = \mathbf{E} - \mathbf{tp}^T, \tag{13}$$

$$\mathbf{F} = \mathbf{F} - b\mathbf{tq}^T. \tag{14}$$

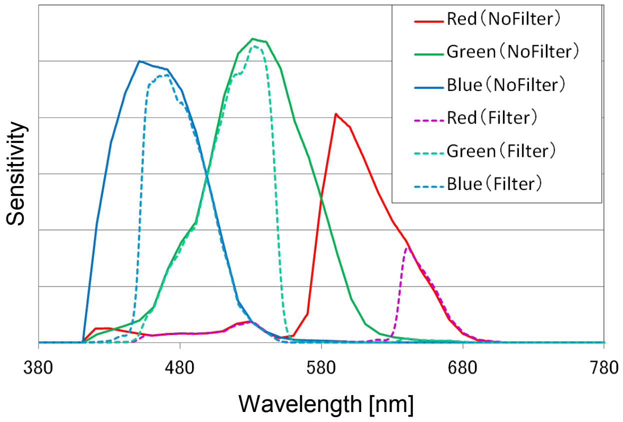
Note that Eqs. (13) and (14) remove the variance associated with the obtained score and loading vectors before the next iteration. If $j < L$, let $j = j+1$ and continue the iteration starting from Eq.(9); otherwise, stop the iteration and compute the PLS transform

$$\mathbf{W}_{PLS}^T = G(P^TG)^{-1}(T^TT)^{-1}T^TR^T, \tag{15}$$

based on which reflectance can be estimated as $\hat{\mathbf{r}} = \mathbf{W}_{PLS}\tilde{\mathbf{u}}$.

As L controls the number of iterations, its value is influential to PLS. If $L = \min(J, K)$, $\mathbf{E}$, and $\mathbf{F}$ become zeros and PLS reduces to ordinary least squares (OLS); otherwise, if $L < \min(J, K)$, the colinearity of matrix $\tilde{\mathbf{U}}$ is reduced. In this work, L is determined according to the spectral accuracy of the reflectance estimation.

3. EXPERIMENTAL RESULTS AND CONCLUSIONS



In the experiments, a two-shot six-band camera system 9 was used for image capture. The number of spectral sampling in visible wavelength was $N = 271$ and the number of color channel was $C = 6$. The two-order polynomial response vector $\tilde{u}$ had 28 elements. The camera system consists of a commercially available digital single-lens reflex camera (D700, Nikon) and a custom interference filter whose spectral transmittance is comb shaped. The spectral sensitivity of the system is shown in Figure 1, which is the same as that of our one-shot six-band camera system[7]. A xenon lamp was used for illumination.

Spectral reflectance and six-band images of 177 color patches in Macbeth Color Checker DC^{TM} were used as training samples to calculate the estimation matrix of spectral reflectance, and 24 color patches in Machbeth Color Checker^{TM} were used as test samples. Below, the estimation results for the PLS method are compared with the results of the Wiener estimation method (Pratt and Mancill 1976):

Root-means square errors of reflectance: Wiener 0.0090; PLS 0.0038

Averaged color difference dEa*b*: Wiener 1.36; PLS 0.28

Maximum color difference dEa*b*: Wiener 4.52; PLS 1.17

Minimum color difference dEa*b*: Wiener 0.02; PLS 0.01

These results show that the PLS method is superior to the Wiener estimation method in terms of spectral and colorimetric error metrics, and that the PLS method can work well even when the number of color channels is six.

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A Study of Relationship between Pitch of Pure Sound and Lightness and Saturation of Color

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ABSTRACT

This study investigates whether the pitch of a sound correlates with color lightness and saturation. Eight sounds were used as the sound stimuli, and 17 achromatic and 32 chromatic colors were used as the color stimuli. The subjects were asked to evaluate the pitch of sound and the lightness and saturation of the color stimuli. The results showed that they chose the color which hears sound and suits an image. On the basis of these results, we conclude that lightness and saturation are strongly correlated. Sound pitch was highly correlated to lightness and saturation individually, and a bright color and a vivid color correlated to a high pitched sound.

1. INTRODUCTION

Cross-modal research has recently attracted attention and various studies have examined color and music. Previous studies investigated the color–sound relationship on the basis of the pitch and tone of the Practical Color Co-ordinate System (PCCS) and reported the correspondence between lightness of color and sound tonality (Takami et al. 2011). In a color study, the correlation between lightness and saturation of a color was demonstrated using the PCCS tone (Wakata et al. 2012). Thus, studies examining the correlation between color and sound have found that both lightness and saturation are important in the correlation between pitch and color. This study investigates whether the pitch of a sound correlates with color lightness and saturation.

2. METHOD

2.1. Stimuli

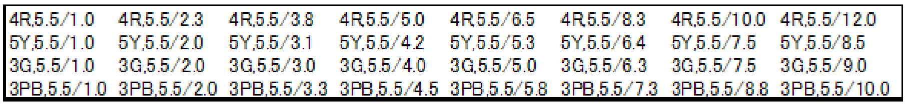
Sound stimuli: The sound stimuli used a total of eight sounds that changed across one octave of pure sounds, one tone at a time, from 32 Hz to 4186 Hz(32 Hz, 65 Hz, 130 Hz, 261 Hz, 523 Hz, 1046 Hz, 2093 Hz, 4186 Hz). This range is almost identical to that of a piano. These stimuli were created using the personal computer software “Audacity.” Sound was transmitted via headphones, with white noise transmitted between sounds. **Lightness stimuli:** The PCCS color system was used as color stimuli. Lightness stimuli used a total of seventeen colors (from 1.5 [Bk] to 9.5 [W]: gray scale). **Chromatic color stimuli**: Chromatic color stimuli used a total of 32 colors (four hues [R, Y, G, B] × eight saturations). The lightness of all the colors was unified and managed such that saturation changed to an equal step target (Table 1).

2.2. Procedure

This experiment consisted of four tasks. **Task A:** The subject heard a sound and chose the color that matched the image of that sound. The color stimulus was the color chips (1.5 cm

× 3 cm), each of which was pasted on the neutral gray mount for every hue and gray scale (Fig. 1). **Task B:** The subject heard a sound and judged its pitch. **Task C:** The subject saw each color of lightness stimuli and judged its lightness. The color stimulus was provided by the color chip (3 cm × 3 cm), which was pasted on the neutral gray mount. **Task D:** The subject saw each color of the chromatic color stimuli and judged its lightness and saturation. The size of each color was the same as that in Task C. The visual analog scale (VAS) was used for evaluating sound pitch (very low–very high), lightness (very dark–very bright), and saturation (very vivid–not vivid at all). Task A was always performed last. Tasks B, C, and D were randomly assigned to the subjects. Furthermore, the stimulus in each trial was randomly provided. This experiment had 41 participants (13male and 28 female, average 25.1±2.1 years old).

Table 1. H V/C of chromatic color stimuli.



4R,5.5/1.0	4R,5.5/2.3	4R,5.5/3.8	4R,5.5/5.0	4R,5.5/6.5	4R,5.5/8.3	4R,5.5/10.0	4R,5.5/12.0
5Y,5.5/1.0	5Y,5.5/2.0	5Y,5.5/3.1	5Y,5.5/4.2	5Y,5.5/5.3	5Y,5.5/6.4	5Y,5.5/7.5	5Y,5.5/8.5
3G,5.5/1.0	3G,5.5/2.0	3G,5.5/3.0	3G,5.5/4.0	3G,5.5/5.0	3G,5.5/6.3	3G,5.5/7.5	3G,5.5/9.0
3PB,5.5/1.0	3PB,5.5/2.0	3PB,5.5/3.3	3PB,5.5/4.5	3PB,5.5/5.8	3PB,5.5/7.3	3PB,5.5/8.8	3PB,5.5/10.0

Figure 1. The presentation method of a color stimuli.

3. RESULTS AND DISCUSSION

3.1. VAS value of sound stimuli

The result of VAS for sound pitch stimuli was that low frequency stimuli were evaluated low and high frequency stimuli were evaluated high (Fig. 2). The correlation coefficient between the psychophysical evaluation and the physically obtained value for sound stimuli was evaluated; the correlation was moderate ($r = .78$). In this study, an octave produced by dodecaphony was used as the sound stimulus. The octave is defined by the logarithm of frequency (Hz). Thus, the sound stimuli were defined not as frequency but the equivalent in the octave (octave value: C32 = 1 – c4096 = 8), and the correlation coefficient between the VAS and octave values was evaluated; the correlation was found to be high ($r = 0.99$). These results suggested that the subjects precisely distinguished the pitch of each sound in the octave.

3.2. VAS value of lightness stimuli

The results of the VAS for lightness revealed that low lightness stimuli were evaluated as dark and high lightness stimuli were evaluated as bright (Fig. 3). Correlation coefficient between VAS value and physical value of lightness showed high correlation ($r = .99$).

3.3. VAS value of chromatic stimuli

Chromatic color stimuli were evaluated for lightness and saturation. First, the VAS for saturation of chromatic color stimuli results revealed that low saturation stimuli were evaluated as having low saturation and high saturation stimuli were evaluated as having high saturation. All hues (R, Y, G and B) produced the same result (Fig. 4: a solid line). Saturations were defined at eight levels (from lowest = 1 to highest = 8), and the correlation between the VAS values and the saturation level in each hue was evaluated. The value of the correlation coefficient was high for all hues ($r = 0.98$[R], 0.94[Y], 0.98[G], 0.95[B]).

