การเปลี่ยนแปลงของการปรากฏสีเนื่องจากการเปลี่ยนแปลงของรูปร่างตัวอย่างสีและสีพื้นหลัง

นางสาวชวิกา ไตรศิวะกุล

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาเทคโนโลยีทางภาพ ภาควิชาวิทยาศาสตร์ทางภาพถ่ายและเทคโนโลยีทางการพิมพ์
คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2554

CHANGES OF COLOUR APPEARANCE DUE TO CHANGES OF SHAPE OF COLOUR SAMPLE AND BACKGROUND COLOUR

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Imaging Technology
Department of Imaging and Printing Technology
Faculty of Science
Chulalongkorn University
Academic Year 2011

Thesis Title	CHANGES OF COLOUR APPEARANCE DUE TO CHANGES OF SHAPE OF COLOUR SAMPLE AND BACKGROUND COLOUR
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ชวิกา ไตรศิวะกุล : การเปลี่ยนแปลงของการปรากฏสีเนื่องจากการเปลี่ยนแปลงของรูปร่างตัวอย่างสีและสีพื้นหลัง. (CHANGES OF COLOUR APPEARANCE DUE TO CHANGES OF SHAPE OF COLOUR SAMPLE AND BACKGROUND COLOUR) อ.ที่ปรึกษาวิทยานิพนธ์หลัก : ผศ.ดร. สุจิตรา สื่อประสาร, 67 หน้า.

พื้นหลังเป็นปัจจัยที่สำคัญปัจจัยหนึ่งที่ส่งผลต่อสีที่ปรากฏของสีตัวอย่าง โดยทั่วไปสีพื้นหลังจะเหนี่ยวนำให้สีตัวอย่างมีสีหรือความสว่างไปในทิศทางตรงข้ามกับสีพื้นหลัง ตัวอย่างเช่น สีเทาบนพื้นหลังสีดำจะมีความสว่างปรากฏมากกว่าตัวอย่างสีเทาเดียวกันที่อยู่บนพื้นหลังสีขาว รูปร่างของสีตัวอย่างเป็นอีกปัจจัยหนึ่งที่ส่งผลต่อความรู้สึกและการรับรู้ของผู้สังเกต งานวิจัยนี้จึงศึกษาผลของรูปร่างของตัวอย่างสีที่มีต่อระดับการเหนี่ยวนำของสีพื้นหลัง โดยทำการทดลองหาค่าความแตกต่างสีระหว่างสีที่ปรากฏบนพื้นหลังสีต่าง ๆ กับสีที่ปรากฏบนพื้นหลังสีเทา โดยใช้ผู้สังเกตคนไทยจำนวน 40 คน เป็นผู้ชาย 20 คนและเป็นผู้หญิง 20 คน มีอายุเฉลี่ย 24.3 ปี ทุกคนมีการมองเห็นสีปกติ ดูตัวอย่างสีที่มีรูปร่างแตกต่างกันบนพื้นหลังแต่ละสี และเทียบหาตัวอย่างสีรูปร่างสี่เหลี่ยมจัตุรัสที่มีสีปรากฏเหมือนกันแต่แสดงบนพื้นหลังสีเทา รูปร่างที่ทดสอบมี 6 แบบ ได้แก่ วงกลม สี่เหลี่ยมจัตุรัส ข้าวหลามตัด สามเหลี่ยมหน้าจั่ว สามเหลี่ยมมุมฉาก และรูปหกเหลี่ยม พื้นหลัง 4 สี ได้แก่ สีแดง เหลือง เขียว และน้ำเงิน เปรียบเทียบผลการเปลี่ยนแปลงของสีที่ปรากฏเนื่องจากอิทธิพลของสีพื้นหลังและรูปร่างของตัวอย่างสีที่แตกต่างกัน จากการทดลองพบว่ารูปร่างวงกลมเกิดการเหนี่ยวนำจากอิทธิพลของสีของพื้นหลังมากที่สุด และรูปร่างข้าวหลามตัดเกิดการเหนี่ยวนำสีของพื้นหลังน้อยที่สุด แสดงให้เห็นว่า ทั้งรูปร่างและพื้นหลังมีผลต่อการเปลี่ยนแปลงของสีที่ปรากฏ

ภาควิชา วิทยาศาสตร์ทางภาพถ่ายและเทคโนโลยีทางการพิมพ์ ลายมือชื่อนิสิต
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ปีการศึกษา 2554

5272274023 : MAJOR IMAGING TECHNOLOGY

KEYWORDS : COLOUR APPEARANCE / SHAPE / BACKGROUND / SIMULTANEOUS CONTRAST

CHAWIKA TRAISIWAKUL : CHANGES OF COLOUR APPEARANCE DUE TO CHANGES OF SHAPE OF COLOUR SAMPLE AND BACKGROUND COLOUR. ADVISOR : ASST. PROF. SUCHITRA SUEEPRASAN, Ph.D., 67 pp.

Background is one of the important factors that affect colour appearance of samples. In general, a background colour induces colour appearance of a sample to shift towards the complementary colour of the background. For example, grey on black background appears lighter than the same grey on white background. Shape of colour sample is also a factor that can affect sense and mood of observers. The degree of colour shifts due to the background colour might be different for different shapes of colour samples. This study thus investigated this aspect. In visual experiments, the observers were 40 Thais, 20 women and 20 men, with an average age of 24.3 years, all with normal colour vision. Each observer matched colour appearance of square samples presented on a grey background with that of test samples with different shapes on a chromatic background. Six shapes, i.e. circle, square, diamond, isosceles triangle, right-angled triangle and hexagon, and four chromatic backgrounds, i.e. red, green, yellow and blue, were investigated. The differences between colours of the test and the matching samples were quantified by CIE total colour difference, ΔE^*_{ab}. It was found that circle induced the most changes in colour appearance of the sample due to the influence of background colour and diamond showed the minimum induction. Both shape and background contributed to changes in colour appearance.

Department : Imaging and Printing Technology   Student's Signature ....

Field of Study : Imaging Technology   Advisor's Signature ....

Academic Year : 2011

ACKNOWLEDGEMENTS

I would like to express my gratitude to my thesis advisor, Assistant Professor Dr. Suchitra Sueeprasan, whose encouragement, guidance and support enabled me to develop an understanding throughout this research. I appreciate her vast knowledge and her assistance in all the time of research and writing of this thesis.

I would like to express my sincere appreciation to Associate Professor Dr. Aran Hansuebsai who serves as a chairman for his comments, and suggestions. I am extremely grateful to Associate Professor Pichayada Katemake for her kindness and invaluable recommendations, and I am also heartily thankful to Professor Dr. Sato Tetsuya for inspirational and expert guidance which has a great benefit.

My appreciation is also to all observers that dedicated their valuable time for participating to complete my experimentations. I am greatly indebted to them. This thesis would not have existed without them.

Many thanks furthermore go to all of the staff in the Department of Imaging and Printing Technology for their support through my graduate.

Lastly, my loving thanks are due to my parents for their loving support. Without their encouragement and understanding, it would have been impossible for me to finish this research.

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CHAPTER I
INTRODUCTION

Human colour vision is caused by light reflected from an object entering the eyes, the brain then interpreting what the observer sees. Thus there are three factors of colour vision, which are a light source, an object and the eyes of an observer. The human eye has two types of photoreceptors: rods and cones. Rods have high sensitivity. They are not able to distinguish colours. Cones, on the other hand, are sensitive only to high-intensity light and can be classified into three different frequency ranges: the short wavelength (blue), the middle wavelength (green) and the long wavelength (red) cones. The phenomena of colour contrast (colour perception changes due to the influence of the background colour), colour constancy (colour perception of the environment is maintained even if lighting conditions change) and the influence of the environment show that colour vision has a direct relationship with the light reflected from the object. The perception of colour depends on the experience of the individual observer [1]. There are many factors that induce the change of colour appearance. One important factor is a background on which the colour is presented. The sample colour is induced by its background colour and/or brightness in the direction opposite to the background colour. For example, a grey sample on a black background will appear brighter than the same grey sample on a white background. This phenomenon is called simultaneous contrast [2].

The shape of the sample is another factor that affects the senses and the perception of the observer. The results from Lee et al's study [3] showed the influence of colours and shapes on the feelings to various objects in 2D and 3D forms. It was found that the forms of circle and sphere yielded the most different feelings from the common sample form of two-dimensional rectangular. Five dimensions of colour emotions [4] were affected by different factors. The dimensions of "activity", "weight", and "heat" were affected by colour of the objects. The dimensions of "softness" and "complexity" were affected by shape of the objects.

In most researches on colour appearance, 2D square samples are commonly used. However, in everyday life, colours are often seen in various shapes, either in print media, or on television, or on the Internet. Colours are used in various shapes on a colour background. Difference in shape of colours may be affected by simultaneous contrast differently. The colour of the background might induce more changes on the colour sample having a certain shape than the others. This research thus investigated the effect of shape on the induction level of the background colour. Different shapes of a grey sample were displayed on a colour background and the effect of shape was determined by the differences in colour perception between the colours in different shapes displayed on a colour background and the matching colour in square shape displayed on a grey background.

1.1 Objective

To investigate the effect of shape of colour samples on the level of chromatic induction of the background colour.

1.2 Scope

Forty Thai people aged 20-28 years with 20 men and 20 women took part in the experiments. Each observer matched colour appearance of square samples presented on a grey background with that of test samples with different shapes on a chromatic background. All samples were shown on a CRT monitor. The experiments were done in a darkened room. Six shapes were included in this study. They were circle, square, diamond, isosceles triangle, right-angled triangle and hexagon. Four chromatic backgrounds were red, green, yellow and blue. They were chosen to have the same lightness as the grey background of the matching samples, so that only the chromatic induction occurs, and the results can be compared between different backgrounds. The differences between colours of the test and the matching samples were quantified by CIE total colour difference, ΔE^*_{ab}.

1.3 Expected Outcomes

1. The degree of colour changes due to the influence of the background colour.

2. The impact of shape on the level of induction of the background colour.

1.4 Contents

Chapter 2 consists of the theoretical consideration and literature reviews that relate to this research. Chapter 3 gives details of experimental set-up. The experimentation consists of pre-experiment, visual experiments, and analysis of the results from the visual assessments. In Chapter 4, the results are reported and discussed. Chapter 5 gives conclusions and suggestions for future work.

CHAPTER II

THEORETICAL CONSIDERATIONS AND LITERATURE REVIEWS

2.1 Theoretical Considerations

2.1.1 Factor of visual system

Human colour vision is caused by the light reflected from the object to the eye and the brain to interpret it as you see. So three factors of colour vision are light source, object and human eye. As already mentioned, that when light from a light source shines on an object, the object radiation is reflected into the eye. The human eye is sensitive to light with three primary colours: red, green and blue. The visual attributes indicate the colour of objects.

1. Colour vision in the red, green or blue, called Hue (h_{ab}).
2. The brightness of the colours. This is a reflection of the light that difference is called Lightness (L*).
3. Colour intensity and purity of colour, called Chroma (C^*_{ab}).

The visual system [5] can be described by both physical actions such as a producing a stimulus in the form of light and subjective results such a receiving and interpreting this stimulus in the eye and the brain, as shown in Figure 2-1.

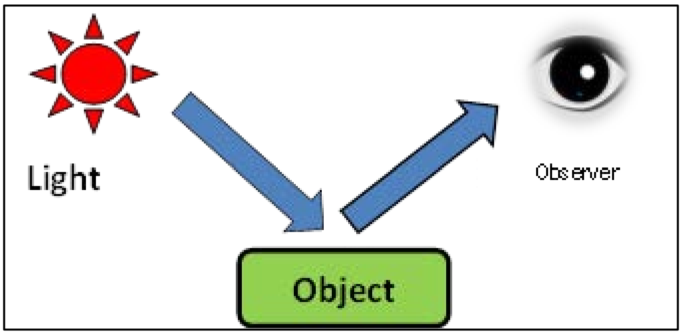


Figure 2-1 Factor of visual system

2.1.1.1 The light Souce

The light source for vision can be divided into two types: natural and artificial light source. Natural light source is light from the sun during the day (Daylight). Light to the earth's surface is white and when white light passes through a prism, it splits into seven different bands of colour. Each region of the country has different energy distributions (Spectral Energy Distribution, SED), based on terrain, climate, season, and time period. Thus, colour vision, with a natural light source, depends on time period different location and weather. They cause the different colours to vision. Light source emits large quantities of photons and light can be described by its wavelength for which the nanometer (nm) is a convenient unit of length. The relative sensitivity of the eye limits the visible part of the spectrum to a very narrow band of wavelength between 380 and 780 nm. Figure 2-2 shows the hue as blue lies below about 480nm, green between 480 and 560, yellow between 560 and 590, orange between 590 and 630 and red at wavelength longer than 630 nm. The purple which is produced by mixing red and blue light from the extremes of the spectrum is not found in the spectrum [6].

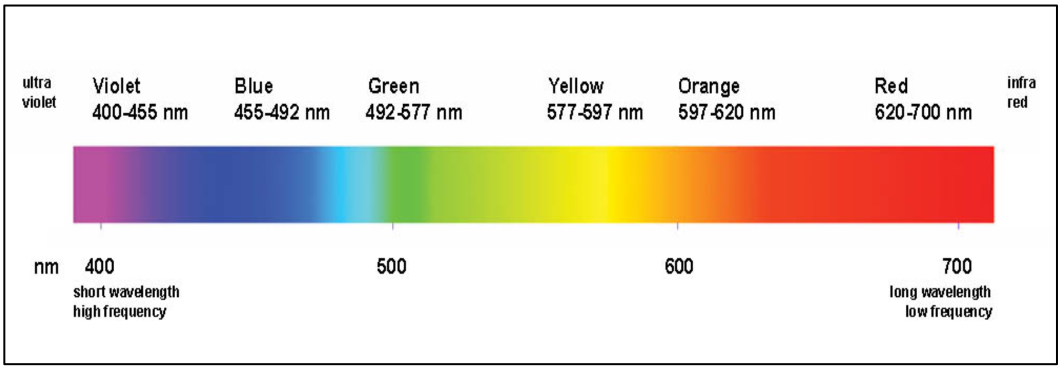


Figure 2-2 The visible spectrum. [7]

2.1.1.2 An object

Light from the light source is incident on an object that has the phenomenon of light reflection at the surface of an object with a smooth and gloss called specular reflection (Figure 2-3). If the surface roughness is not glossy, when light passes through the object, it will (Figure 2-4). Some waves are reflected off the surface and some are absorbed. We call this phenomenon the Diffuse transmission. But if the object is transparent, like glass, light passing through transparent objects is a phenomenon called Regular transmission.

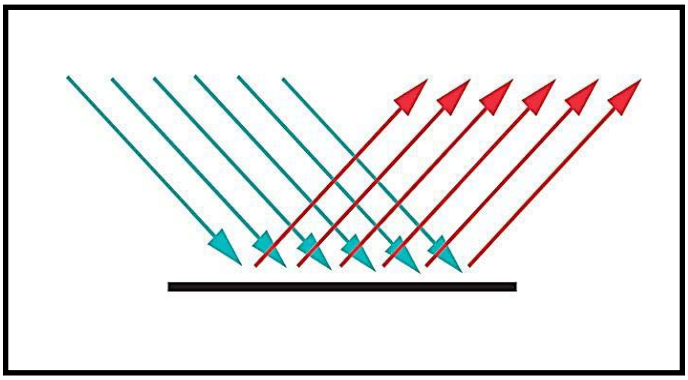


Figure 2-3 Specular reflection (smooth surfaces). [8]

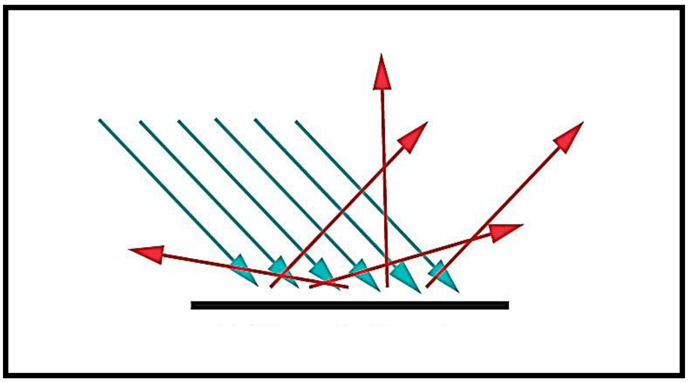


Figure 2-4 Diffuse reflection (rough surfaces). [8]

2.1.1.3 An observer

The observer is another factor of vision system. When light is incident on object and reflected into the eye of the observer. The observer will see the image on the retina and the brain interprets. The capture of the eye is similar to the camera capture [6]. The retina is made up of a complex network of cells and nerve cells (Figure 2-5). The retina consists of a large amount of cells which are sensitive to light. These cells have two types: rod and cone [9]. Rods detect amount of light which only see object as shade of grey. As the amount of light increases so the rods become desensitized and cease sending signals to the brain. The rod cells are inactive during the day. Cone are cells with three different types, which respond to red, blue and green regions of light, respectively, and it is though these that all colours are seen [10]. When the three types of cones are all stimulated equally, the eye and the brain see achromatic, but if one type of cone is stimulated more than the other two, the image appears to be tinted with the corresponding primary hue.