Table 2. Correlation between dimension1 value and VAS value.

	Lightness stimuli	***Chromatic stimuli***			
		R	***Y***	***G***	***B***
pitch of sound	0.92	0.95	0.95	0.91	0.97
Lightness	0.92	0.91	0.86	0.88	0.89
Saturation	-	0.94	0.94	0.91	0.92

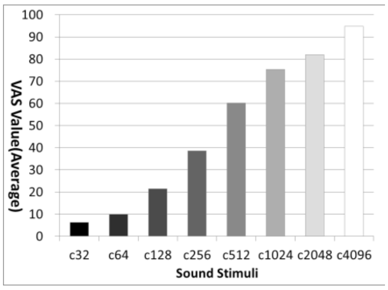


Figure 2: Average VAS value of sound stimuli (pitch of sound)

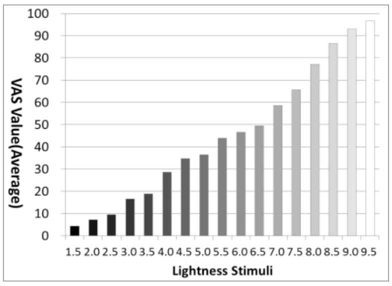


Figure 3: Average VAS value of lightness stimuli (lightness)

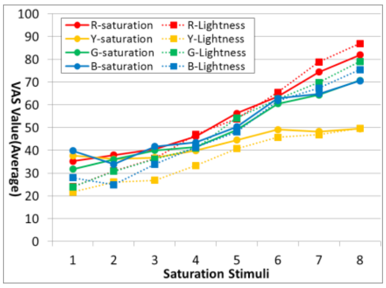


Figure 4: Average VAS value of chromatic stimuli (saturation and lightness)

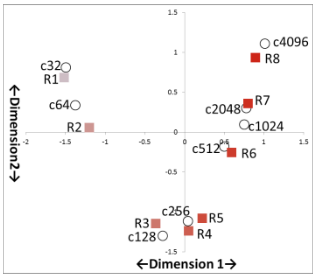


Figure 6. Chromatic stimuli:R

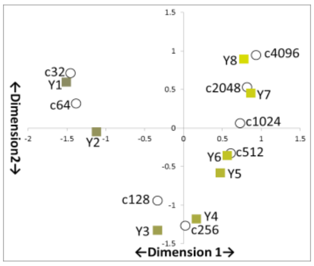


Figure 7. Chromatic stimuli:Y

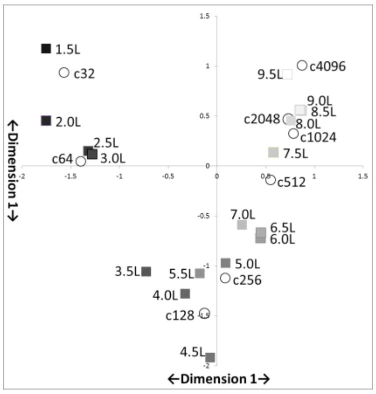


Figure 5. Lightness stimuli

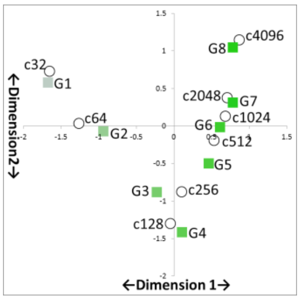


Figure 8. Chromatic stimuli:G

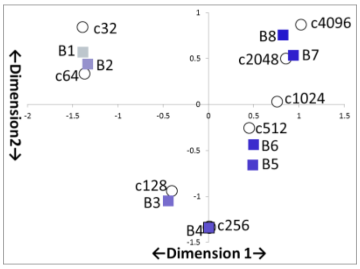


Figure 9. Chromatic stimuli:B

Figures 5-9: Scatter diagram of a dimension score of correspondence analysis.

Second, the VAS result for lightness of chromatic color stimuli revealed that low saturation stimuli were evaluated as having low lightness and high saturation stimuli were evaluated as having high lightness. All hues produced the same result (Fig. 4: a dotted line). In this study, lightness (physical value) was not changed for all saturation stimuli, but we observed a change in the VAS value of lightness, despite lightness remaining unchanged.

3.4. Relation between lightness and saturation

The feature common to lightness and saturation was that, although the difference of the VAS value was small in low-saturation colors, it was large in high-saturation colors. It means the approaches for the evaluation of lightness and saturation were similar. The correlation coefficient between the VAS value of saturation and lightness was evaluated for each hue; all pairs showed high correlation ($r = 0.99$[R], 0.97[Y], 0.99[G], 0.99[B]). These results suggest that lightness is taken into consideration for evaluating saturation levels. This is described in a previous study "*Saturation seems to be more complicated than hue or lightness and to have several elements include*" (Yabe 1967).

3.5. Correspondence analysis

To examine the relationship between sound pitch and color, correspondence analysis was conducted on the results obtained from Task A (Figs. 5–9). Fig. 5 shows that the pitch of sound and lightness are directly proportional (e.g. c4096 and 9.5[W], c32 and 1.5[Bk]). This result is reflected in Figs. 6, 7, 8 and 9 (e.g. c4096 and R8, c32 and R1 in Fig. 6). All hues produced the same result.

Dimension 1 value changed with the pitch of sound, lightness, and saturation (Fig. 5-9). The correlation coefficient between the value of dimension 1 in the correspondence analysis and the VAS value of pitch, lightness, and saturation is shown in Table 2. There was a high correlation between the lightness of the gray scale and the saturation and lightness of chromatic colors. Thus, sound pitch and color correlate on not only lightness but also saturation. The VAS value of lightness and saturation strongly correlate, and it may also have influenced the correlation between sound and color. Because it was completely difficult to separate lightness and saturation, the findings suggest that when evaluating saturation, we must also consider change of lightness. Using the tone of PCCS as stimuli, another study suggested that the pitch of sound corresponds to lightness (Saito et al. 2013). However, in this study, what took only saturation out was used as stimuli, and thus, sound and saturation corresponded. This suggests that the results when lightness and saturation are used as stimuli may be different from the results when a tone of PCCS is used.

4. CONCLUSIONS

The pitch of sound as well as the lightness and saturation of color can be precisely identified. Lightness and saturation correlated strongly, and lightness will also be assessed as high in the presence of high saturation. Sound pitch correlated highly to lightness and saturation individually, and a bright color and a vivid color correlate to a high pitched sound.

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Harmonious Relationship between Color and Music Focusing on Psychological Evaluation of Key and Tempo

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ABSTRACT

The purpose of this study was to analyze the harmonious relationship between tones of *PCCS* (Practical Color Co-ordinate System) and music by impressionistic evaluation of human beings, focusing on key (tonality) and tempo as components of music. One hundred and twelve university students participated in psychological evaluation by the SD method (with 13 adjective pairs) for Satie's *Gymnopédies* and a musical composition of our own, both of which were modulated into 3 different keys, and the evaluation of our own composition in 5 different tempos by the same SD method along with the degree of harmonious evaluation in a 7-scale measurement evaluation of music and color with 11 different *PCCS* tones (arranged in a hue-circle) as color stimuli. These tones were also evaluated by the same SD method. The results were analyzed by Factor analysis which extracted 3 factors named Activity, Potency and Evaluation respectively. As a result, when focusing on Potency, key and lightness are in accordance, and when focusing on Activity, tempo is in accordance with saturation. However, we found a tendency for tempo to correspond not only to saturation but also to lightness. According to our analysis mentioned above, it can be considered that tempo has a multi-dimensional relationship with lightness and saturation. That is, a faster tempo was more likely to correspond to higher lightness and higher saturation, and a slower tempo was more likely to correspond to lower lightness and lower saturation.

1. INTRODUCTION

Some celebrated people such as Vasily Kandinsky, a painter, and Franz Liszt, a composer, are said to have had synesthesia and are believed to have used their experiences creatively. Synesthesia is described as a kind of sensory phenomenon or a sensation whereby stimulation of one sensory or cognitive pathway of one sense modality (such as hearing) leads to automatic, involuntary experiences in a second sensory or cognitive pathway of another modality (such as vision) (Cytovic 1993). This phenomenon has been studied for many years (from the late 19th century) and is reported as being an inherent quality accounting for special artistic gifts. However, not only such talented synesthetes but also non-synesthetes experience cross-modal perception; for example, we sometimes associate color with a certain genre or piece of music, although we are not chromosthetes or sound-to-color synesthetes. The experience is quite natural and common to us because two or more different sensory modalities usually interact in our brain. It is also reported that sound-color synesthetes, as a group, tend to see lighter colors for higher sounds (Ward et al. 2006). A recent study suggested that nonhuman animals share cross-modal correspondences as well: Chimpanzees also associate higher pitch with higher luminance (Ludwig et al. 2011). It is suggested that rather than being a culturally learned or a linguistic phenomenon, this mapping constitutes a basic feature of the primate sensory system. Although there have been several studies which have tried to clarify the relationship between color and music association, few studies have considered their harmonious pespective. Thus we conducted a pilot study to research the relationship between harmonious combinations of colors and music ranges (Takami et al. 2011). Sixty university students were asked to select harmonious or disharmonious combinations of *PCCS* (Practical Color Co-ordinate System) colors, and different music keys (C, B, B ♭, A, G, F, E, D) of two musical compositions (J. S. Bach's 'Suiten für Violoncello solo', and Mussorgsky's 'Tableaux d'une Exposition') using psychological evaluation by the SD method. The result of Factor analysis showed that the music registers were well related with the Potency factor, which consisted of adjective pairs such as feminine-masculine, light-heavy, bright-dark and sharp-dull. In other words, high ranges harmonized well with bright, light and clear colors, while low ranges were compatible with dark and heavy colors.