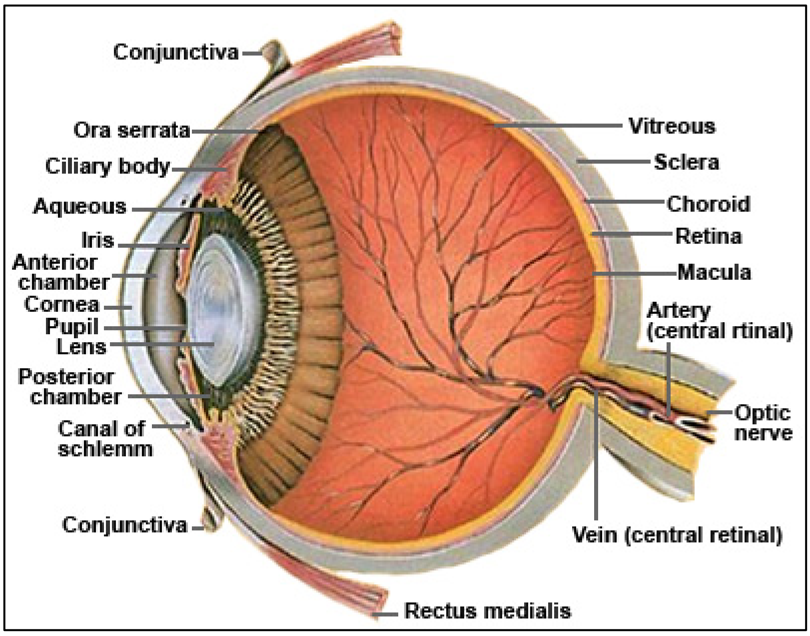


Figure 2-5 Cross-section illustration of the human eye, with structures labeled. [11]

The most central of the retina is called the fovea, and has the largest concentration of cells. The fovea vision is used for distinguishing very fine detail such as reading and seeing objects at distance. Outside the fovea, the number of cone is reduced. The signals leave the retina through the optic nerves and finally arrived at the back of the brain. The brain signals are interpreted through mental process of perception [6, 12].

In Figure 2-6, the relative spectral sensitivities of L, M, and S cones are shown. These spectral sensitivities are based on measurements in front of the eye rather than of isolated photoreceptors. The letters S, M, L represent the three cones with their peak sensitivities in short, middle long wavelength. Their spectral sensitivities overlap quite a bit of the L and M cones. If the receptor did not overlap, colour visual would only perceive three hues in the spectrum because of the uneven sampling of the wavelength. The spectral difference is only rarely used to predict visual differences [6]. The three maxima are found in the greenish yellow, the yellowish green, and in the violet regions of the spectrum. The hues of the spectrum are only approximately reproduced.

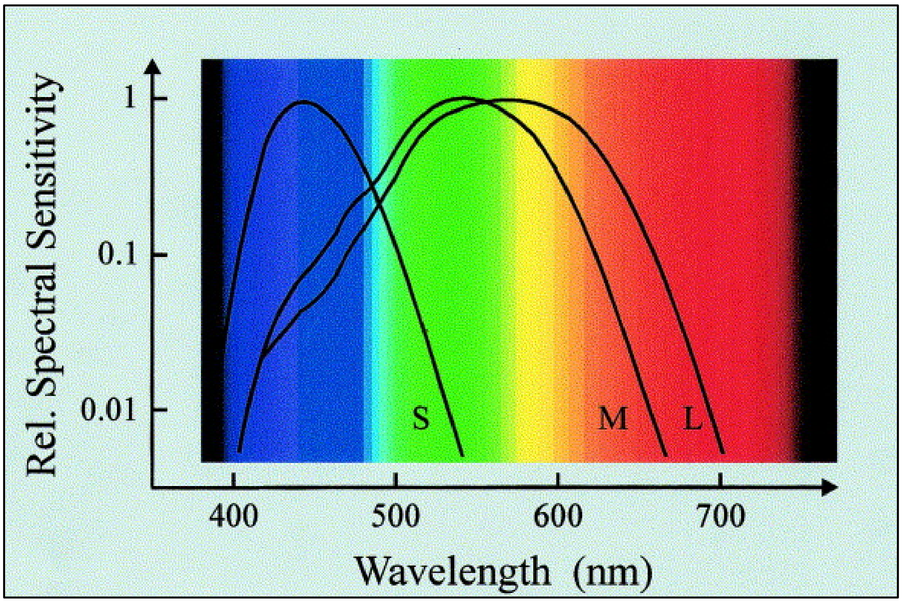


Figure 2-6 The relative spectral sensitivity of three types of cone photoreceptors, L, M and S, in the human retina. [13]

2.1.2 Simultaneous contrast

Simultaneous contrast [14] is a phenomenon that the colour appearance of colour changes due to the influence of the colour of the background. The background colour induces the opposite colour contrast (opponent-colour theory) onto the center colour. When the background is dark, the sample placed on the background is light. The light background induces a darker colour. Green background induces red; yellow background induces blue. And a blue background induces yellow. For example, the grey colour in the second plate is placed on a black background in Figure 2-7. The plate is placed on a white background. We can see that the colour grey on a black background colour is brighter than the grey on a white background.

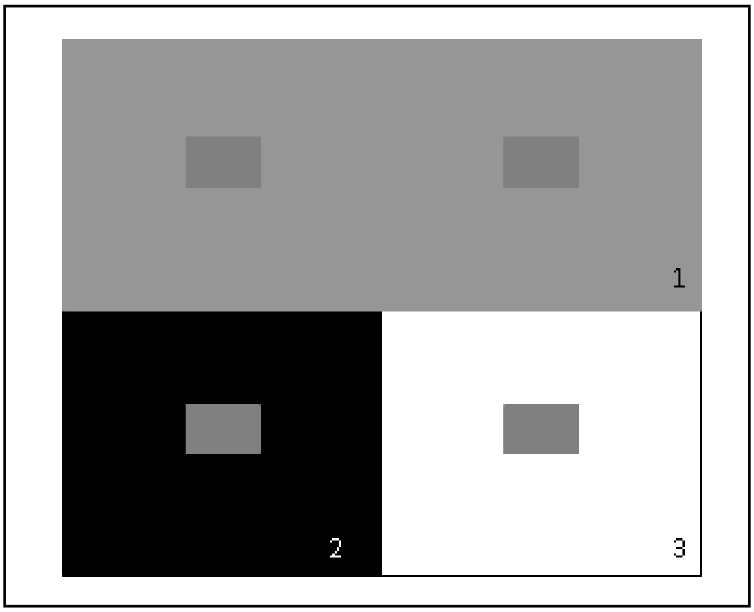


Figure 2-7 The phenomenon of simultaneous contrast (1) the same grey colour on two sheets of grey background (2,3) the same grey colour on the second sheet is placed on a black background. And another, on a white background, respectively.

Figure 2-8 shows an example of the colour grey on a dark blue background in comparison with the same grey on a green background. We can see that the colour grey on a blue background colour is yellowish and brighter than the colour grey on a green background that we see with reddish colour and darker. Figure 2-8.

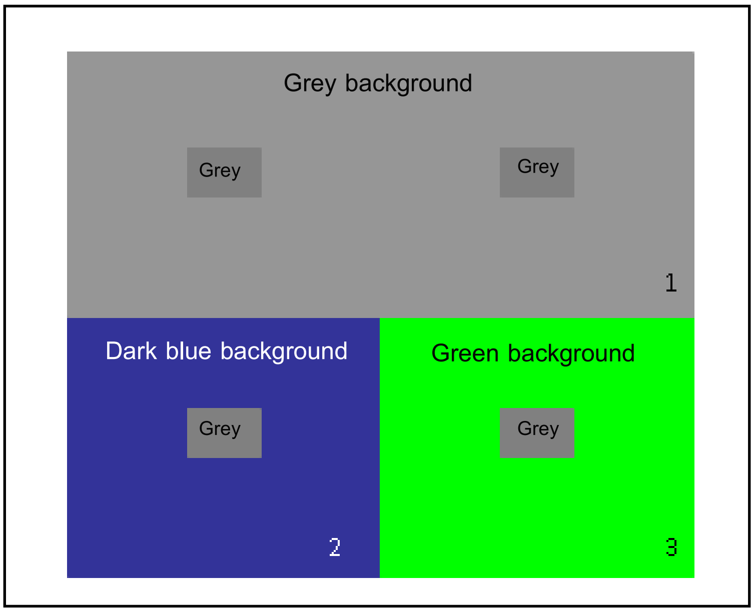


Figure 2-8 The phenomenon of simultaneous contrast on chromatic backgrounds. (1) The same grey on grey background. (2) The same grey on a dark blue background. (3) And another, on a green background.

Josef Albers [15], in his classic study Interaction of Colour, explored various aspects of simultaneous contrast and taught artists and designers how to avoid the pitfalls and take advantage of the effects. More-complete explorations of the effect are available in classic colour-vision texts such as Hurvich [16], Boynton [17] and Evans [18]. Cornelissen and Brenner [19] explored the relationship between adaptation and chromatic induction based on the concept that induction can be at least partially explained by localized chromatic adaptation. Blackwell and Buchsbaum [20] described some of the spatial and chromatic factors that influence the degree of induction.

Robertson [21] showed simultaneous contrast is a phenomenon that depends on the structure of the region. Figure 2.9 (A) shows the simultaneous contrast with a single colour red on the colour yellow and blue. Because it is surrounded by a yellow background and blue colours as well, but the two sides of the colour red on a yellow colour is induced by the colour yellow. The red colour on the colour blue is induced by blue. The same effect is shown in Figure 2.9 (B), which suggests that this phenomenon depends on the structure of the area.

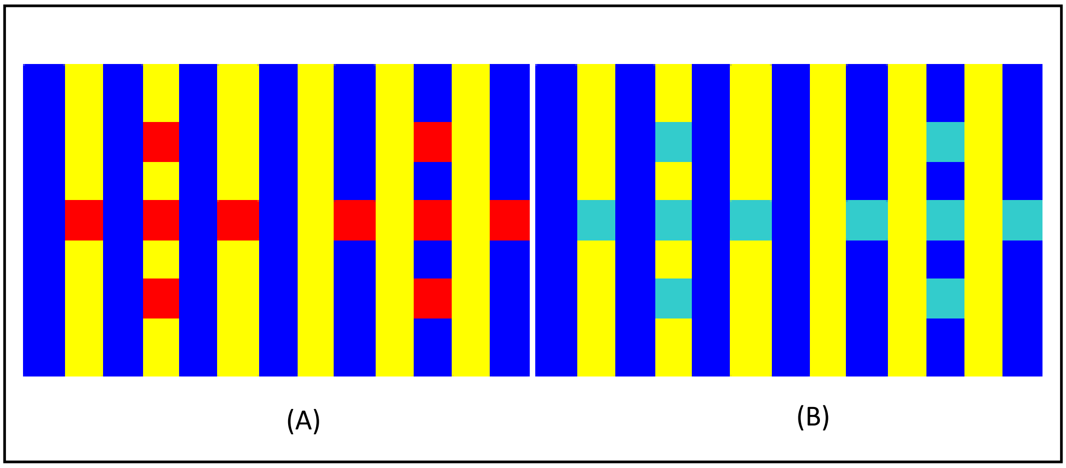


Figure 2-9 The phenomenon that depends on the structure. (A) The colour sheets of red squares put on the yellow and blue colours. (B) The colour sheets of cyan squares put on the yellow and blue colours.

2.1.3 The CIE colour system

The CIE colorimetric system comprises the essential standards and procedures of measurement that are necessary to make colorimetry a useful tool in science and technology. The CIE system is usually employed in connection with instrument for colour measurement. This system has been established by the Commission International de l' Eclairage, the French title of international committee, or International Commission of Illumination in 1931. The system started with the premise developed on the human colour perception process that stimulus for colour is provided by the proper combination of a source of light and on observer [22, 23]

2.1.3.1 CIELAB colour space

The CIELAB colour values of the colour vision are based on opponent-colours theory, which is different from the measurement of colour with a tristimulus system, based on the theory of colour vision trichromatic by the space of a 3-D including 3-axes of L*, a* and b * (Figure 2-10).

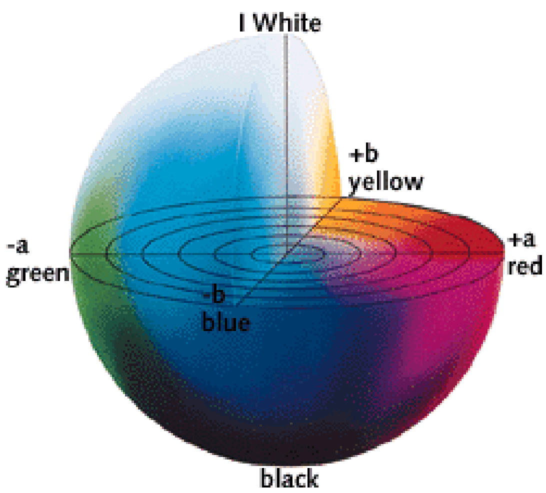


Figure 2-10 CIELAB Three-dimensional space. [24]

L* represents the relative brightness of the colour space. L* values are between 0-100.

a* axis indicates the red and green. Positive values represent red. The negative values represent green. If a* is in a positive way, it shows that the colour is more red. But if a* is negative, it indicates that there is more green.

b* axis indicates the yellow and blue. Positive values represent yellow. The negative values represent blue. If a* is in a positive way, it shows that there is more yellow. But if a* is negative, it indicates that there is more blue.

The CIE L* a* b* [22] is based on the theory of trichromatic colour vision and is calculated as follows.

$$
\begin{aligned}
&L^* = 116\,(Y/Y_n)^{1/3} - 16 && \text{for } Y/Y_n && > && 0.008856 \\
&L^* = 903.3\,(Y/Y_n) && \text{for } Y/Y_n && \leq && 0.008856 \qquad (1)\\
&a^* = 500[F(X/X_n) - F\,(Y/Y_n)] \\
&b^* = 200[F(Y/Y_n) - F\,(Z/Z_n)]
\end{aligned}
$$

When,

$$
\begin{aligned}
&F(X/X_n) = (X/X_n)^{1/3} && \text{for } X/X_n && > && 0.008856 \\
&F(X/X_n) = 7.787(X/X_n) + 16/116 && \text{for } X/X_n && \leq && 0.008856 \\
&F(Y/Y_n) = (Y/Y_n)^{1/3} && \text{for } Y/Y_n && > && 0.008856 \\
&F(Y/Y_n) = 7.787(Y/Y_n) + 16/116 && \text{for } Y/Y_n && \leq && 0.008856 \\
&F(Z/Z_n) = (Z/Z_n)^{1/3} && \text{for } Z/Z_n && > && 0.008856 \\
&F(Z/Z_n) = 7.787(Z/Z_n) + 16/116 && \text{for } Z/Z_n && \leq && 0.008856
\end{aligned}
$$

XYZ are tristimulus values of colour

X_n, Y_n, Z_n are tristimulus values of a reference white, such as paper used for printing or the colour of the light source.

From Equation 1, the values of L*, a* and b* can be calculated to obtain Hue (h_{ab}) and Chroma (C^*_{ab}), as shown in Equations 2 and 3.