2. METHOD

The study comprised two experiments; one was the psychological evaluation by the SD method (with 13 adjective pairs: bright-dark, cheerful-gloomy, gaudy-simple, calm-restless, tense-loose, sharp-dull, beautiful-ugly, stable-unstable, quiet-noisy, heavy-light, manly-feminine, warm-cool, like-dislike, measured on a 7-point-scale) of Satie's *Gymnopédies* (original key is D and tempo is BPM80) and music of our own computer-software produced composition (original: E ♭, BPM140), both of which were modulated into 3 different keys (F,C,G, in the order of high to low). The other was the evaluation of our own composition at 5 different tempos (BPM60, BPM90, BPM120, BPM150, BPM180) using the same SD method together with the degree of harmonious evaluation on a 7-scale measurement evaluation of music and color with 11 different *PCCS* tones (vivid, bright, deep, light, soft, dull, dark, pale, light-grayish, grayish and dark-grayish arranged in a hue-circle) and a gray-scale as color stimuli (Fig.1). These tones were also evaluated using the same SD method. The total number of the subjects who participated in these experiments was 121 university students (male:58, female:63, average age:21.36 years, SD=1.88).

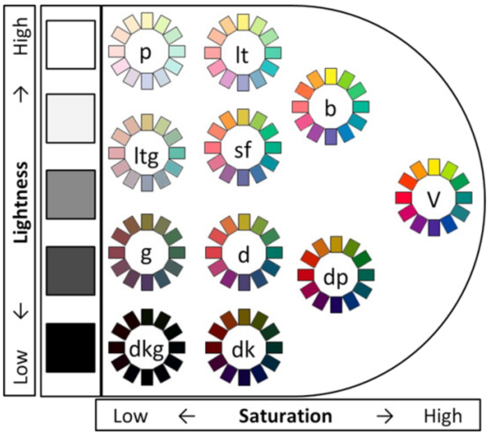
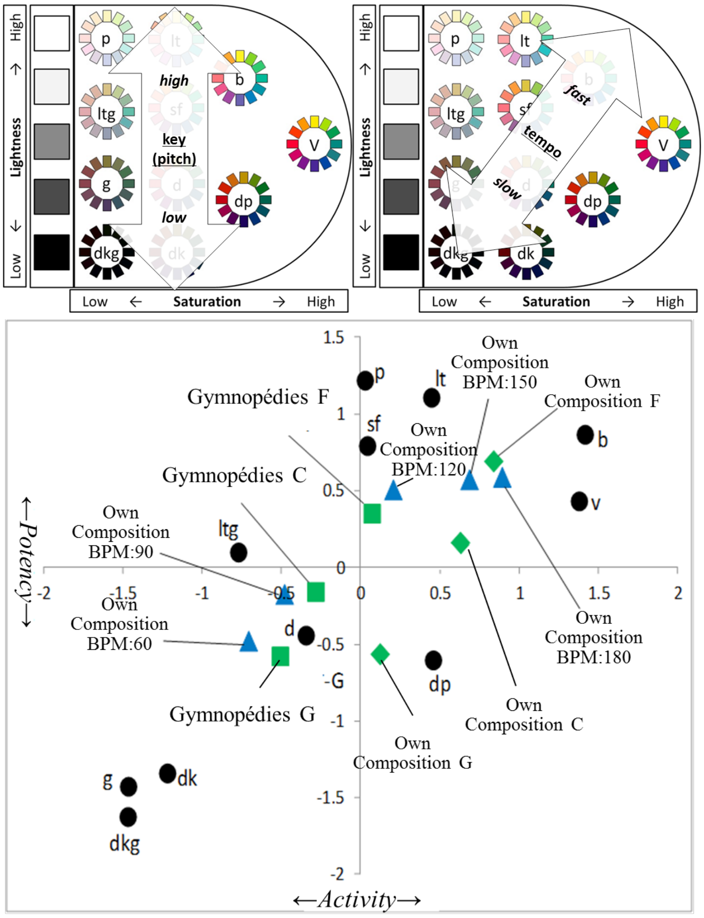


Figure 1: Color stimulus of PCCS tone map.

3. RESULTS AND DISCUSSION

3.1 Factor Analysis

Using Factor analysis we analyzed the data obtained from both experiments (Likelihood Method, Promax rotation), and extracted 3 factors designated Activity (consisting of the adjective pairs: quiet-noisy, gaudy-simple, sharp-dull, cheerful-gloomy, bright-dark), Potency (heavy-light, manly-feminine, tense-loose), and Evaluation (stable-unstable, calm-restless, beautiful-ugly, like-dislike) respectively. Our observation indicated a pattern in which keys showed a higher factor score in Potency as ranges went up, as well as a pattern in which the factor score of Activity increased in tandem with the tempo stimuli. Focusing on color tone, the factor score of each stimulus showed a configuration of plots similar to the PCCS tone map, in which Potency was more likely to correspond to lightness, and Activity was more likely to correspond to saturation. When paying attention to the degree of harmonious combination, a higher range was more likely to correspond to higher lightness, while a lower range was more likely to correspond to lower lightness in key stimuli. Moreover, focusing on tempo stimuli, a faster tempo was more likely to correspond to higher lightness and higher saturation, while a slower tempo was more likely to correspond to lower lightness and lower saturation (Fig.2).



v:vivid, b:bright, dp:deep, lt:light, sf:soft, d:dull, dk:dark, p:pale, ltg:light-grayish, g:grayish, dkg:dark-grayish

Figure 2: Scatter diagram of factor scores (right) and the relationship between PCCS tone map and music components (key and tempo).

As a result, when focusing on Potency, key and lightness were in accordance, and when focusing on Activity, tempo was in accordance with saturation. However, we found a tendency whereby tempo corresponded not only to saturation but also to lightness. According to our analysis described above, it can be construed that tempo has a multi-dimensional relationship with lightness and saturation.

As suggested in the Introduction, certain associations of color and music were observed in the participants even though they were non-chromosthetes (sound-to-color synesthetes). In addition, the relationship between color and music keys along with music tempos indicated somewhat regular or definite standards when the attributes of color were applied, namely, hue, lightness and saturation. This suggests that the components of music may be classified by means of the components of color.

4. CONCLUSIONS

In conclusion, we posit the following: Changes in key correspond to changes in lightness of *PCCS* tone. On the other hand, results indicating that changes in tempo corresponds to changes in lightness and saturation in *PCCS* tones from lower levels to higher levels suggests that tempo has a multi-dimensional relationship with lightness and saturation. From a cross-modal point of view, it is also suggested that the components of music can be classified by means of the components of color, which may play an important role as a node of cross-modal perception.

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Application of Color Coding in Color-music Composition

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ABSTRACT

Color coding used specific colors to represent the identification. From the view point of synesthesia of vision and audition, color coding in music application have been usually employed to identify notes of music scores or positions of music instruments by vision. The color coding method recently promoted to music teaching, music analyzing and music composition. In this paper, the authors compose the color-music composition according to the color coding method and the twelve-tone technique. The twelve pitches have been chosen corresponding to the twelve colors of Itten's color wheel. The pitch-classes sets of trichords and tetrachords are coding three colors and four colors. Based on the applications of trichords and tetrachords, a color-music composition, "Kaleidoscope", has been composed and demonstrated. Through the music design of color coding, we could hopefully provide musicians or music professionals a new music composition method. Furthermore, music educators with the aid of the proposed color coding method would teach music learners to analyze the structures of music compositions. In future, the color coding may be a vehicle to investigate the human's health and spirit when human's emotion is agitated by color (vision) and music (audition).

1. INTRODUCTION

Color-Music was proposed by some professionals (Peacock, K. 1988). Color coding had been applied to identify notes of music scores and positions of music instruments visually. Rogers (1991) tried to promote the color coding to music identification, music teaching and music analyzing. Based on synesthesia of vision and audition, color and music have the strong relationship from the view point of frequency. This paper intended to compose the color music according to the color coding method and the twelve-tone technique devised by Schöenberg (Lester, 1989). Besides, this paper designed twelve pitches to implement the twelve-tone technique (Perle, 1996). The twelve pitches have been chosen corresponding to the twelve colors of Itten's color wheel (Itten, 1997). The two types of pitch-classes sets are trichords (a group of three different pitches) and tetrachords (a group of four different pitches) (Forte, 1973) which are corresponded to three colors and four colors. Through the design process of color coding, characteristics of different music sections would be identified hopefully in the color-music composition. Finally, the proposed color coding could help musicians or music professionals create music compositions. Music educators would teach music learners to analyze the structures of music compositions with the aid of the color coding method. In future, the application of color coding in color-music compositions could be linked to the modern technologies in multimedia. Because of the different presentations of color-music compositions, human may be aroused their emotions and the related associations. When human's emotion is agitated by vision and audition, the synesthesia of color and music may affect human's health and spirit. In our research, a music piece, "Kaleidoscope", is composed by the twelve-tone technique and the pitch-class sets to represent the structures of music similar to the process of kaleidoscope.