When,

$$h_{ab} = \arctan\,(b^*/a^*) \qquad (2)$$

$$C^*_{ab} = (a^{*2} + b^{*2})^{1/2} \qquad (3)$$

2.1.3.2 Colour difference

The colour difference is the distance between two colours in the colour space, denoted by the symbol ΔE. Colour difference in CIELAB colour space, colour calculated from the distance between any two colours in the colour spaces is denoted by ΔE^*_{ab} and can be calculated using Equation 4.

$$\Delta E^*_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (4)$$

When, ΔL^* = difference of L* between the two colours.

Δa^* = difference of a* between the two colours.

Δb^* = difference of b* between the two colours.

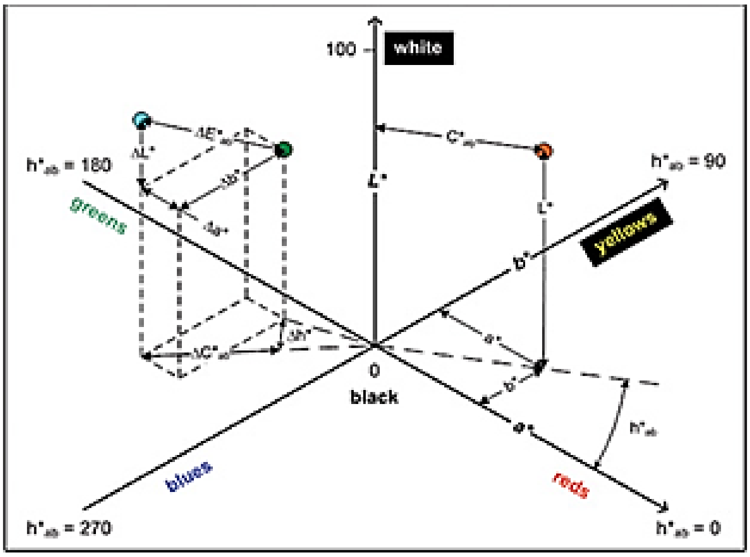


Figure 2-11 The distance between colours in the colour space. [25]

Colour difference (ΔE^*_{ab}) tells the difference between a standard colour (Standard) and colours in production (batch). It contains no information about the direction of differences, but the total difference from all directions. Thus, it is normally used in production quality control to reproduce the same colour products.

Hue difference (ΔH^*_{ab}) is calculated from the difference between the colour difference (ΔE^*_{ab}) Lightness difference (ΔL^*) and Chroma difference (ΔC^*_{ab}), as shown in Equation 5.

$$\Delta H^*_{ab} = \sqrt{(\Delta E^*_{ab})^2 - (\Delta L^*)^2 - (\Delta C^*_{ab})^2} \qquad (5)$$

2.2 Literature reviews

Luo et al's [26] experiments were carried out to investigate the effect of simultaneous contrast on colour appearance by varying the lightness, colourfulness, and hue of an induction field surrounding a test colour. A total of 814 test/surround combinations were displayed on high-resolution colour displays. Each was assessed by a panel of five to six observers using a magnitude estimation technique.

The results indicate that colours presented on a computer display are affected by simultaneous contrast in a similar way to surface colours. All three colour appearance parameters studied (i.e., lightness, colourfulness, and hue) are affected and these effects are summarized. In general, the results support and add to the findings of the other studies. The Hunt colour appearance model was tested and gave a somewhat poor prediction to this data set. Further modifications are required to improve its performance.

Bloj et al's [27] study about perception of three-dimensional shape. Objects in the natural world possess different visual attributes, including shape, colour, surface texture and motion. Previous perceptual studies have assumed that the brain analyses the colour of a surface independently of its three-dimensional shape and viewing geometry, although there are neural connections between colour and two-dimensional form processing early in the visual pathway. Colour perception is strongly influenced by three-dimensional shape perception in a novel, chromatic version of the Mach Card—a concave folded card with one side made of magenta paper and the other of white paper. The light reflected from the magenta paper casts a pinkish glow on the white side. The perceived colour of the white side changes from pale pink to deep magenta when the perceived shape of the card flips from concave to convex. The effect demonstrates that the human visual system incorporates knowledge of mutual illumination—the physics of light reflection between surfaces—at an early stage in colour perception.

Lee et al's [3] the aim of this study is to investigate the impact of physical appearance attributes (in terms of colour and shape) on our affective feelings of 2D and 3D objects. Twelve colours were studied, each consisting of 12 two-dimensional and 12 three-dimensional shapes. This resulted in 144 2D and 144 3D color-shape combinations. Each colour-shape combination was assessed using 20 emotion scales in a viewing cabinet by a panel of observers with normal colour vision. The results show that there are five underlying factors of these 20 scales, i.e., “activity,” “weight,” “heat,” “softness,” and “complexity”. The first three factors were mainly related to colour and the other two were linked with shape.

CHAPTER III

METHODOLOGY

3.1 Apparatus

3.1.1 Spectroradiometer

Model	: Konica Minolta CS-1000A
Wavelength range	: 380-780 nm
Spectral bandwidth	: 5 nm
Wavelength resolution	: 0.9 nm/ pixel
Display wavelength bandwidth	: 1 nm
Luminance accuracy	: ±2%, ±1 digit
Chromaticity accuracy	: ±0.0015x, ± 0.001y
Luminance repeatability	: ±0.1% ±1 digit
Chromaticity xy repeatability	: ±0.0002
Polarization error	: Less than 5%

3.1.2 CRT Monitor

Model	: LACIE electron 22 blue ISZ
Size	: 22”
Weight	: 67.2 lbs
Enclosure	: Blue
Max resolution	: 2048 x 1536/ 86.0 Hz

3.1.3 Laptop Computer

Model name	: MacBook Air

Model Identifier	: MacBook Air 3.1
Processor	: 1.4 GHz Intel Core 2 Duo
Memory	: 2 GB 1067 MHz DDR3

3.1.4 Software application

OpenOffice.org™3	: Version 3.2.1
Preview	: Version 5.0.3
Microsoft Office	: Microsoft Excel 2010
	: Microsoft PowerPoint 2010

3.2 Observer

Forty Thai observers, including 20 males and 20 females, ranging in age from 20 to 28 years old, with an average of 24.3 ± 1.6 years, took part in visual experiments. Among observers were 25 employees, 12 bachelor degree students and 3 master degree students. Each observer had normal colour vision, examined by Ishihara Test.

3.3 Experimentation

This research investigated the effect of shape on the induction level of the background colour. Different shapes of a grey sample were displayed on a colour background and the effect of shape was determined by the differences in colour perception between the colours in different shapes displayed on a colour background and the matching colour in a square shape displayed on a grey background.

Consequently, the experimentation process of this study was divided into three parts, as illustrated in Figure 3-1. The first part was the pre-experiment which included preparation of CRT monitor, test samples and matching colours. The second part involved experimental procedures whereby observers chose a matching colour that matched the test colours with different shapes on different background colours. The last part was analysis of observers' results. The detailed descriptions of each part are given in Sections 3.3.1, 3.3.2 and 3.3.3, respectively.

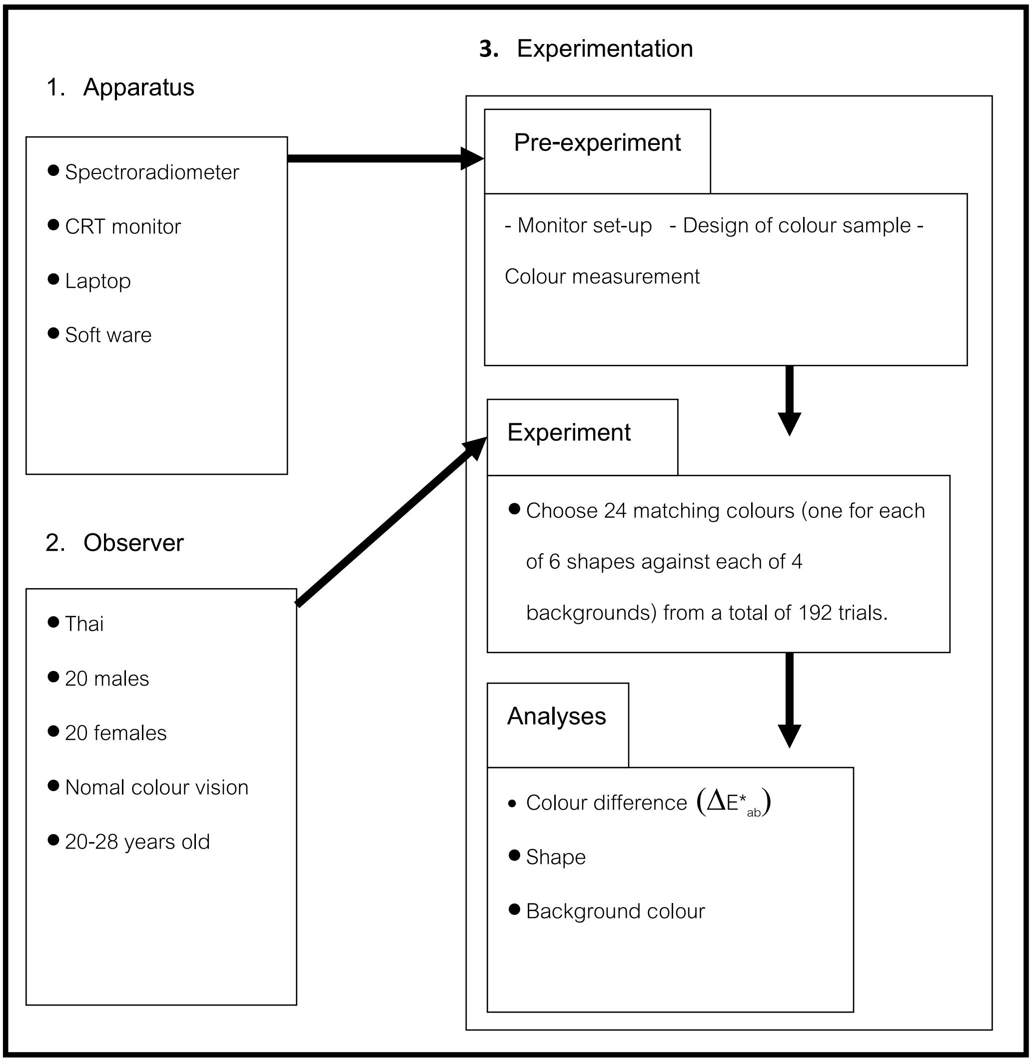


Figure 3-1 Overview of experimentation process.

3.3.1 Pre-Experiment

A process of experimental preparation was comprised of three parts (Figure 3-1). The first part was a process of a monitor set-up, to ensure the consistency of the monitor throughout the entire experiments. The second part was a colour measurement process. The third was a design of colour samples for this study. These three processes are explained in details in Section 3.3.1.1, 3.3.1.2 and 3.3.1.3, respectively.

3.3.1.1 Monitor set-up

In visual experiments, colour samples were displayed on a CRT monitor. The visual assessment was conducted in a darkened room. A spectroradiometer was stood in front of the CRT monitor with the distance around 100 cm. Temporal stability is a test to find out when the screen is fixed. This was done by measuring luminance of a full-screen white with RGB values set to 255, 255 and 255, and the monitor's white point set to D65. The measurements were mode from the first minute of turning-on, and every 3 minutes until 45 minutes, then every 15 minutes until 2 hours, and every 30 minutes until 4 hours. Figure 3-2 shows the set-up of this process, and the stability of the CRT monitor is shown in Figure 3-3.

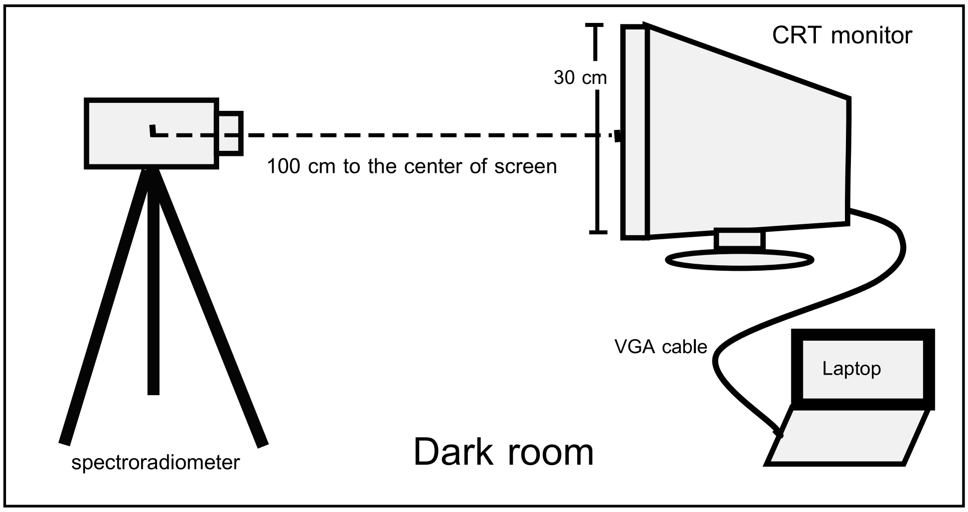


Figure 3-2 A set-up for colour measurements.

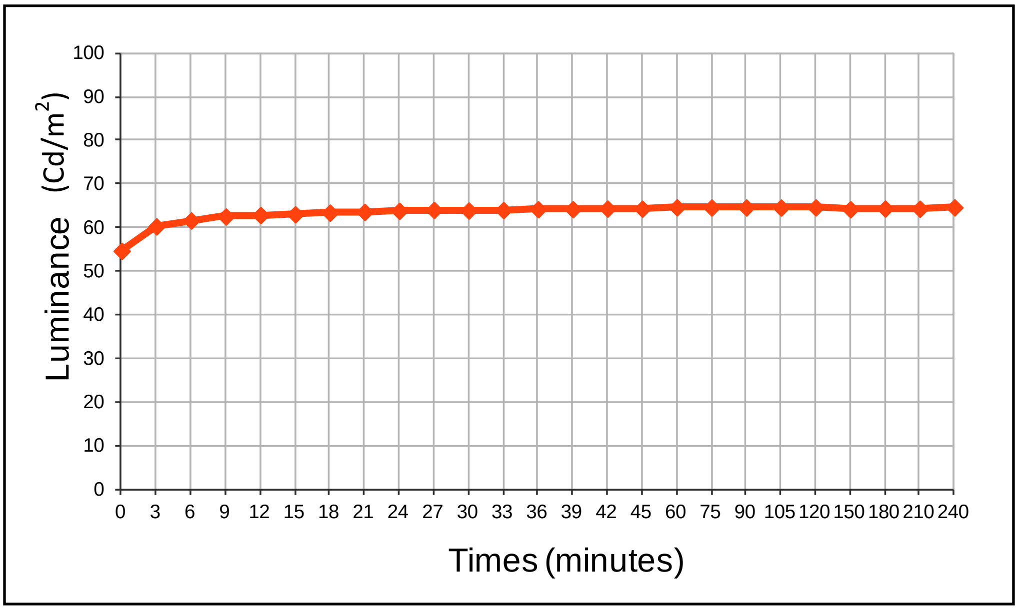


Figure 3-3 Stability of the CRT monitor.

Figure 3-3 shows the results of the stability test. It can be seen that the monitor is stable after 10 minutes of starting-up. Thus the visual experiments were carried out after 10-minute warm-up.

3.3.1.2 Colour measurement

Colour measurements were made for each colour sample and background colour under the same viewing conditions as visual experiments. The measuring configuration is shown in Figure 3-2. Colour samples displayed on the CRT monitor were measured in terms of CIE XYZ tristimulus values with a spectroradiometer. The XYZ values were then transformed to CIE L*, a*, b* values with the monitor white point ($X_wY_wZ_w$ = 94.71, 100, 104.34). CIE total colour difference between two samples was obtained by: $\Delta E^*_{ab} = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}$.

3.3.1.3 Design of colour sample

The colour samples used in the visual experiments were divided into two categories: test colour samples and matching colour samples.

- Test colours

Test colours were grey samples that were displayed against a colour background. They had 6 different shapes, i.e. circle, square, diamond, isosceles triangle, right-angled triangle and hexagon (Figure 3-4). These shapes were in the same height and width (height=5.2 cm, width=5.2 cm). The test colours were presented on 4 different background colours: red, yellow, green and blue. These background colours were prepared to have the same apparent lightness as a grey background on which the matching colours were presented, so that the main influence of the background is its chromatic induction effect. Note that the test colours in different shapes were the same grey colour. The XYZ values, along with CIE L* a* b* values, of these samples are given in Table 3-1.