2. METHOD

The trichords and tetrachords of pitch-class sets produce the different characteristics of the music sections that will affect the unity and variation of music composition. The design and coding method of the music composition:

2.1 Design of music composition

The design of music composition uses the twelve-tone series (Table 1). Four types of the twelve-tone series: (1) Prime (P), (2) Retrograde (R), (3) Inversion (I), (4) Retrograde Inversion (RI). The theme A uses tetrachords, and the theme B uses trichords. The rhythm of the theme A uses the syncopation notes, and the theme B uses the triple notes.

Table 1. The twelve-tone series of the color-music composition "Kaleidoscope"

P	C	G^b	B^b	G	A^b	A	B	F	D^b	E	E^b	D
R	D	E^b	E	D^b	F	B	A	A^b	G	B^b	G^b	C
I	C	G^b	D	F	E	E^b	D^b	G	B	A^b	A	B^b
RI	B^b	A	A^b	B	G	D^b	E^b	E	F	D	G^b	C

2.2 Coding of color and pitch

The coding mode for colors relies on hues because frequencies of pitches and colors are relative. In this paper, colors and pitches are related to frequencies and synesthesia, and the color wheel is adopted which is developed by Itten (Figure 1). This color wheel has 12 colors corresponding to 12 semitones. Pitches are based on pitch frequencies that correspond to color frequencies. The 12 semitones correspond to the 12 colors of a color wheel (see Table 2).

Figure 1. Color wheel - Johannes Itten. Source: Itten, J. (1997). The art of color: the subjective experience and objective rationale of color. New York: John Wiley & Sons. INC.

Table 2. Comparative table of pitches and colors

Color name	***Red***	***Red-Orange***	***Orange***	***Yellow-Orange***	***Yellow***	***Yellow-Green***
Hue	●	●	●	●		●
CIE Luv	(0.43, 097)	(0.42, 0.94)	(0.36, 0.81)	(0.31, 0.70)	(0.23, 0.52)	(0.19, 0.42)
Letter name	C	$C^{\#}/D^{b}$	D	$D^{\#}/E^{b}$	E	F
Color name	***Green***	***Blue-Green***	***Blue***	***Blue-Violet***	***Violet***	***Red-Violet***
Hue	●	●	●	●	●	●
CIE Luv	(0.13, 0.30)	(0.14, 0.31)	(0.15, 0.33)	(0.19, 0.42)	(0.26, 0.58)	(0.31, 0.69)
Letter name	$F^{\#}/G^{b}$	G	$G^{\#}/A^{b}$	A	$A^{\#}/B^{b}$	B

Table 3. The form of the color-music composition "Kaleidoscope"

Section	A	B	A'	Coda
Measure	1-24	25-49	50-74	75-88

3. RESULTS AND DISCUSSION

The form of the color-music composition "Kaleidoscope" are A, B, A', and Coda (Table 3). In section A, the pitch-class sets (tetrachords) are the important elements (Figure 2). In section B, the pitch-class sets (trichords) are the important elements. In section A', the texture of music composition is more complex than section A and section B. In coda, the section applies the variations of meter, tempo, range, and intensity, and the section uses clusters to destroy the order of pitch class sets to represent the statuses of kaleidoscope.

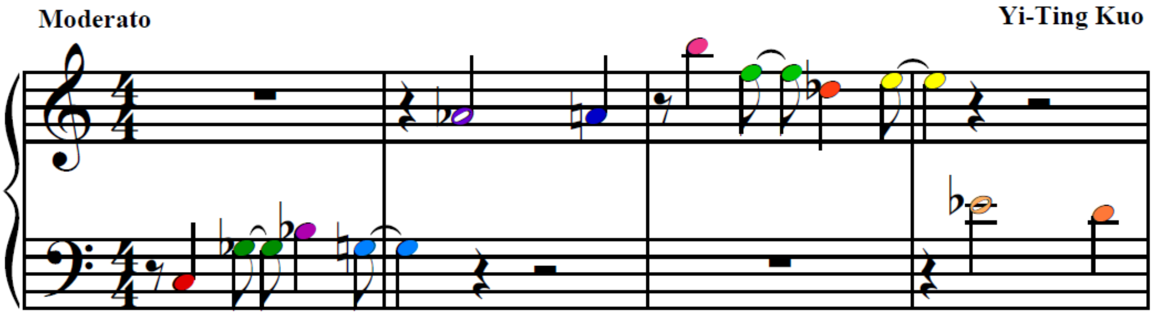

Figure 2. A part of the color-music composition, "Kaleidoscope"

4. CONCLUSIONS

This music composition, "Kaleidoscope", combines color theory and music elements to represent the various processes of kaleidoscope, and the different interval structures of pitch-class sets of the twelve-tone series are to make the characters of music sections. Through the research of this paper, we can find the pitch and color coding method by color theory can raise the analysis and identification of theme and music sections, and the textures of music composition show links by vision and audition. This is a new way to compose music composition by the concepts of color and music.

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Outstanding Colour in Printing Techniques

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ABSTRACT

In today's printing, the correct chromatic reproduction of an image is possibly the most important and yet the most challenging aspect. In order to achieve excellence in this field, technology and human creativity must work together to recreate not only the formal chromatic features of a subject, but also the emotions associated to the original image. When we consider the chromatic dimension of an image in offset printing, quality is mostly measured by the degree of chromatic correspondence between the original and the print. Superior results can only be achieved by creating a product that, within the limits imposed by the means used, covers the biggest possible range of the visible spectrum. This paper will briefly illustrate how scientific research and practical experimentation helped overcoming the chromatic limitations of the current offset printing techniques.

1. INTRODUCTION

Every printing process, however complex it might be, can be essentially broken down into two phases. The first one consists in the acquisition of all the useful data of the subject being reproduced. This set of information mostly concerns the visual sphere, although in some cases, with the help of specific printing techniques and materials, it is possible to widen the end-user experience, adding tactile or even olfactory sensations. The second phase consists in the translation of all these data into a finished product. The process between these two phases requires the use of complex equipment, chemical and natural compounds and the most advanced graphic design software. And yet, what a printer is really asked is not a mere reproduction, but the interpretation of a subject.

A good printer will be able to maintain a correspondence between the original subject and what comes out of the printing process. Excellence, on the other hand, demands a further step, which can be taken only by those who can combine technical mastery and a deep aesthetic awareness. If a good printer reproduces a subject accurately, an excellent printer goes beyond that and creates not only an item but a unique experience, able to affect the emotive sphere of the user by stimulating its senses.

2. MULTI-CHANNEL PRINTING: EXCELLENCE IN OFFSET CHROMATIC FIDELITY

Today, the standard printing method is Process Colour (cyan, magenta, yellow, black), where four sections, each representing the position of one hue on the final print, are sequentially superimposed in order to recreate the original image. Nevertheless, while the term Four colour printing is commonly referred to a specific combination of colours (CMYK), it is possible to choose among a number of different options to recreate specific hues, e.g. by using Pantone colours. Although Process Colour is, today, the most commonly used printing technique, it presents some substantial limitations to the quality of the print, such as a loss in brilliance.

Furthermore, the range of shades obtainable with this combination is rather limited compared to the gamut visible to the human eye. In the attempt to overcome these limitations, the market developed alternative techniques, like Hexachrome printing, in which two additional colours are used in order to expand both the range of obtainable hues and the overall brilliance. While this technique has proven useful and it is often considered as a high-quality standard in offset printing, it still can't achieve superior quality in the chromatic reproduction of an image. Going beyond Hexachrome by adding more colours is, in fact, more an experimental process than a merely technical one and represents, today, the real frontier in offset printing. For each added colour, the overall complexity of the process increases exponentially, requiring superior technical knowledge, thorough research and continuous experimentation. Trying to overcome the limitations imposed by the current set of technologies to create superior-quality printing products has always been a distinguishing trait of Fontegrafica. It is with this mission in mind that we studied and perfected a rather unique printing technique: Multi-channel printing. Just like Hexachrome printing, Multi-channel printing is the answer to the need for a more realistic reproduction of hues in an offset print. It represents a remarkable technological innovation as it allows to drastically expand the available chromatic spectrum by adding more colours to the standard combinations.

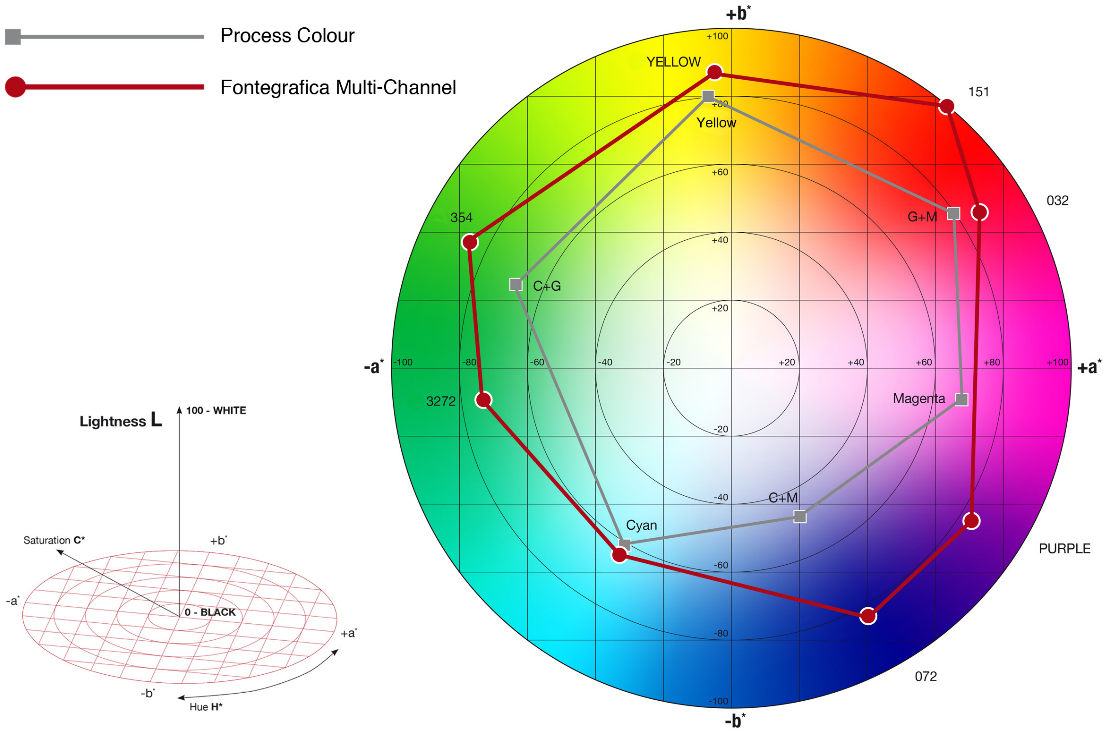

Figure 1: Gamut comparison in Process Colour and Multi-channel printing.

This technique allows us to recreate shades which cannot be obtained with standard combinations and, furthermore, to use "spot" colours in the printing process. Thanks to this, we have more leeway both on the Chroma and the Lightness axes and we are able to speed up the entire printing process. By expanding the width of the reproducible chromatic spectrum, we are also able to obtain a *Hi-Fi* Multi-colour and, as a consequence, achieve an extreme adherence to the original and a superior degree of brilliance on the print.

2.1 Process Colour and Multi-channel Printing: A Spectrophotometric Comparison

In this section of the paper we will demonstrate our thesis by comparing the spectrophotometric readings of an image printed in Process Colour and comparing it to the data we can obtain with the Multi-channel printing developed by Fontegrafica.

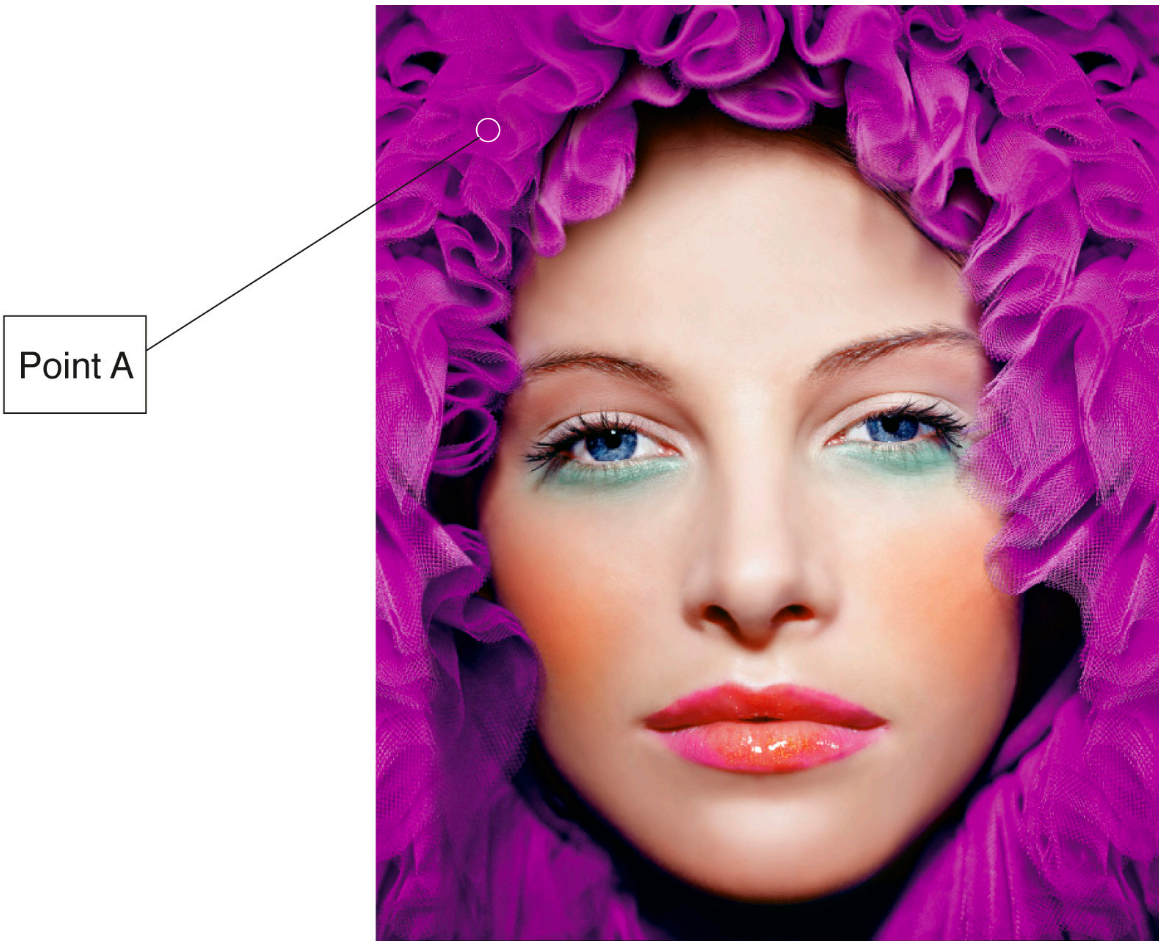

Figure 2: Subject 1.

Colour percentage on Point A	Process Colour	Multi-channel
Cyan	49	10
Magenta	97	35
Yellow	1	0
Black	0	3
Purple Pantone	-	96

LAB Readings		
L	38.82	40.35
A	47.31	69.80
B	-25.72	-37.45

As we can see from the measurements taken from the Subject 1 in the image above, this innovative technique allows the reproduction of unique colour shades, achieving a result close to reality. With Multi-channel printing, colour saturation looks much more “natural”.

Furthermore, smoother tonal variations and higher-quality shadows confer an outstanding "realistic" look to the image.

3. CONCLUSIONS

Every printing process has to deal with a number of variables and possible complications. Trying to achieve excellence in this art is, at the same time, an accomplishment and a constant learning process. The scope of the chromatic spectrum and the endless combinations of available supports, inks and techniques are the instruments allowing us to recreate, for instance, the deepness of shadows and all the different hues a complex image might contain. In the current market, overcoming the standardization of printing techniques and the limitations imposed by inks, supports and equipment (hardware and software) is not only possible but essential to achieve excellence. Printing is an ancient art that, from its very beginning, successfully combined technological progress, craftsmanship and aesthetic talent. It is especially today, in the middle of the ongoing digital revolution, that the human factor has to remain central. Only experience, technical expertise and creative experimentation can overcome the limitations imposed by the means; only human sensitivity can interpret and reproduce the emotive spectrum of an image.

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Development of Skin Colour Reproduction using 3D Colour Printing

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ABSTRACT

A colour reproduction system for the advanced manufacture of facial prostheses was proposed and implemented for a 3D colour printing system. The process involved the production of a 3D silicone infiltrated powder construct to produce facial soft tissue prosthesis. A colour profile was developed to manage colour output for a Zcorp 3D printign system in which 240 traing colours were adopted and modelled using a polynomial regression with least square fitting. The results demonstrated that the system can be effectively used to reproduce a range of human skin colours for the application of facial prostheses.

1. INTRODUCTION

Maxillofacial prostheses are constructed to correct facial disfigurement caused by surgical intervention due to cancer, severe facial trauma and congenital craniofacial anomalies (Leonardi et al. 2008) Conventionally, the manufacture of these soft tissue prostheses is a lengthy and technically demanding process, and the outcomes are heavily dependent upon the skill of a small number of highly experienced technologists. An accurate colour match between the subject's skin and prostheses is always highly desired and affect the overall quality of facial prostheses significantly.

With 3D digital imaging technology being ever more developed and utilised, and the ability for it to be directly interconnected with advanced manufacture techniques, it can produce custom-based production models with excellent accuracy and savings in terms of both time and cost. This technique has been utilised for some time with rapid prototyping and is gaining popularity in non-manufacturing fields including medicine and dentistry. More recently, human skin reproduction for facial prosthetics utilising 3D imaging production techniques have been recognized as an important innovative manufacturing process that may have a significant impact on the delivery of these prostheses to patients (van Noort 2011).