- Matching colours

Matching colours were in square shapes, with their dimensions equivalent to the test colours. They were presented on a grey background. The colorimetric values of the grey background are given in Table 3-1.

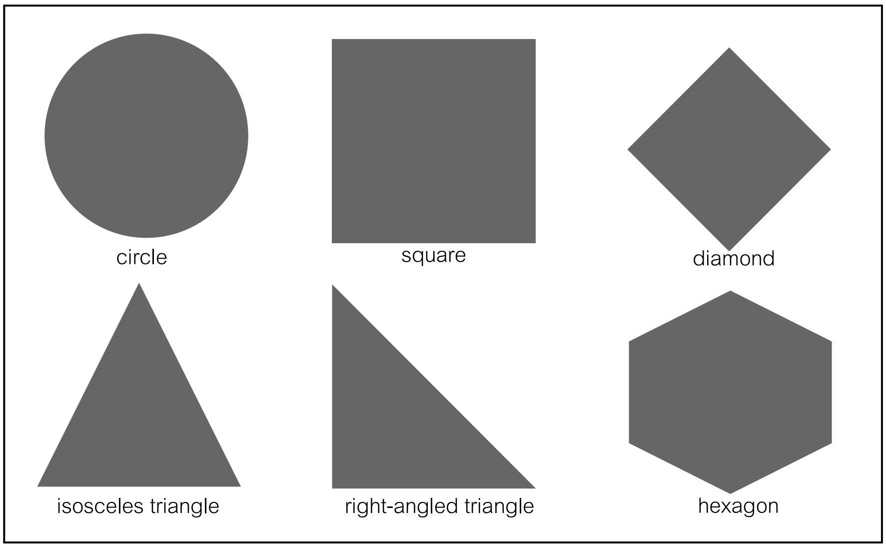


Figure 3-4 Test colours with different shapes.

Table 3-1 Colorimetric values of experimental samples.

	X	Y	Z	L^*_{ab}	a*	b*
Test colour (grey)	13.26	14.22	14.66	44.55	-2.95	1.29
Background						
Red	23.14	13.66	2.79	43.74	53.18	43.68
Yellow	49.99	60.34	11.33	82.02	-20.90	74.39
Green	7.16	14.62	2.79	45.11	-53.29	46.08
Blue	10.68	5.89	46.76	29.13	45.58	-73.96
Grey	19.51	21.02	21.59	52.97	-3.79	1.60

A set of matching colours were prepared for each background colour. In the preparation, the experimenter conducted a preliminary experiment to find a matching colour for each background. Frist, the test colour in a diamond shape on red background was tried. The matching colour on the grey background was adjusted freely until it matched in colour appearance with the test colour. This process was done for all the shapes on all backgrounds. Based on the matching colours found in the prelimirary experiment, a set of matching colours were established by decreasing and increasing the apparent hue of the matching colours found. There were a total of 8 matching colours (deviating away from neutral grey of the test colour, with the first sample being the same grey as the test colour, samples 2-6 with tinting colours — in an increasing level — opposite to the background and samples 7-8 with tinting colours of the background) in one set for a given background. For instance, when the test colour was presented on a red background, the matching colours were different from the test colour in the directions of red and green. Figure 3-5 manifests 4 sets of matching colours for 4 backgrounds. In total, there were 29 matching colours. Note that each set of matching colours had one colour in common – the test colour, thus 4 sets of matching colours comprised 1 grey + (7 colours x 4 backgrounds). Figures 3-6 - 3-9 show a set of matching colours for the test colour presented on red, yellow, green, and blue background, respectively. The colorimetric values of matching colours can be found in Appendix A.

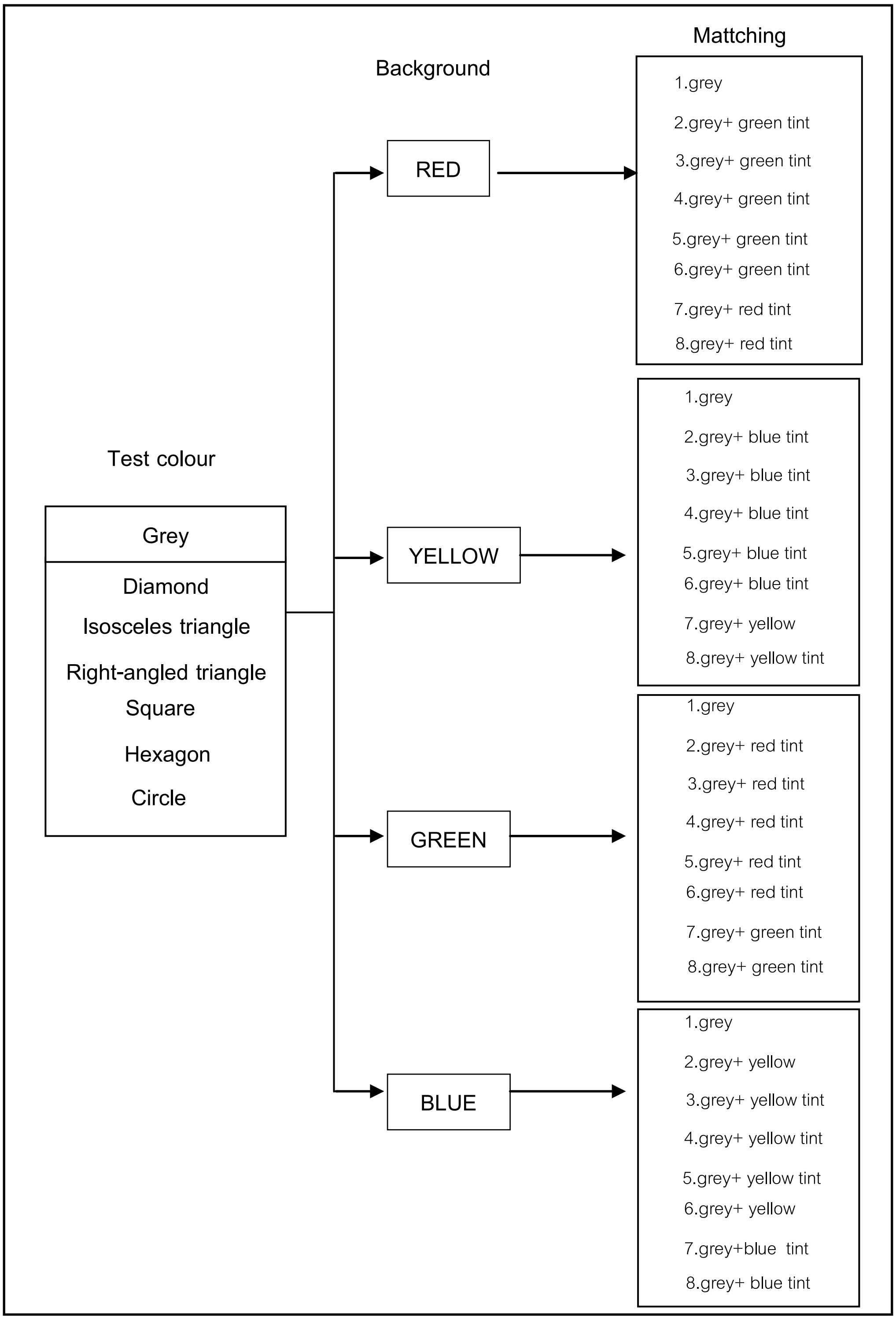


Figure 3-5 Matching colours.

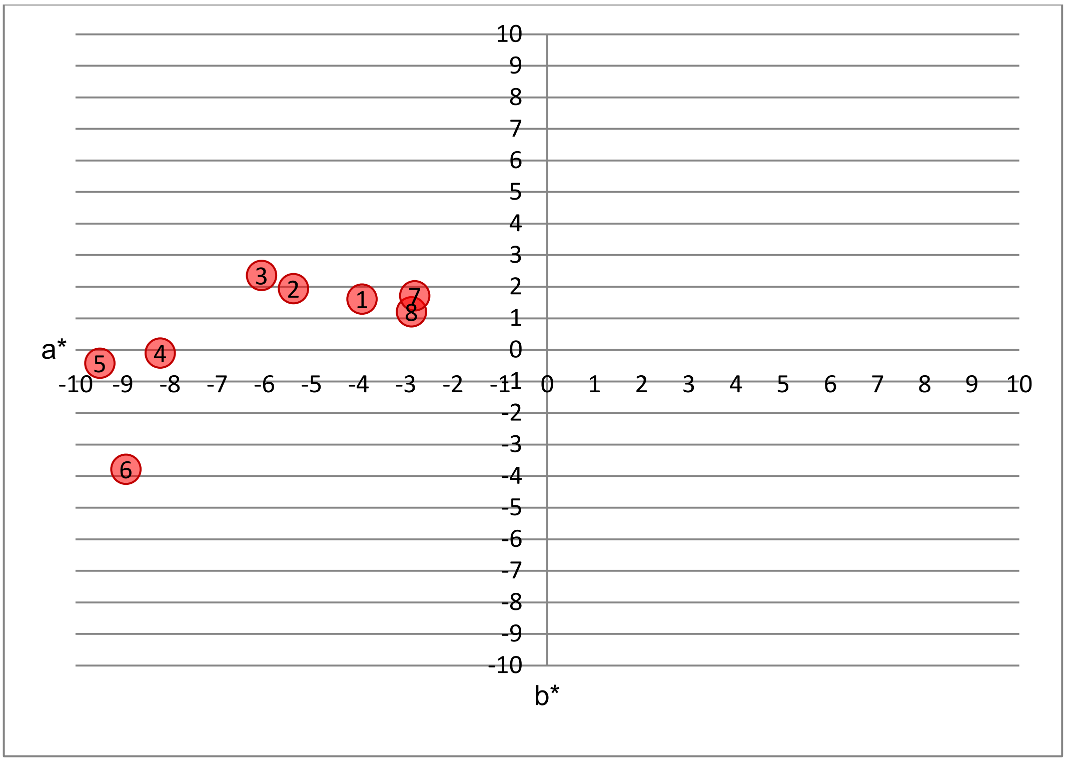


Figure 3-6 Matching colours for red background.

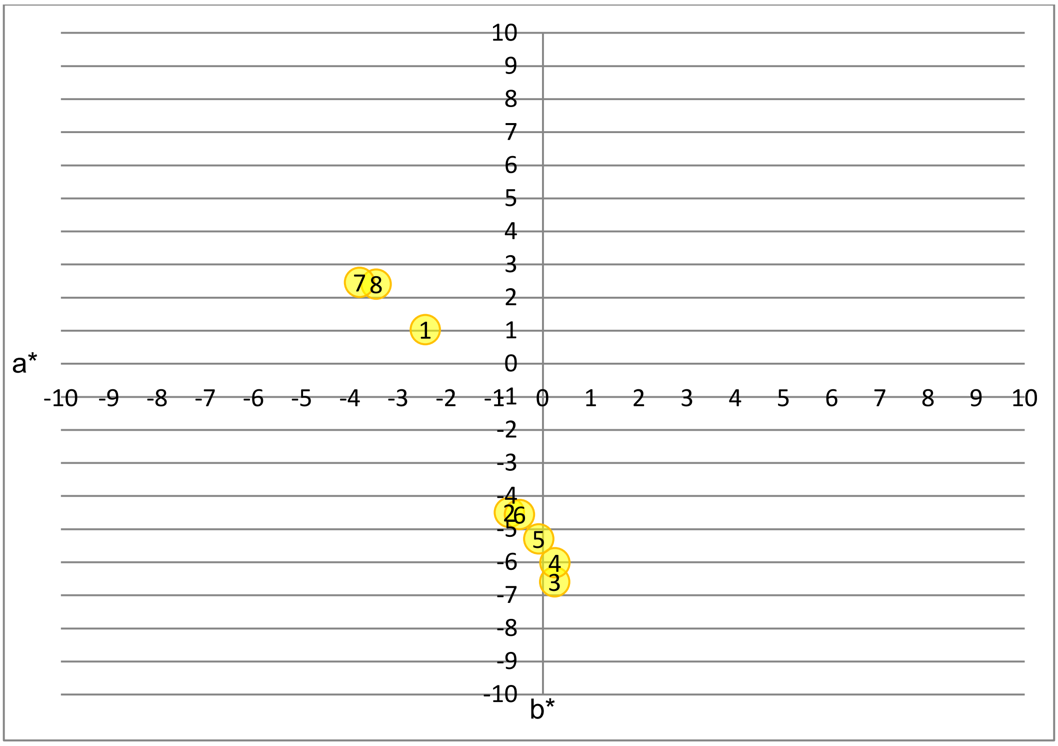


Figure 3-7 Matching colours for yellow background.

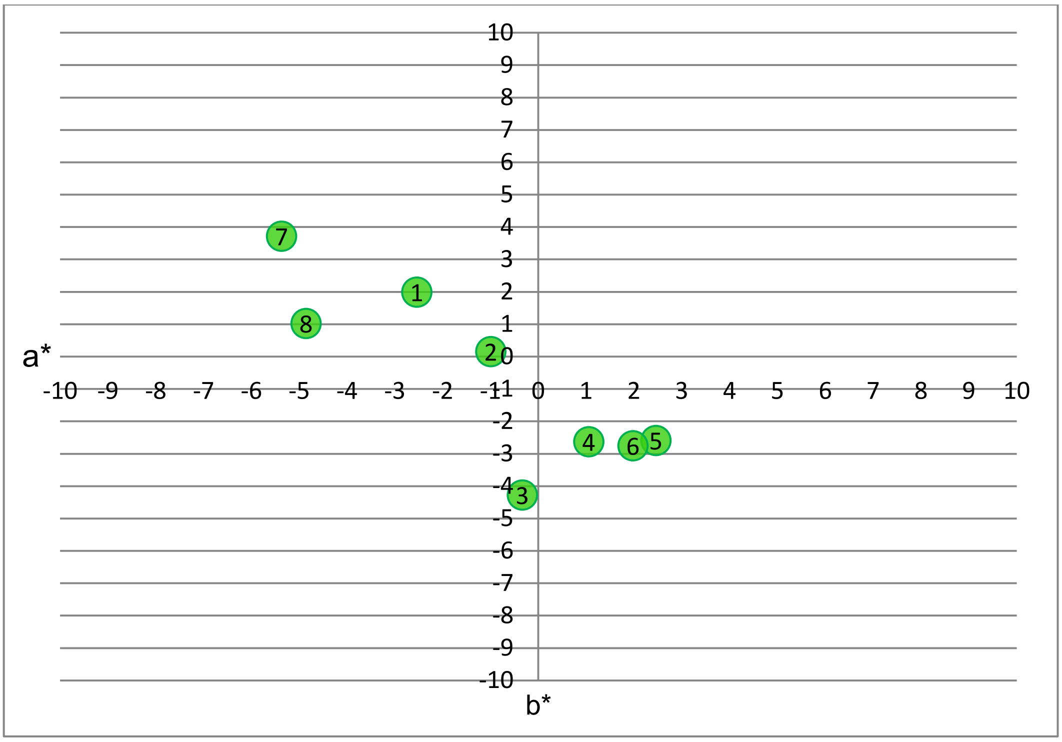


Figure 3-8 Matching colours for green background.

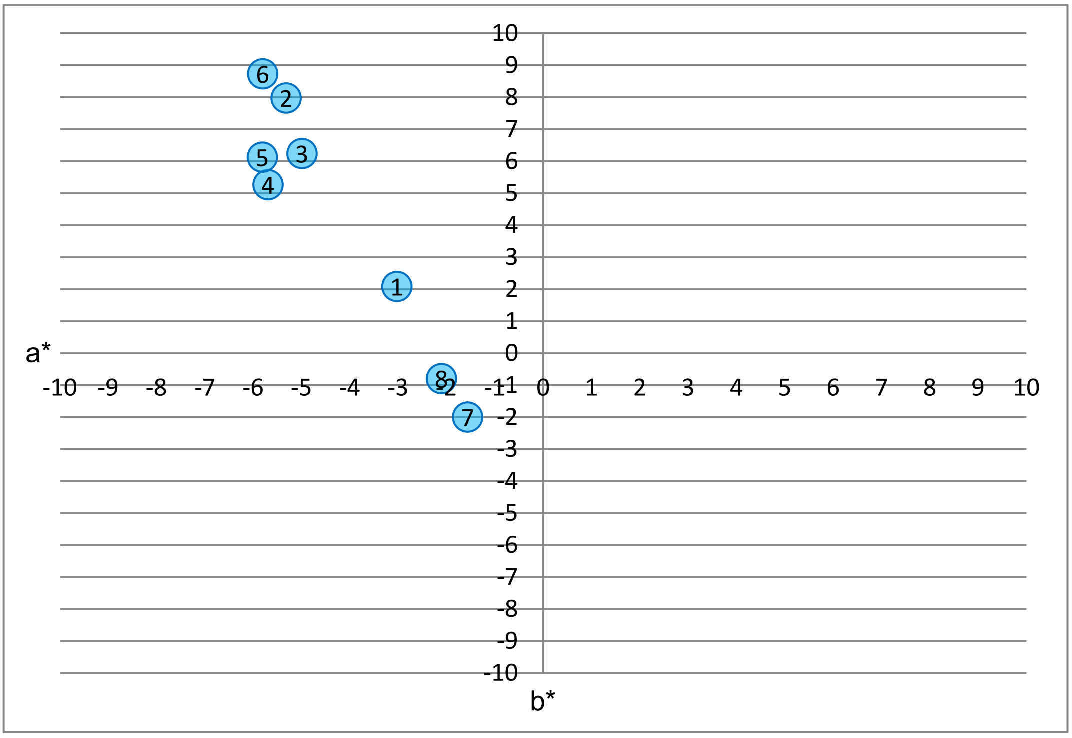


Figure 3-9 Matching colours for blue background.

3.3.2 Experimental Procedure

Before observers starting the visual experiments, the experimental procedure was described in detail to ensure accurate results. Observers sat on a chair in a darkened room (situated in the same position as the spectroradiometer when doing colour measurements) (Figure 3-10). The Observers adapted their eyes in the experimental condition for about 30 seconds by looking at the CRT monitor which presented a uniform grey background before conducting the actual visual assessments.

The CRT display showed a test colour on a chromatic background on the left and a matching colour on a grey background on the right (Figure 3-11). To find the matching colours that had the same colour appearance as the test colour, observers changed the matching colours until they found the match. For each background, observers made the comparisons for 48 pairs (6 shapes x 8 matching colours). Thus, they had to find 24 matches for 6 shapes on 4 backgrounds from 192 comparisons (6 shapes x 4 backgrounds x 8 matching colours). The order in which the shape and background was shown was the same for each observer. Figure 3-12 shows the experimental steps, where the comparisons were made for the diamond shape on red background, followed by the other 5 shapes in order of isosceles triangle, right-angled triangle, square, hexagon and circle. The same steps were repeated on the other 3 remaining backgrounds: yellow, green and blue, in order. The average time to complete the experiments for each observer was 30 minutes.

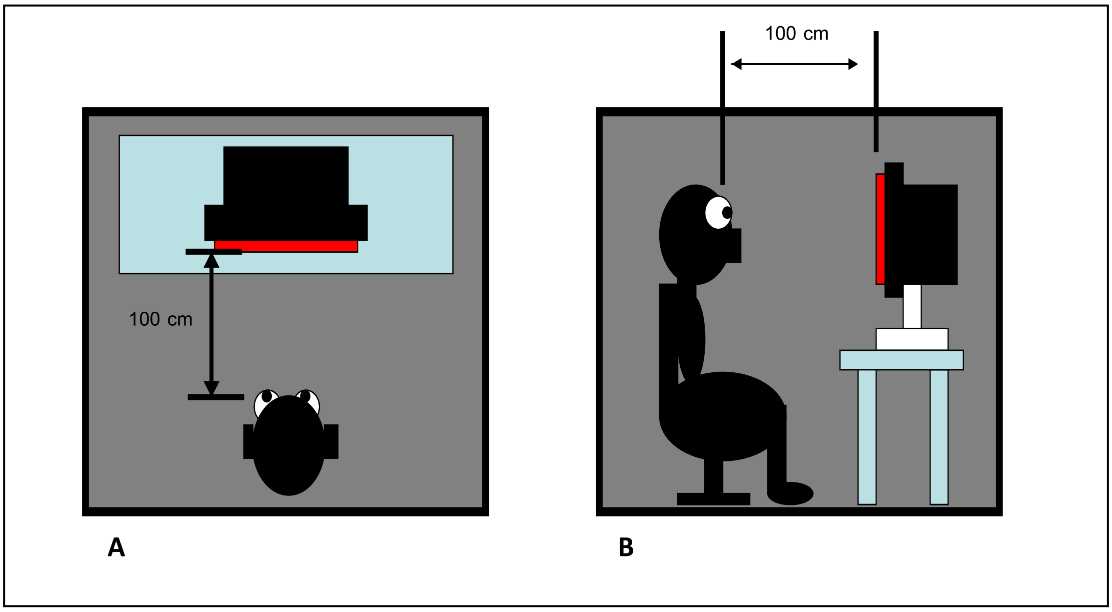


Figure 3-10 Screen position of the observer A) top view B), side view.

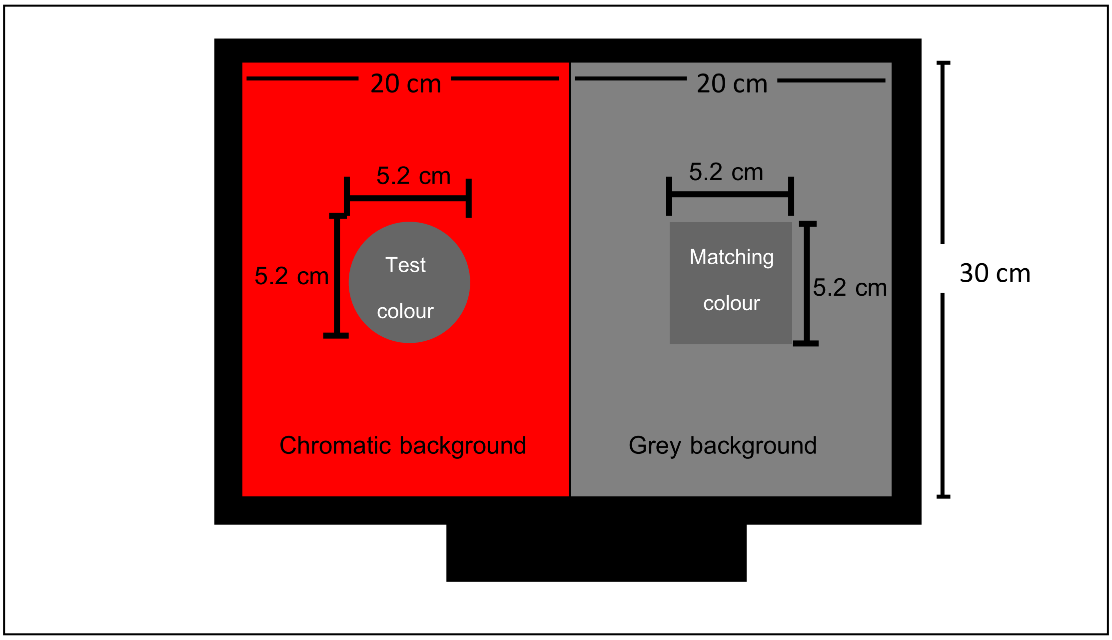


Figure 3-11 Sample layout on CRT screen

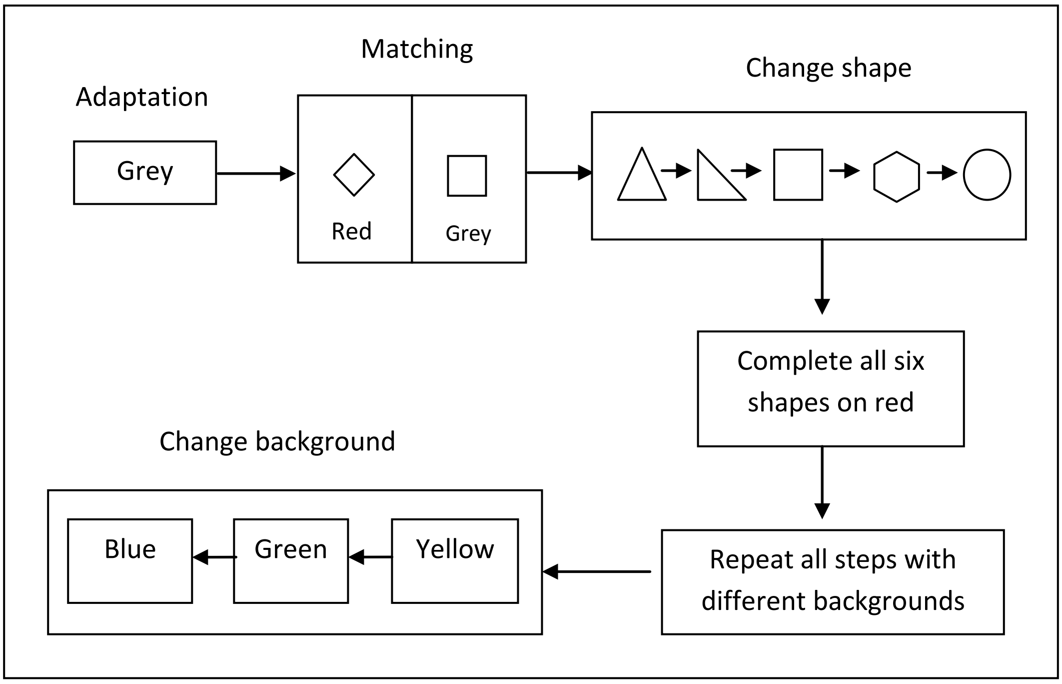


Figure 3-12 Experimental steps

3.3.3 Data analysis

1. The frequency of 'yes' responses to the matching colours was recorded for each shape on each background. The matches were the samples that obtained most yes responses.

2. The differences in terms of colorimetric values – L*, a*, b* and C^*_{ab} – between the test colour in a square shape and its corresponding match were calculated for each background, to investigate the effect of background colour.

3. The differences in terms of colorimetric values – L*, a*, b* and C^*_{ab} – between the match to the square shape of test colour and the matches to different shapes were calculated for each background, to investigate the effect of shape.

4. The differences in terms of colorimetric values – L*, a*, b* and C^*_{ab} – and the CIE total colour difference, ΔE^*_{ab}, between the test colour in different

shapes and the corresponding matches were calculated for each background, to compare the degree of colour changes between different shapes.

5. The matches to the test colour in all shapes were averaged for each background and the CIE total colour differences, ΔE^*_{ab}, between the test and the matches averaged from all shapes were calculated, to compare the degree of colour changes due to background colours.

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Experimental data

In visual experiments, observers compared the test colour presented on a colour background with the matching colour presented on a grey background. Four colour backgrounds, including red, yellow, green and blue, were tested. The test colours varied in 6 shapes, i.e. square, diamond, isosceles triangle, right-angled triangle, hexagon and circle. The matching colours were all in a square shape. There were 4 sets of matching colours, according to background colours; each set contained 8 samples. Observers' task was to find the samples that matched in colour appearance with the test colours. The results were the frequencies of 'yes' responses given to the particular matching samples for each shape of test colours on each background. Tables 4-1 – 4-4 summarise the results obtained from 40 observers for the test colours presented on red, yellow, green, and blue background, respectively. The CIE total colour differences, ΔE^*_{ab}, shown in the tables were calculated from the test colour (the same grey for all shapes and backgrounds) and the relevant matching samples.

Overall results showed the good agreement among observers. In 13 cases out of 24 cases, more than 80% of observers selected the same samples. The least agreement was found to be 70%, and it was only one case (isosceles triangle on yellow background, Table 4-2). None of the cases gave a unanimous answer. This reveals that the good agreements were not caused by robust samples. The matching samples were carefully prepared to be distinguishable between them but not to be too obvious.

The reliability of the visual results is attributed to the good agreements between observers' results. Based on this finding, the results are considered to be reliable.

Table 4-1 Results for each shape on red background.

Red background						
Shape	Sample	L^*_{ab}	C^*_{ab}	h_{ab}	ΔE^*_{ab}	Observer
◇	1	44.55	3.22	156.41	0.00	35
	2	42.25	5.72	160.19	2.80	3
	7	43.18	3.29	148.66	1.82	2
△	2	42.25	5.72	160.19	2.80	35
	3	43.71	6.50	158.74	2.43	5
◺	2	42.25	5.72	160.19	2.80	35
	3	43.71	6.50	158.74	2.43	5
□	3	43.71	6.50	158.74	2.43	34
	4	45.57	8.21	180.71	4.70	6
⬡	4	45.57	8.21	180.71	4.70	33
	5	48.75	9.50	182.56	7.22	7
○	5	48.75	9.50	182.56	7.22	37
	6	48.80	9.70	202.95	8.46	3

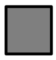
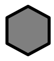
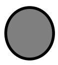
The highlighted figures show the most frequently selected samples for each shape.

Table 4-2 Results for each shape on yellow background.

Yellow background						
Shape	Sample	L^*_{ab}	C^*_{ab}	h_{ab}	ΔE^*_{ab}	Observer
◇	1	44.55	3.22	156.41	0.00	31
	2	40.72	4.55	261.24	6.91	3
	7	47.33	4.53	147.10	3.47	6
△	2	40.72	4.55	261.24	6.91	31
	3	39.68	6.60	272.15	9.40	9
◺	2	40.72	4.55	261.24	6.91	12
	3	39.68	6.60	272.15	9.40	28
□	3	39.68	6.60	272.15	9.40	32
	4	38.06	6.02	272.41	9.90	8
⬡	4	38.06	6.02	272.41	9.90	31
	5	39.61	5.30	269.11	8.32	9
○	5	39.61	5.30	269.11	8.32	34
	6	40.96	4.58	263.95	6.89	6

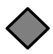
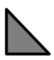
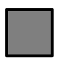
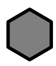
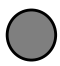
The highlighted figures show the most frequently selected samples for each shape.

Table 4-3 Results for each shape on green background.

Green background						
Shape	Sample	L^*_{ab}	C^*_{ab}	h_{ab}	ΔE^*_{ab}	Observer
	1	44.55	3.22	156.41	0.00	32
	2	51.37	1.01	171.20	7.26	6
	7	50.38	6.53	145.31	6.73	2
	1	44.52	3.23	141.95	0.00	5
	2	51.37	1.01	171.20	7.26	32
	3	50.29	4.29	265.49	8.80	3
	2	51.37	1.01	171.20	7.26	32
	3	50.29	4.29	265.49	8.80	8
	3	50.29	4.29	265.49	8.80	34
	4	49.93	2.83	291.79	7.97	6
	4	49.93	2.83	291.79	7.97	35
	5	50.33	3.57	313.46	8.93	5
	5	50.33	3.57	313.46	8.93	37
	6	49.59	3.39	305.65	8.29	3

The highlighted figures show the most frequently selected samples for each shape.

Table 4-4 Results for each shape on blue background.

Blue background						
Shape	Sample	L^*_{ab}	C^*_{ab}	h_{ab}	ΔE^*_{ab}	Observer
	1	44.55	3.22	156.41	0.00	32
	2	48.59	9.59	123.68	7.41	4
	7	43.26	2.53	231.94	4.58	4
	2	48.59	9.59	123.68	7.41	33
	3	50.19	7.99	128.62	7.15	7
	2	48.59	9.59	123.68	7.41	33
	3	50.19	7.99	128.62	7.15	7
	3	50.19	7.99	128.62	7.15	34
	4	51.53	7.76	137.20	7.98	6
	4	51.53	7.76	137.20	7.98	35
	5	52.64	8.45	133.46	9.32	5
	5	52.64	8.45	133.46	9.32	38
	6	50.61	10.49	123.59	9.31	2

The highlighted figures show the most frequently selected samples for each shape.

The samples that the majority of observers gave yes responses were taken to represent the matches for the relevant shapes and backgrounds of the test colour (highlighted samples in Tables 4-1 – 4-4). These results are further analysed to investigate the effects of background and shape in the following sections.