However, the accuracy and consistency of colour reproduction has become a critical element in the 3D advanced manufacture of facial soft tissue prostheses, and there are still significant shortcomings in achieving this using the current system. This is primarily due to differences in the way RGB colour systems are used in the 3D colour printing process, these being quite different from the way human visual perception does. That is to say, RGB colour signals used in manufacturing processes cannot be directly linked to the human visual system, and in order to reproduce a subject's skin colour that can be considered "accurate" in terms of human perception a colour reproduction system has to be developed for the 3D colour printing process.

The primary objective of this study was to develop a colour reproduction system for 3D colour printing and to comprehensively evaluate its colour reproduction performance for the application of facial soft tissue prostheses. This new approach was established to apply conventional colour management techniques to a Zcorp 3D colour printer. 3D colour images were downscaled into 2D colour images and transformed from target CIE LAB values to corresponding printer RGB values. 3D texture mapping was then conducted to map the processed 2D image into a 3D model. The system was then evaluated using human skin colours.

2. MATERIAL AND METHOD

2.1 3D colour printing

In this study, a Zcorp Z510 3D colour printer (Figure 1) was employed and a protocol to make soft tissue prostheses was developed and is described below.

First, a 3D colour image is sent to the 3D colour printer for the printing of a 3D object using starch powder (Z15e, 3DSYSTEMS Limited). During the printing, instead of ink the printing heads release a binder onto a powder foundation according to the 3D digital images, and this allows printing in a cross sectional 2D layer. The process is then repeated to produce a new 2D layer on top of the previous layer. The process of printing continues until a full 3D colour object has been built up. In the second step, the 3D colour object is removed after printing within 20 minutes of completion and any excess powder removed. It is then left for 30 minutes in an airtight storage container. Third, infiltration processing is conducted in order to infiltrate the 3D object with a clear medical grade silicone polymer (Silskin 25). Finally, the 3D object is left for 24 hours to dry completely.

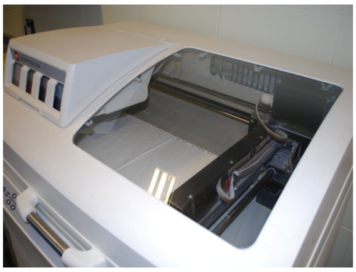
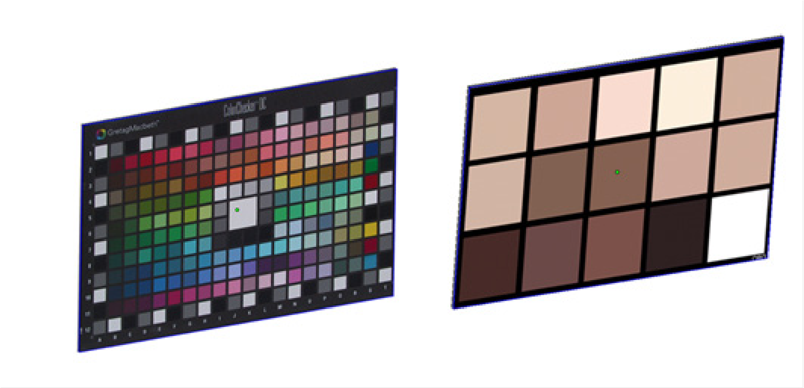


Figure 1: Zcorp Z510 3D colour printer.

2.2 Printer colour profile

In order to achieve an accurate colour reproduction for facial prostheses, a colour profile was developed for the 3D Zcorp Z510 3D printer to transform target CIELAB values to printer RGB values using the conventional colour management technique (Johnson 1996). To achieve this result, in this study, 240 training colours were selected using a Macbeth ColorChecker DC chart and converted to a 3D model with dimensions of 200(l) ′ 150(w) ′ 3(h) as demonstrated in Figure 2a. For each of the training colours, a digital RGB was achieved in Adobe Photoshop (Adobe Inc., San Jose, USA) and their CIELAB values were obtained by colour measurement using a Minolta CM-2600d spectrophotometer applying SpectraMagic NX Colour Data Software under a CIE standard D65 lighting source. A polynomial regression with least square fitting (Hong et al. 2001) was adopted to predict relationship between CIE XYZ tristimulus values and printer RGB values for the printer colour profiles. Ultimately, and the third order polynomial regression model for the Zcorp Z510 printer achieved the best performance and were therefore adopted in this study. Colour Image processing was performed using MATLAB (MathWorks, Inc., Natick, Massachusetts).



(a) Training colours　　*(b) Testing colours*

Figure 2: Colour charts for 3D image reproduction.

3. RESULTS AND DISCUSSION

A colour managerment system was developed for the advanced manufacture of soft tissue prostheses using 3D printing. The performance in colour reproduction was evaluated using 14 known human skin colours including 4 Caucasian, 2 Chinese, 2 Asian, 4 African and 2 Caribbean skin shades. Their CIELAB values were obtained by direct skin colour measurements using the spectrophotometer and refered as original LAB values. To evaluate the accuracy of the proposed 3D colour reproduction system, the colour difference between original LAB values and reproduced LAB values were calculated for those 14 testing colours. The results in terms of mean, maximum, minimum and standard deviation are shown in Table 1. Figure 3 also illustrates the colour reproduction performance for each skin shade. For soft tissue prostheses, colour differences less than 3.0 units have been deemed acceptable, according to research published by Paravina et al. (2009). A solid black line was plotted in Figure 3 to demonstrate the acceptable colour difference when referring to skin colour reproduction. This demostrates that apart from one Caucasian skin colour, the colour reproduction error for the majority of skin tones was very close to the $3\Delta E^*_{ab}$, indicating that colour reproduction was acceptable.

By comparison, conventional inkjet printers, using the same approach, can achieve a colour reproduction accuracy of approximately 2 ΔE^*_{ab}. Therefore, our study indicates that the proposed colour reproduction system cannot achieve the same level of performance with the 3D colour printer. One of the main reasons for this is that the 3D colour printing system cannot maintain a consistent colour output due to its complicated processing method.

Table 1: Colour difference between original colour chart and reproduction colour charts.

Colour Reproduction	**Mean**	**Max**	**Min**	**STDEV**
CIEΔE$^*_{ab}$	4.3	10.0	0.2	2.1

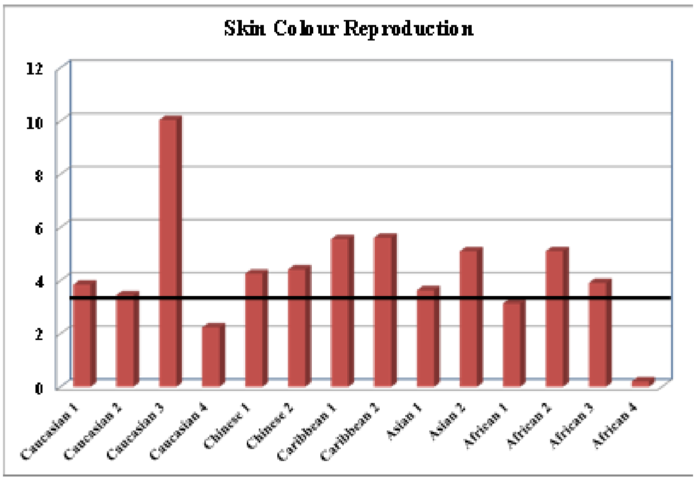


Figure 3: Colour reproduction for human skin colours.

4. CONCLUSIONS

In this study, we proposed a colour reproduction system for the advanced manufacture of soft tissue prostheses. A 3D printing system was adopted that printed 3D objects using a Zcorp Z510 3D colour printer and silicone infiltrated starch powder models. Using a sample of 240 printed training colours, the colour profile for the 3D colour printing system was developed using a third order polynomial repression model. The colour reproduction system was developed and system performance was then evaluated to have a satisfartory results.

ACKNOWLEDGEMENTS

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Colour Analysis of Degraded Parchment

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ABSTRACT

Multispectral imaging was employed to collect data on the degradation of an 18th century parchment by a series of physical and chemical treatments. Each sample was photographed before and after treatment by a monochrome digital camera with 21 narrow-band filters. A template-matching technique was used to detect the circular holes in each sample and a four-point projective transform to register the 21 images. Colour accuracy was verified by comparison of reconstructed spectra with measurements by spectrophotometer.

1. INTRODUCTION

Large collections of parchment documents exist in public and private libraries, archives, and museums in varying degrees of preservation. Parchment is prepared from an animal skin that has been wetted, immersed in lime water, dehaired, scraped, then left to dry under tension on a wooden frame. The stretching has the effect of reorganising the collagen fibre network into a laminate structure. The resulting material is a fairly stiff sheet which is durable and can last for centuries, provided it is kept cool and dry (Clarkson, 1992).

Figure 1: Detail of C18th parchment.

In this project, we investigated the processes of controlled document degradation using multispectral imaging. We obtained an 18^{th} century manuscript de-accessioned from the London Metropolitan Archives (Fig. 1). Although in good physical condition, this manuscript was deemed to hold no historical value, and it was kindly donated for experimentation. It comprised two large sheets of prepared animal skin, i.e. parchment, written in iron gall ink and highlighted in red ink. Each sheet measured approximately 70×70 cm (Fig. 1), and the two had been tightly folded together for storage. The document was an indenture (contract) between Mr John Sherman and Mr Christ Gardiner dated 11th August 1753.