4.2 Effect of Background

In order to investigate the influence of the background colour, the differences between the test colours on various colour backgrounds and their corresponding matches on a grey background were calculated. The test colours and the matches were in the same shape – square – so that there was no influence from the shape difference, only the influence of background contributed to appearance changes of the test colours.

Figure 4-1 demonstrates the investigation of the background effect. The differences in hue (Δa^* and Δb^*), lightness (ΔL^*) and chroma (ΔC^*_{ab}) were calculated between the test colour and the matches. If the background has no influence on the perception of grey sample, the differences will be zero, i.e. the grey sample has the same appearance on colour and grey backgrounds, so the same grey colour is used to match the test colour. However, that is not usually the case. In most cases, simultaneous contrast occurs, so the sample that matches in appearance with the test colour when they are viewed on different backgrounds is not the same sample of the test colour.

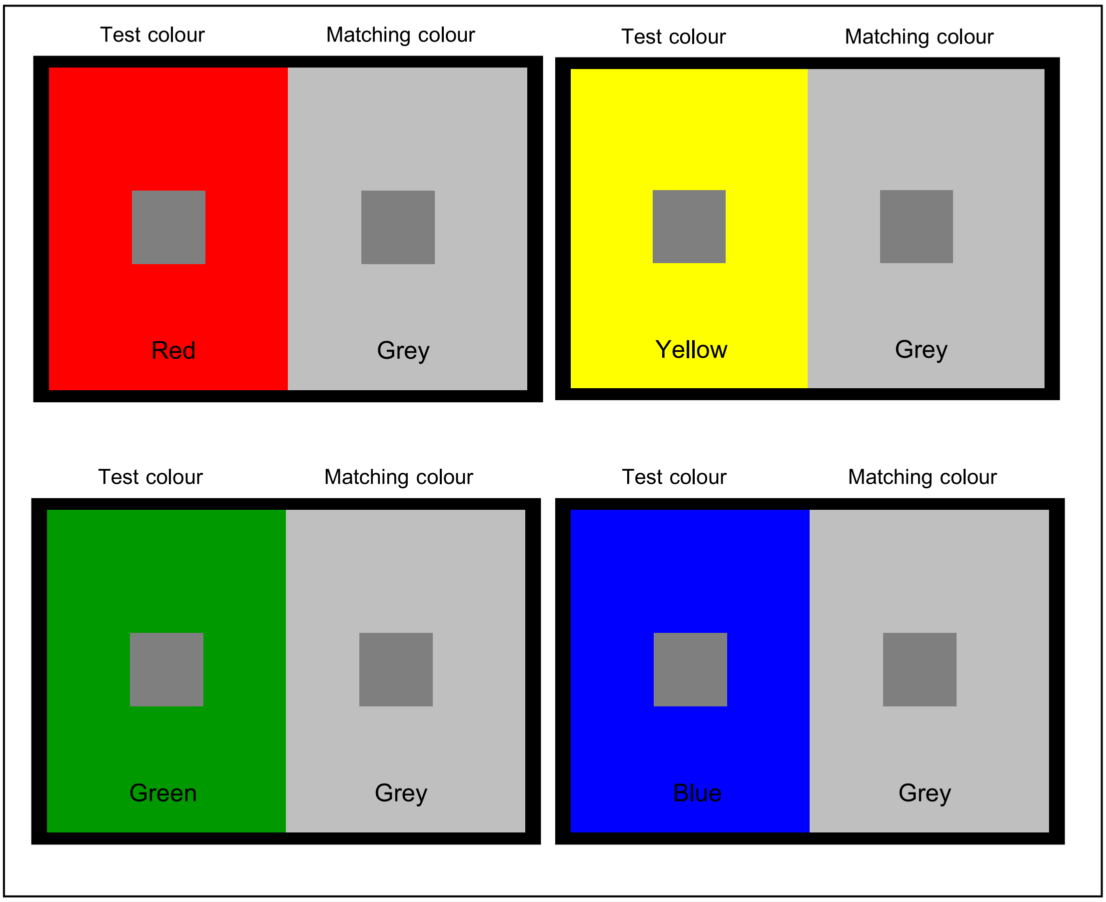


Figure 4-1 Testing for the influence of background colour: (A) red, (B) yellow, (C) green and (D) blue.

Figure 4-2 shows the results of Δa^* and Δb^* between the test colour and its corresponding matches on different backgrounds. Positive Δa^* means that the match is redder than the test colour, and negative Δa^* means the match is greener. Positive Δb^* means the match is more yellowish than the test colour, negative Δb^* means the match is bluer.

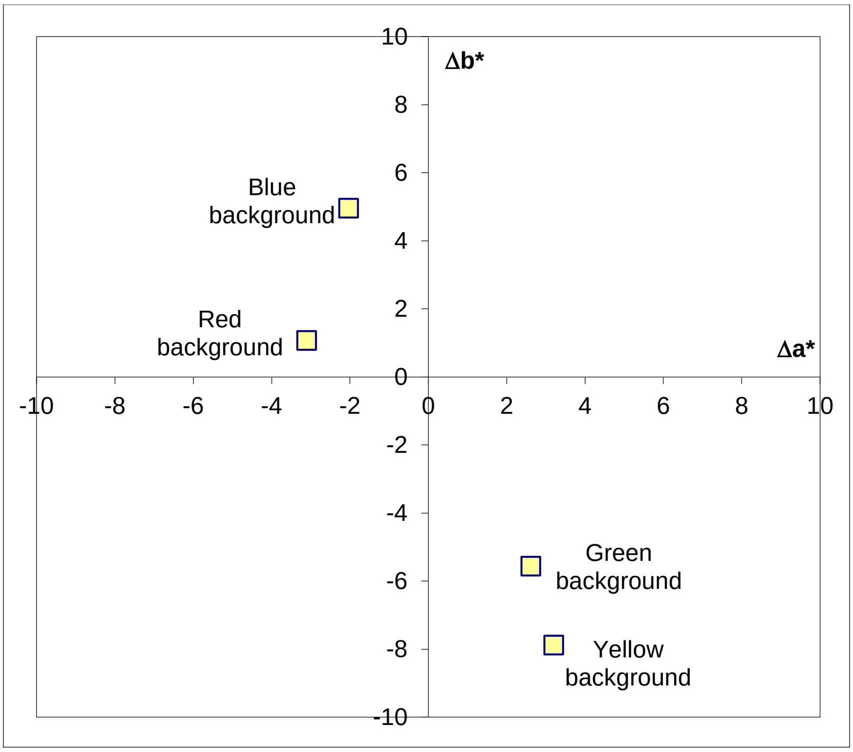


Figure 4-2 Colour changes in Δa^* and Δb^* due to background colours.

Figure 4-2 shows that the colour of background induces the colour changes in the direction opposite to the colour of the background. In order to match the grey colour on red background, the matching colour needed to be greenish. By the same token, the reddish sample was required to match the grey colour on green background. On the other hand, the bluish sample was required to match the test colour on yellow background, and the yellowish was used to match the test colour on blue background. These results confirm that simultaneous contrast occurs – the appearance of the patch is affected by its background colour, in which the opponent hue and lightness of the background induce upon the patch.

Given that the test colour was grey, the degree of chromatic induction could be quantified by the difference in chroma between the test colour and the matches on different backgrounds. The level of lightness induction was quantified by lightness differences. Positive ΔL^* means that the match is lighter than the test colour, and negative ΔL^* means the match is darker. Figure 4-3 shows the results of colour changes in terms of ΔC^*_{ab} and ΔL^*.

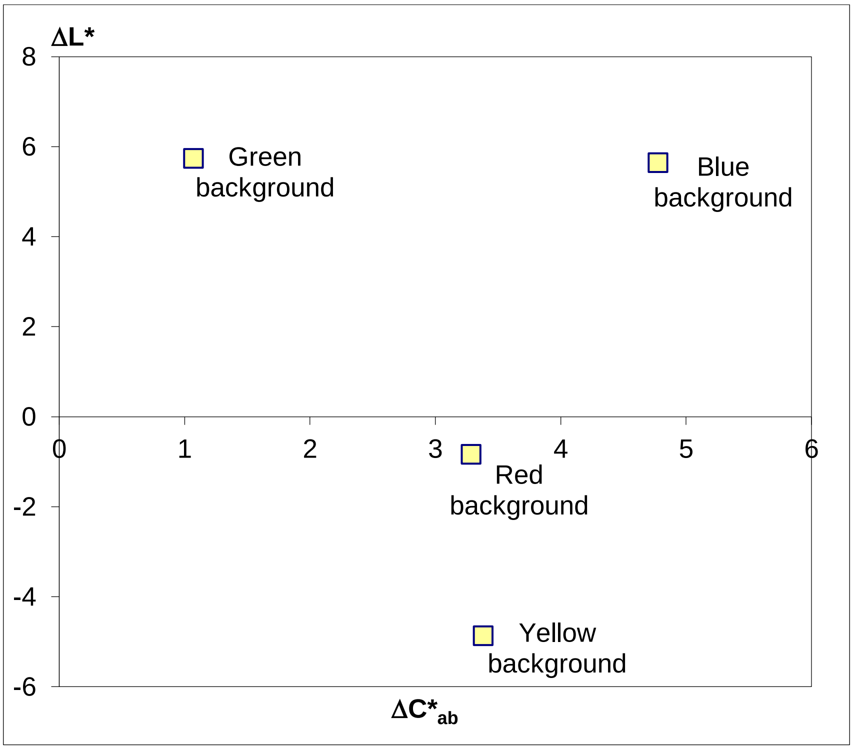


Figure 4-3 Colour changes in ΔC^*_{ab} and ΔL^* due to background colours.

The results showed that different backgrounds had different degrees of chromatic induction. This is because the background colours used in the present study had different levels of chroma. The background with strong chroma will induce high chromatic intensity upon the patch. The effect of lightness induction happens likewise. The yellow and red backgrounds seemed brighter than the grey background of the matching colours; thus, they required the darker samples to match the test colours. In contrast, the green and blue background looked darker than the grey background, so the test patches appeared brighter, requiring the lighter samples to match.

4.3 Effect of shape

The results from Section 4.2 showed the influence of background colour without the influence of shape because the test colour and its corresponding matches were in square shapes. It was found that simultaneous contrast occurred, so the test patches appeared different on different backgrounds. The corresponding matches represented the degree of changes in colour appearance due to the background colours. In order to investigate the effect of shape on colour changes, the results from the square shape were used as the reference colour and were compared to the results from different shapes. If there is no difference between the matches of the square shape and the other shape, the given shape has no contribution to the change in colour appearance of the test patch. The results for each background are given in the following sub-sections.

Note that the backgrounds used in the present study were not the unique hue of red, yellow, green, and blue. Thus the changes of hue were not varied in one dimension of either a* or b*. However, the discussions were made based on one dimension of either a* or b* according to the main contribution of the background hue.

4.3.1 Results on red background

Figures 4-4 and 4-5 show the degree of colour changes as influenced by shape for chromatic differences and lightness-chroma differences, respectively. If shape has no influence on colour appearance, the difference will be zero. If Δa^* is positive, the match from that shape is redder than the reference colour, indicating that the given shape reduces the simultaneous contrast effect because it appears in the same direction as the background colour. If Δa^* is negative, the match from that shape is greener than the reference colour, indicating that the given shape enhances the simultaneous contrast effect because it appears in the opposite direction to the background colour. In the case of ΔC^*_{ab}, the positive ΔC^*_{ab} enhances the simultaneous contrast effect, while the negative ΔC^*_{ab} reduces the effect.

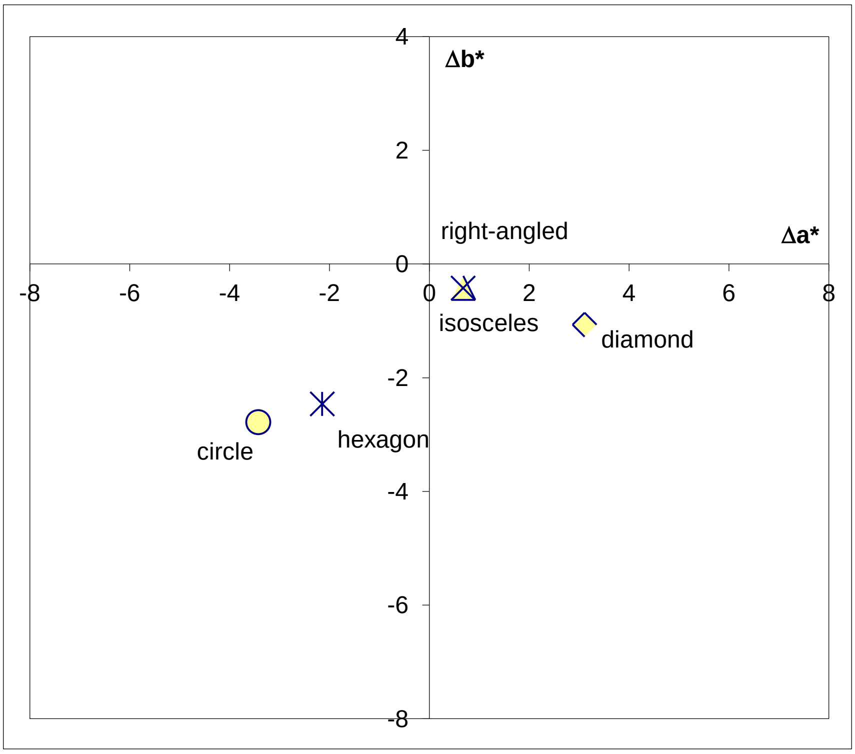


Figure 4-4 Δa^* and Δb^* between the matches to a square and the other shapes on red background.

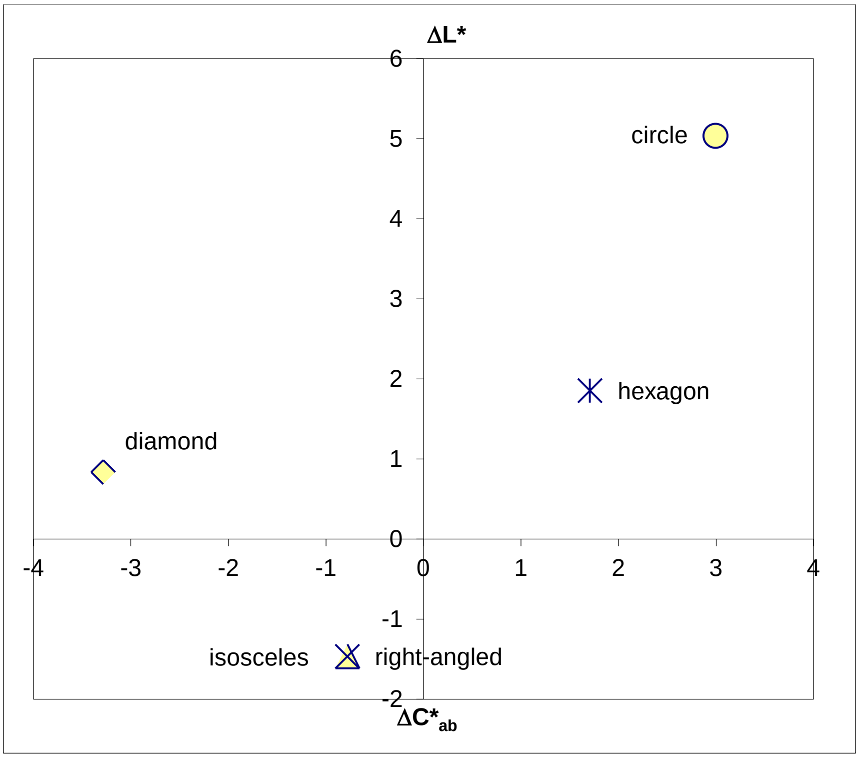


Figure 4-5 ΔC^*_{ab} and ΔL^* between the matches to a square and the other shapes on red background.

It was found that the diamond, isosceles and right-angled triangles reduced the effect of simultaneous contrast, while the hexagon and circle enhanced it. Both diamond and circle showed to be the most influential shapes, but in the opposite direction.

4.3.2 Results on yellow background

The results on yellow background show in Figures 4-6 and 4-7 for chromatic differences and lightness-chroma differences, respectively. Since the background was yellow, the test colour should appear bluish. The positive Δb^* indicates that the colour appearance of that shape is more yellowish than the reference colour, meaning that the given shape reduces the effect of simultaneous contrast. The negative ΔC^*_{ab} indicates the degree of reduction. The higher the number of negative ΔC^*_{ab}, the more the shape reduces the simultaneous contrast.

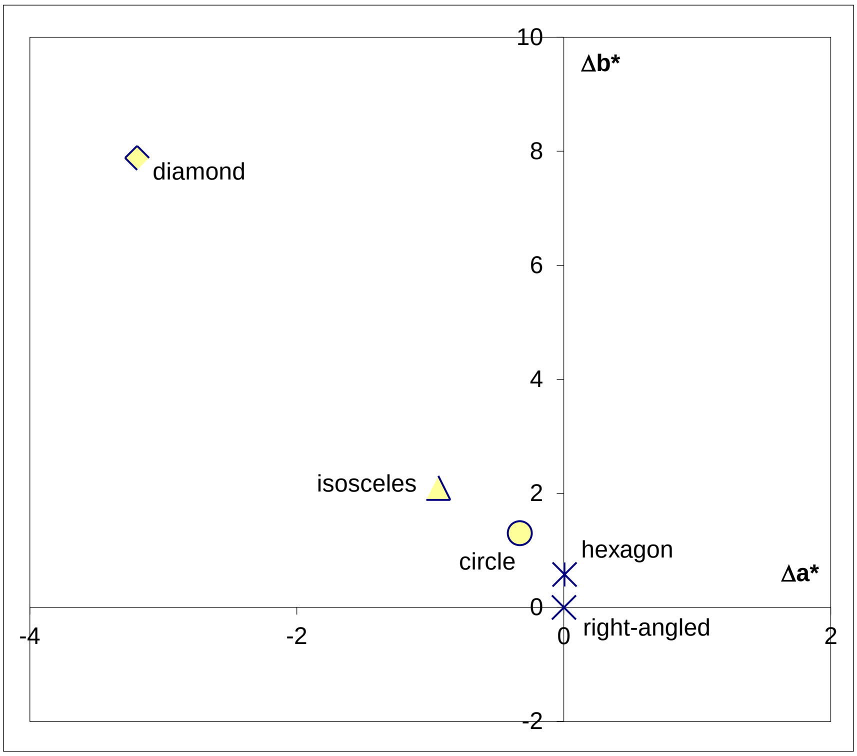


Figure 4-6 Δa^* and Δb^* between the matches to a square and the other shapes on yellow background.

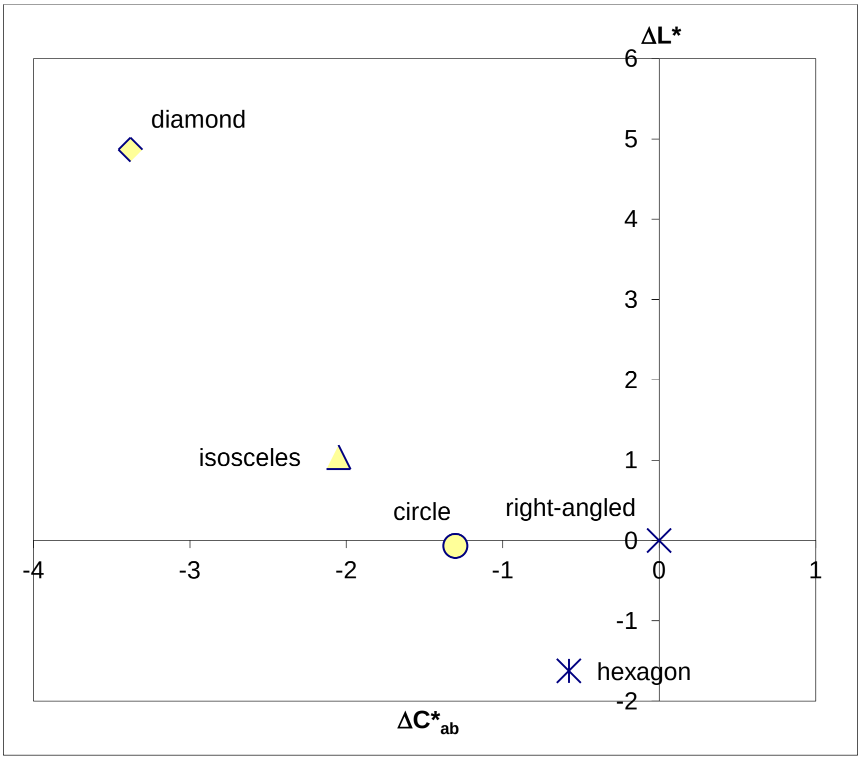


Figure 4-7 ΔC^*_{ab} and ΔL^* between the matches to a square and the other shapes on yellow background.

It was found that right-angled triangle had no contribution to simultaneous contrast, as was shown by the differences of zero between the reference colour and the match from the right-angled triangle. This means that the square and right-angled triangle appeared the same on yellow background. However, the colour appearance of the other shapes differed from the reference colour. The diamond, isosceles triangle, circle and hexagon appeared more yellowish than the reference colour. Hence, they all reduced the effect of simultaneous contrast, with the diamond having the highest degree of reduction and the hexagon the least.

4.3.3 Results on green background

Figures 4-8 and 4-9 show the comparisons between the reference colour in square shape and the colour appearance of other shapes on green background for Δa^* Δb^* and ΔC^*_{ab} and ΔL^*, respectively. If shape has no influence, the difference will be zero. On green background, the test patch should appear more reddish. Thus, if Δa^* is positive, it means that the shape magnifies the simultaneous contrast effect. On the contrary, the negative Δa^* shows that the shape diminishes the induction of opponent colour on the patch. The ΔC^*_{ab} value represents the intensity of chromaticness in comparison with the square.

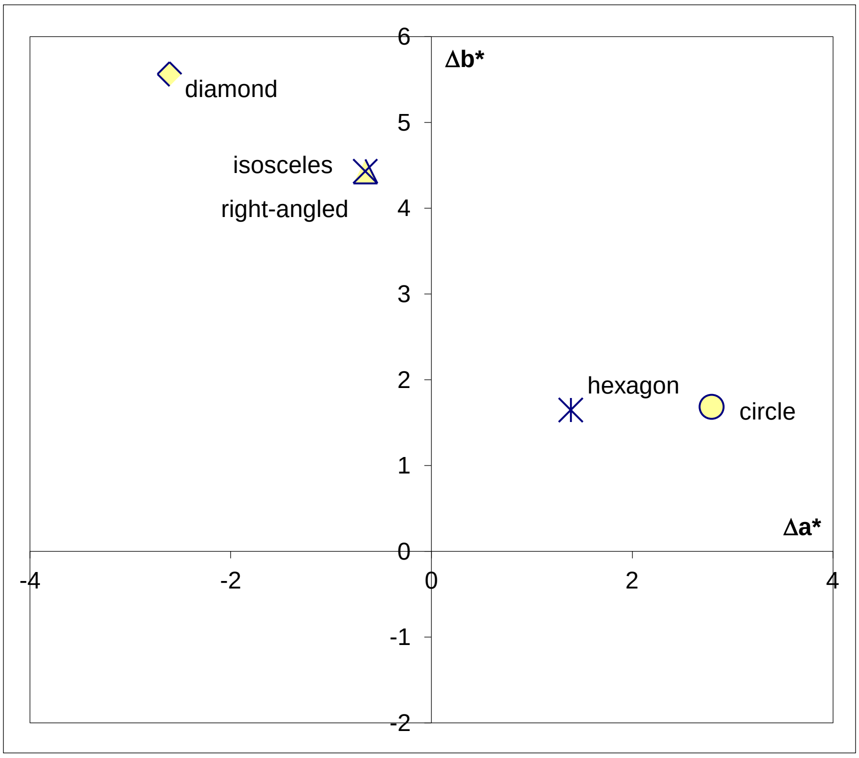


Figure 4-8 Δa^* and Δb^* between the matches to a square and the other shapes on green background.

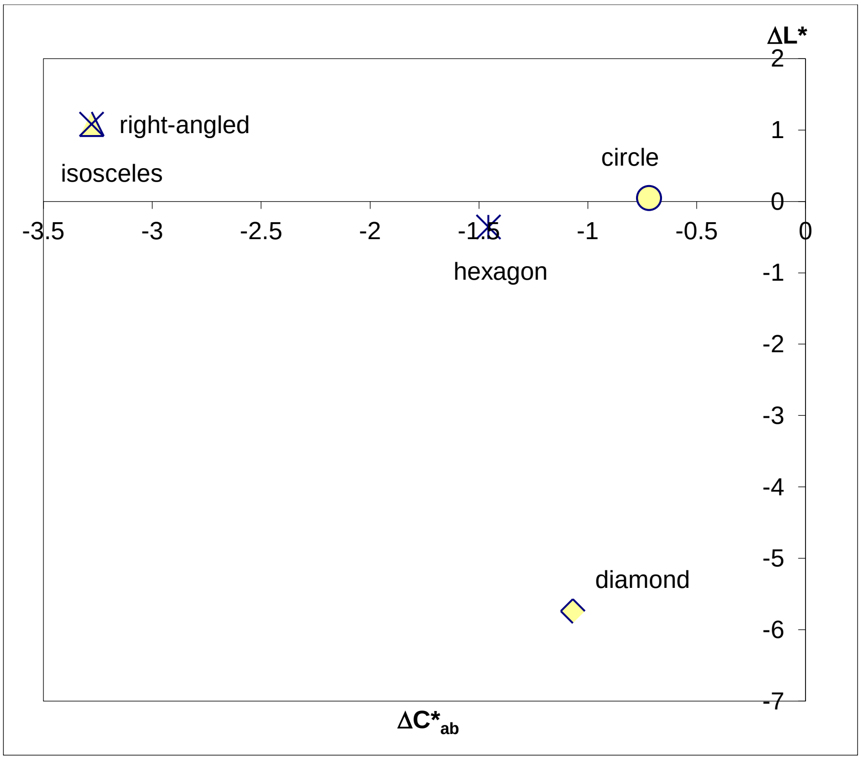


Figure 4-9 ΔC^*_{ab} and ΔL^* between the matches to a square and the other shapes on green background.

It was found that all shapes had influence on colour appearance of the test patch in different degrees and directions. The hexagon and circle increased the effect of simultaneous contrast – the colour of these shapes appeared redder on green background – while the diamond, isosceles and right-angled triangles decreased the effect, as they appeared less reddish. Nevertheless, all shapes had less chroma than the reference colour.

4.3.4 Results on blue background

The effect of shape on blue background is signified in Figures 4-10 and 4-11, in which Δa^* Δb^* and ΔC^*_{ab} and ΔL^* between the square and the other shapes are shown, respectively. If the shape has no contribution to the changes in colour appearance, these differences will be zero. The increment of simultaneous contrast effect is signified by the positive Δb^* value, meaning that the colour appears more yellowish than the reference colour on blue background. In contrast, the negative Δb^* value signifies the decrement of simultaneous contrast effect, as the colour appears less yellowish. The positive ΔC^*_{ab} value shows that the colour of the shape appears more chromatic than the square, while the negative shows less chromatic.

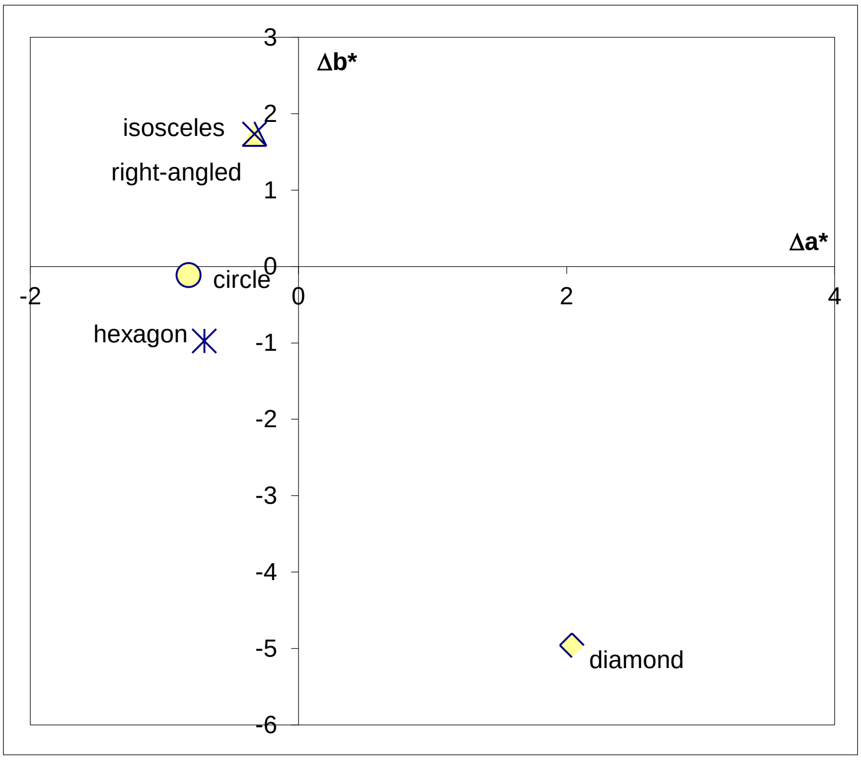


Figure 4-10 Δa^* and Δb^* between the matches to a square and the other shapes on blue background.

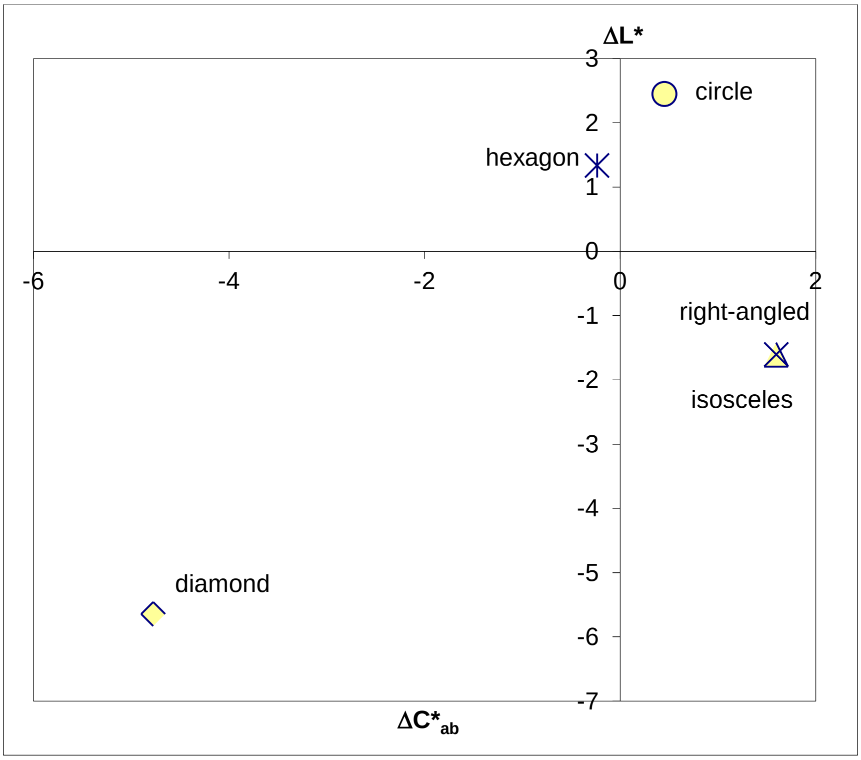


Figure 4-11 ΔC^*_{ab} and ΔL^* between the matches to a square and the other shapes on blue background.

The results showed that both triangle shapes increased the intensity of simultaneous contrast, while the other shapes decreased it. The diamond prominently showed the decrement of simultaneous contrast.

4.4 Comparison between different shapes

The changes in colour appearance of the grey sample with different shapes on various background colours – red, yellow, green, and blue – were analysed by means of the differences in hue (Δa^*, Δb^*), lightness and chroma (ΔL^* and ΔC^*_{ab}), and the total colour differences (ΔE^*_{ab}). The test colours were of the same grey for all shapes on all backgrounds. If the colour appearance of the test patches does not change, the corresponding match will be the same grey. Hence, the colour of the matches signifies the colour changes due to the shape and background of the test patch.