Twenty-three square sections of 8×8 cm were cut from the original manuscript, with each section containing written text. Each sample was exposed to a different external deteriorating agent to produce a controlled degradation, including mechanical damage, heat, humidity, abrasion and a variety of substances with different chemical properties, such as acid, alkaline, bleach, red wine, tea, human blood and mould. These affected the appearance and condition of the samples in different ways, typical of the actual damage suffered by parchment in real archives. Preliminary tests proved the viability of the procedures for degrading the samples and enabled parameters to be established for each treatment process (Giacometti *et al*, 2012).

2. MULTISPECTRAL IMAGE CAPTURE

Multispectral imaging can be used to discriminate between reflectance spectra, and hence to identify and separate different types of inks in a single document, showing whether the document has been edited. The carbon black ink of antiquity consisted of graphite or soot particles suspended in an organic binder and applied with a stylus. Such inks do not penetrate the parchment but rest on top, with particles adhering to the micro-structure of the surface. Iron gall ink, also known as gallo-tannin ink, was introduced around the third century AD, prepared with organic material that penetrates more deeply into the substrate and reacts, staining it black. Chabries *et al* (2003) noted that parchment reflectance increases at longer wavelengths, resulting in greater contrast of text in infrared images.

Each of our parchment samples was imaged before and after treatment through a series of bandpass filters, illuminated by four tungsten-halogen lamps on a photographic copystand. The Kodak Megaplus 1.6i camera with Nikkor 50 mm f/2 lens captured monochrome images of 1536×1024 pixels in both the visible and near-infrared spectrum over the range 400–1100 nm. A set of 21 bandpass optical interference filters was used, spaced at 20nm intervals across the visible spectrum and 50nm in the infrared. The spectral transmittance of each filter was measured with an Ocean Optics HR2000+ spectrometer.

Because parchment is prone to curl, a 3 mm glass plate with anti-reflective coating was placed over the sample to hold it flat on the baseboard. In total 23×21×2 = 966 images were captured by the Kodak camera for all parchment samples before and after treatment. Four circular holes of diameter 1 mm were drilled in each sample at approximately one third and two thirds of the width and height. These holes are apparent in each image and remained as persistent features after the samples were degraded, both as reference points for registration of the multispectral image channels and for comparison of image sets of the samples before and after treatment.

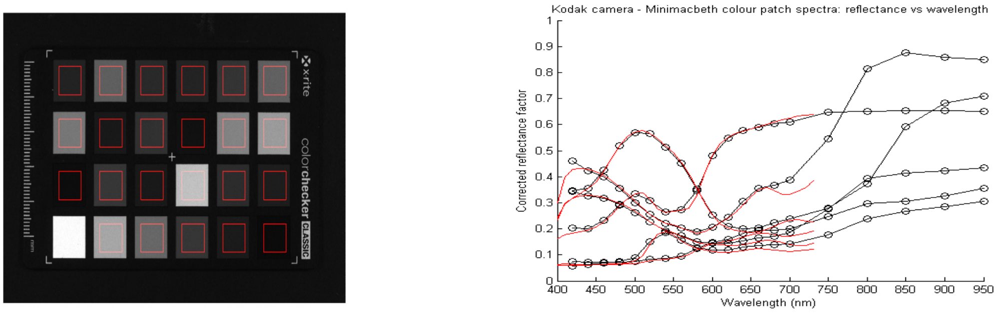

Figure 2: (left) 580nm image of MiniMacbeth target with sampling boxes; (right) reflectance factor vs wavelength for camera (black lines with circles) and spectrophotometer (red lines) for top row.

To check the accuracy of reconstruction of reflectance spectra from the multispectral image sets, a MiniMacbeth target was measured with an X-rite i1Pro spectrophotometer at 10nm intervals from 380 to 730 nm. The results were in good correspondence with the corrected camera responses for all four rows of the MiniMacbeth target (Fig. 2). The camera values at 400 nm were not reliable because the very low power of the lamp in this waveband required excessively long integration times for image capture, with consequent low signal-to-noise ratio. The CIE $L^*a^*b^*$ values were calculated for each reflectance spectrum, using the CIE 2° standard observer and illuminant D65, and the mean colour difference over the 24 patches was $\Delta E^*_{ab} = 3.4$. The maximum error was 6.5 for the fourth patch in the second row (purple).

3. IMAGE REGISTRATION AND ANALYSIS

Because of differences in refractive index of the camera lens for different wavelengths of light, the geometry of the successive images in the multispectral sequence varied from one image to the next, so that no two were in perfect register. Also the treatment in some cases radically altered the parchment, causing substantial distortion to its geometric structure. To make a composite image of all the wavebands it was necessary to put them all into accurate register, using the four holes drilled in each parchment sample as the anchor points for a projective geometric transform (MacDonald *et al*, 2013).

The image of the sample before treatment taken through the 600 nm filter was chosen as the reference and all other images, both before and after treatment, were registered to it. A template matching procedure enabled the centroid of each of the four holes in each sample to be located accurately (Fig. 3 left). Given an approximate starting position, the algorithm incremented the diameter of a circular anti-aliased template in units of 0.1 pixel over the range 12 to 16 pixels (1.0 to 1.3 mm), and the template was successively translated along the x and y axes. At each coordinate position a cross-correlation was performed between the template and the corresponding image section. The accuracy of the registration procedure is shown in the false-colour image composite (Fig. 3 right). The transformed image (red channel) is closely in register with the reference image (blue channel), so that they appear everywhere as a unified magenta.

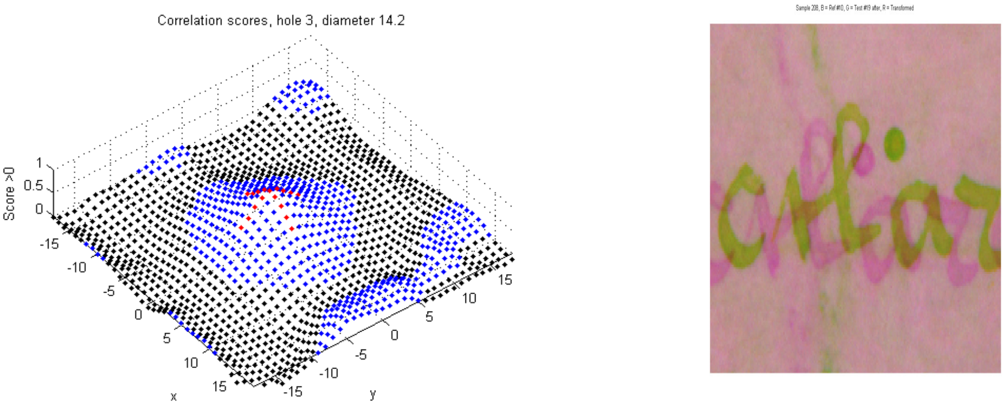

Figure 3: (left) Correlation scores from template matching on one of the registration holes, visualised as a surface on a pixel grid, showing the peak score at the hole centre, and secondary peaks caused by the ink strokes. Scores < 0 are represented by black dots, and scores > 0 by blue dots. The red cross shows the row and column indices of the peak score. (right) False-colour composite of reference 600 nm channel of sample before treatment (blue), 850 nm channel of sample after treatment (green), and the latter after registration (red).

When all of the image channels for the sample before and after treatment had been accurately registered, it was possible to compare the reflectance spectra at any pixel position. Fig. 4 shows the effect of the treatment by blood on the parchment and iron gall ink. The spectra are plotted for all nine pixels in a 3×3 pixel region around the selected coordinates, together with the mean in green (before) and red (after). The blood clearly affected the colour of the parchment, reducing its reflectance factor from about 0.5 to less than 0.1 in the short wavelengths, rising to about 0.4 at long and NIR wavelengths, producing a dark red colour. The ink spectrum was apparently not much changed except at wavelengths greater than 850 nm.

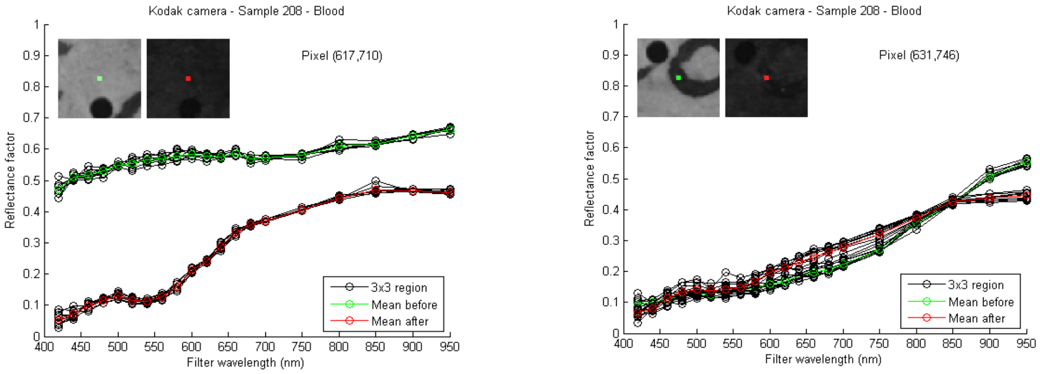

Figure 4: Reflectance spectra before and after treatment for (left) parchment and (right) ink.

A typical problem where a degraded parchment is subjected to analysis is that its original state (both text and material) is not known, and so assumptions must be made in guiding the digital restoration. Our dataset of the parchment samples before treatment provides a 'ground truth' for analysis of the effectiveness of image processing algorithms in restoring images of the degraded samples. Our dataset of the samples after treatment shows exactly the effect of the physical changes on the reflectance. Analysis of multispectral images of scraped or mechanically damaged samples enables us to identify even faint traces of ink. It also enables the discrimination of inks similar in appearance, and the recovery of writing from darkly stained parchment and from charred and burned fragments. Because the reflectance spectrum can be estimated from the multispectral image set, the appearance of the parchment under any illumination source of known spectral power distribution can also be predicted.

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Teaching Colour Theory Online: Challenges, Opportunities and Experiences

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ABSTRACT

Over the past decade, various paradigm shifts and challenges have rapidly changed learning and teaching in higher education including meeting student expectation for more engaging, more interactive learning experiences, the increased focus in the tertiary sector to deliver content online, and dealing with the complexities of fast-changing technologies. Rising to these challenges and responding to them is a complex and multi-faceted task. This paper discusses a case study undertaken applying a framework drawn from engineering education teaching and learning methods using the concept of academagogy, which is learner-centric, actively empowering students in building effective learning and engages facilitators in meaningful teaching and delivery methods.

1. INTRODUCTION

The challenges and shifts in the tertiary education context are complex and are good reason to change out-dated teaching and learning practices. One of the driving reasons for transformation is the generational change in students, and another is the increased focus of online teaching and learning in the university sector. Considering these factors, the current learning approaches in academia are not always in sync with the current generations as learning must be perceived as relevant and content must be specific, concise and fast. Teaching and learning has changed significantly in the past two decades, and as the new generations of students begin moving through today's higher education systems, curricula and teachers need to evolve and develop new teaching methodologies to reach this generation, which spends as much time stimulated by digital media as it does in the learning environment.

Proposing a new direction in teaching and learning is the notion of 'academagogy' (McAuliffe, Winter, Hargreaves and Chadwick 2008), developed from the Greek roots from pedagogy, andragogy and heutagogy. One of the primary aims of academagogy is to

> Open up teaching concepts, and allow the informed academic to apply what works for them in their own context. This means that the facilitator, or, in the university context, the lecturer, could select certain concepts from the "buffet" of educational concepts – take what is required for the appropriate learning outcomes, because they have permission to look at the whole spread and evaluate it for their own purposes (Winter, McAuliffe, Chadwick and Hargreaves 2009:993).

Added to the above concerns is the issue of teaching colour in design courses. One of the main problems of teaching colour in higher education is the reticence of specifically including colour theory in design programs, and those universities who do include it often misunderstand the theories and complexities of colour theory, despite its existence as an essential element in art, design and architecture. O'Connor (2010) suggests that there are three fundamental reasons for the relegation of colour theory to low priority in higher education curriculum.

The first issue relates to the diversity of colour theories and their link to a range of different domains from which theories of colour have evolved, such as art and design, history, physics and psychology. Whilst diversity is important in many domains, such as in architecture and design, in colour theory it has led to a lack of commonality among colour theories especially in terms of embedded theoretical paradigms and ontological assumptions. The second issue is that these diverse theories have largely not evolved to reflect current theoretical paradigms. For example, many well-known and referenced colour theories depend on "outdated theoretical paradigms and include constructs that are questionable, problematic or in need of review and revision" (O'Connor 2010:1). The third issue is that the colour theories that are taught are "a jumbled maze of explanatory, normative and predictive colour theories coupled with colour manifestos and personal opinions masquerading as theory, plus a host of colour creation and colour combination techniques" (O'Connor 2010:1).

As such, the diversity of ontological assumptions and paradigms apparent in various colour theories have resulted in ambiguity and confusion, which has led to an inability to clearly define and describe colour. It has also been problematic in attempting to explain the interface between colour and human perceptual, cognitive, affective, physiological and behavioral response. This lack of clarity has led to the marginalisation of colour theory, thus demeaning its status in higher education; most particularly in architecture and design curriculum.

2. IMPLEMENTATION

Taking the principles of academagogy, a subject[1] addressing colour theory, light and lighting was developed for online delivery at a university[2]. This subject was previously delivered successfully in face to face format, but this was the first iteration of the subject as a 'hybrid' or mixed-delivery – part online, part face to face.

The aims of the subject were to develop knowledge in the theory and application of colour, light, and lighting fixtures, focusing on experimental research and design applicable to colour, light and lighting relevant to design and design practice. On completion of the subject, students would be expected to: 1. apply knowledge in advanced colour theory and lighting and the properties and interrelationships of colour and light, the uses of colour, light, types of lighting and fixtures in the context of architecture and interior design; 2.demonstrate a developed understanding of the psychological properties and symbolic roles of colour and light, and the critical, creative and analytical issues in colour, light and lighting in relation to various contexts including built environment and spatial design; and, 3.integrate and adapt knowledge and skills through the application of an acquired theoretical and technical knowledge of colour and lighting related knowledge in the context of design scenarios.

In Semester 1, 2013, the subject was developed for 'hybrid' delivery, where more than 85% of the subject was to delivered online (including lectures and tutorials), and the remaining was held on-campus and delivered in traditional face to face mode. The lectures delivered online were as 'mini-lectures' and uploaded to a video sharing website; the students were provided with full digital copies of the lectures; weekly class tutorials were held online using the University's online learning site via a virtual classroom; and students who wished to converse with the lecturer or tutors were to meet with them over teleconferencing software at arranged times as one to one tutorials.

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[1] The subject is called Colour and Light

[2] The university is Queensland University of Technology, Queensland, AU.

Over the course of the semester, the subject was reviewed and feedback garnered from students over email, teleconferencing and text message, and the unit content was modified in order to ensure that students were able to grasp and absorb content. New approaches in explaining complex concepts were explored and simple examples were drawn upon. Overall, the most attractive aspect of online learning for students was the ability to watch lectures at their own pace and when they liked; they felt as though they had much more control over their own learning. The least attractive aspect of online learning was that the students felt that the responsibility of learning was placed on them, rather than simply showing up to lectures and tutorial, as is the usual case in face to face learning.

3. RESULTS AND DISCUSSION

When applying the academagogical model in teaching colour theory, care was taken to leverage the strengths of the cohort of learners and their educational and social needs. The outcomes aimed to ensure the encouragement of social connectivity (an important aspect of tertiary education), group work (learning about and from each other), flexible learning settings, and most importantly of all, empowerment for lifelong learning.

Feedback from the students identified that overall, most students were happy with the hybrid approach, and appeared confident in their own learning ability. Releasing lecture content in ‘bite-size pieces’ gradually over the course of the semester (without reducing the content), increasing the number of worked examples for concept mapping, developing research questions, critiquing literature, identifying ‘gaps’ in knowledge, reviewing research, developing user needs and design objectives, and learning to take concepts to final design all appeared to have beneficial effects to the students learning. In terms of the overall success of the subject, the pass percentage was up 40%, with higher grades increasing by 10%, compared to past years’ iterations.

Implementing academagogy is not a ‘one size fits all’ approach, and as such, is very time consuming for the lecturer because of the need to tailor the delivery to the student’s requirements (which will most likely change from semester to semester). Extra support and planning time is one of the major requirements for academagogy. Delivering material online also requires the lecturer to play more of a facilitator role - rather than a more directive or authoritative one, which conflicts with traditional teaching methods. Furthermore, it requires the teacher to somewhat ‘trust the learning processes’; to step back and allow learning to happen without ‘hands-on’ direction and guidance.

In teaching colour theory online using academagogical principles, students develop the knowledge and confidence as independent thinkers and can understand the relationship between colour, light and design, which, coupled with their own research skills, lead to new thought processes. This approach has challenged the students to ‘step up to the plate’ in terms of their own learning, and they have responded to this challenge exhibiting that they are empowered by having input into what and how they learn. This has enabled them to broaden their knowledge, being able to think holistically about the interdependence and interrelationships of design, colour, light and lighting, and that the complexity of colour and light serve as a medium in all aspects of design, not simply applied post-design in a superficial or decorative manner.

In developing online content for teaching colour, there are various external issues at stake. Not only is it difficult to teach the various facets of light, lighting and colour in their many descriptive, normative and predictive theories, but the challenge is to make these relevant and coherent for real world and real design practice. Added to this, academics do not simply deliver knowledge and content to a ‘tabula rasa’; students are taught the content, and as such, a variety of student characteristics affect the way learning occurs. As such, online learning and teaching in this context ‘raises the bar’ in terms of what we know and understand about traditional ‘pedagogical’ practice.

Delivering content for colour and light through ‘hybrid’ methods also requires alignment of educational outcomes with course requirements, as well as industry expectations. Emphasis should be placed on active enablement and engagement with technologies and constructing effective connections with students to build a vibrant learning ecology. This helps to achieve three significant benefits: firstly, promote a joint ‘ownership’ of outcome based academic curriculum between learners and facilitators; secondly, encourage communication and teamwork; and finally, leverage on the students’ need for social connectivity on a 24/7 basis. Additionally, it also seeks to support the holistic transformation from using of information to application of wisdom and the converting of knowledge into action through experiential learning. Lastly but importantly, it nurtures a positive attitude toward new technologies and ways of imparting knowledge.

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