4.4.1 Hue differences

Figures 4-12 – 4-15 show the differences in hue between the test colour and the matches to each shape on red, yellow, green, and blue background, respectively. As mentioned earlier, the matches signify the changes in colour appearance of the grey sample due to its shape and background colour. The results showed that all shapes, except diamond, had the chromatic appearance of the hue opposite to that of the background.

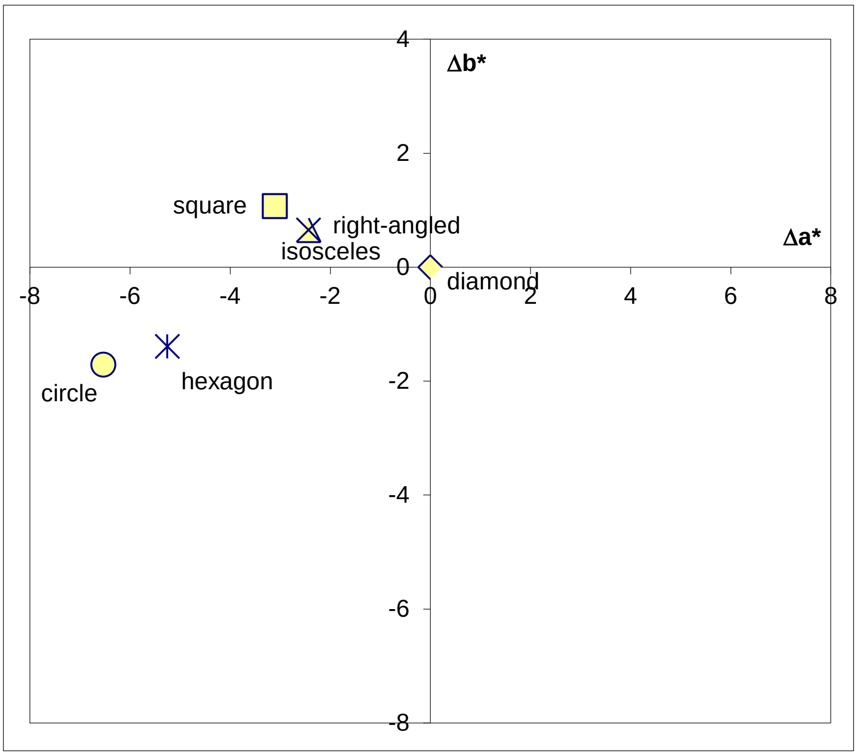


Figure 4-12 Hue differences between the test colour and the matches of each shape on red background.

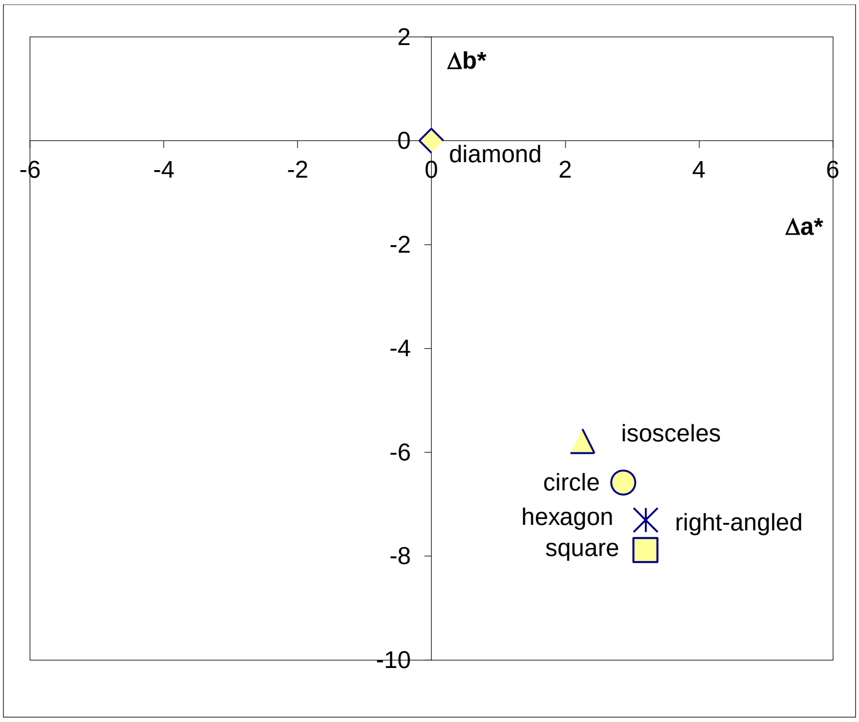


Figure 4-13 Hue differences between the test colour and the matches of each shape on yellow background.

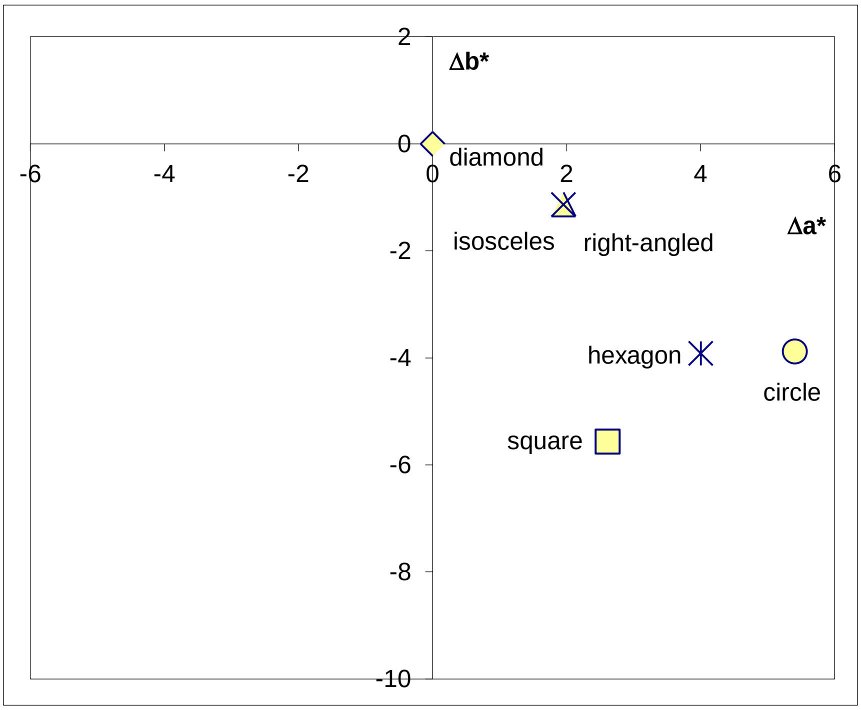


Figure 4-14 Hue differences between the test colour and the matches of each shape on green background.

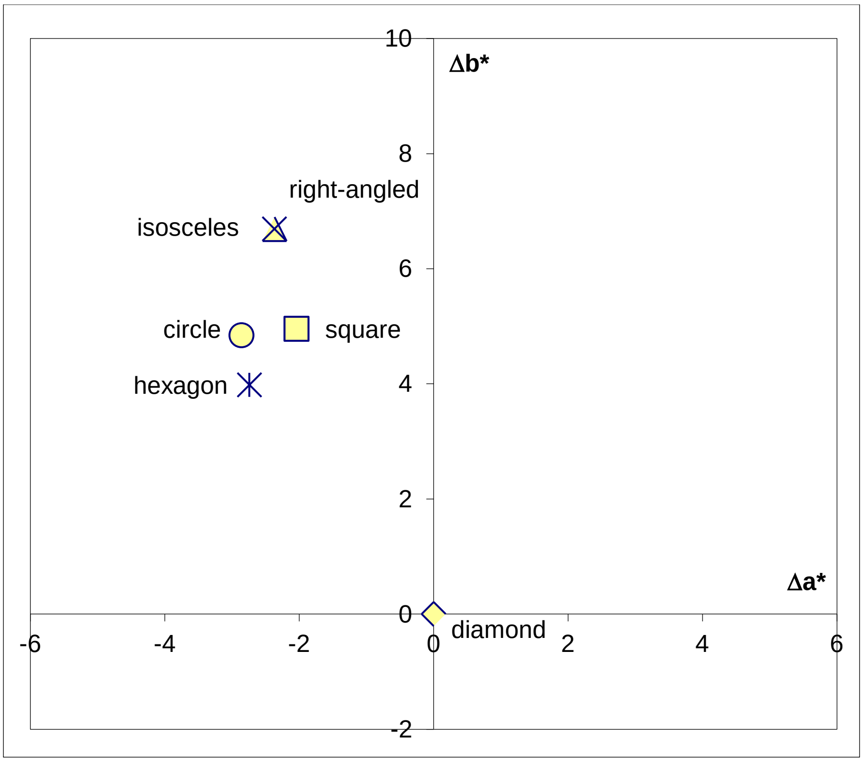


Figure 4-15 Hue differences between the test colour and the matches of each shape on blue background.

The results showed that the intensities of simultaneous contrast were different, depending on the shape of the test patch. Taken the square shape as the reference, as it was the same shape as the matching colours, it was found that some shapes magnified the chromatic induction, while some diminished it. These results conform to the findings in Section 4.3. The diamond decreased the effect of simultaneous contrast so much so that it cancelled out the effect, in which its colour appearance did not change when presented on different backgrounds. This is possibly because the diamond looks smaller than the other shapes when presented with the same height and width. Note that its area is the same as the area of isosceles and right-angled triangles (13.52 cm^2), but both triangles did not always shows the similar results to the diamond. It is possible that the results were affected by the perception of area, not the physical area, of the sample shape. Since the square had the largest area (27.04 cm^2) and also appeared largest, but the intensity of chromatic induction was not always the highest, this reveals that the area of the shape is not the main contribution of the differences in colour appearance among different shapes.

4.4.2 Lightness and chroma differences

Figures 4-16 – 4-19 show the differences in lightness and chroma due to the shape and background of the test patch. In all cases, except on green background, the test colours appeared more chromatic on colour backgrounds. These results were expected as the colour of the background induced the grey patch to appear more chromatic. The exception on green background could be explained by the fact that the test colour was not exactly neutral, but it was slightly bluish. This was because the white point of the monitor was set to D65, which is bluish white. The interaction between the background and the test patch with the influence of the sample shapes could result in the less chromatic appearance of the test colour. These results were found for the shapes of hexagon and both triangles.

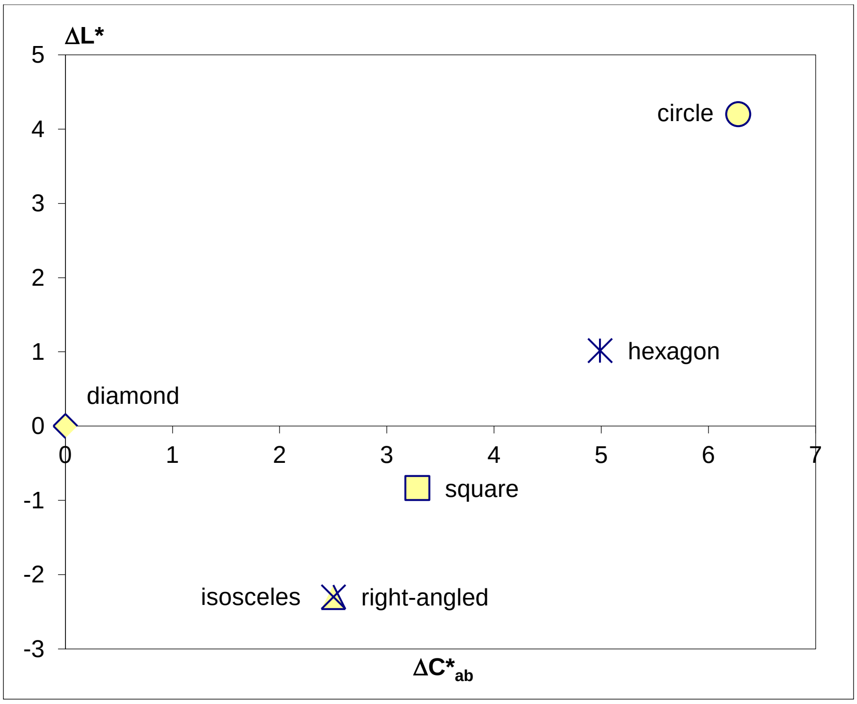


Figure 4-16 Lightness and chroma differences between the test colour and the matches of each shape on red background.

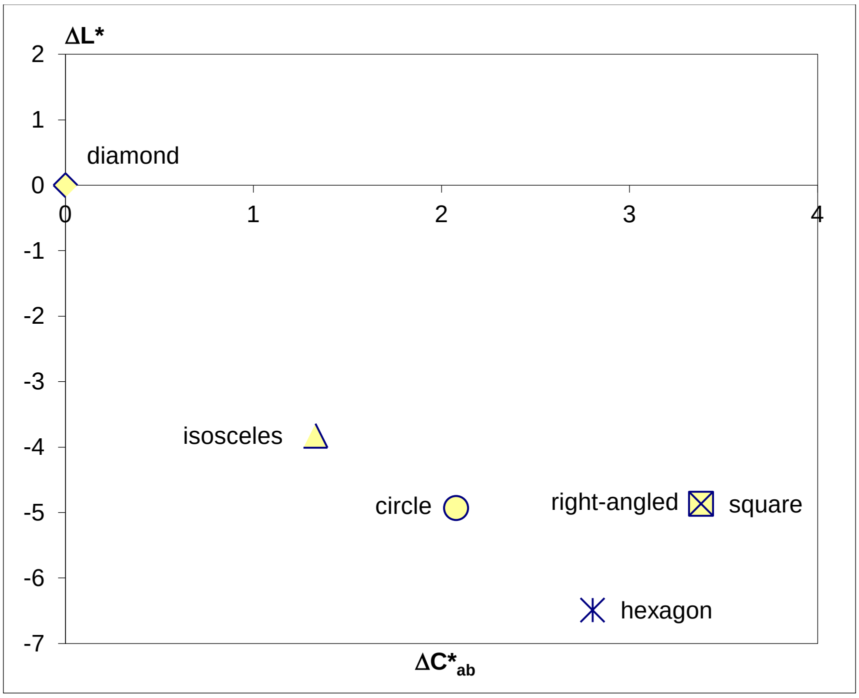


Figure 4-17 Lightness and chroma differences between the test colour and the matches of each shape on yellow background.

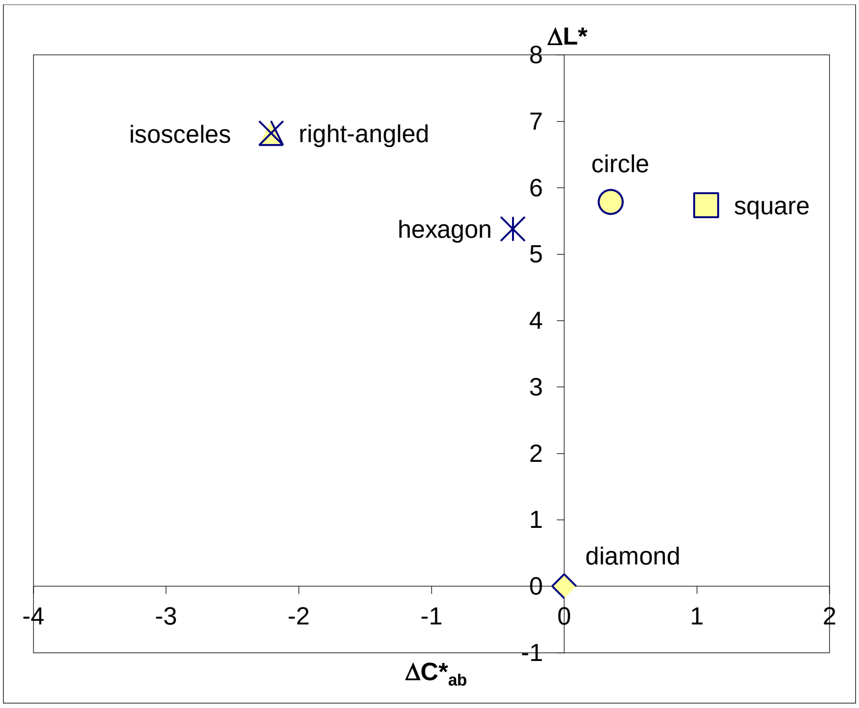


Figure 4-18 Lightness and chroma differences between the test colour and the matches of each shape on green background.

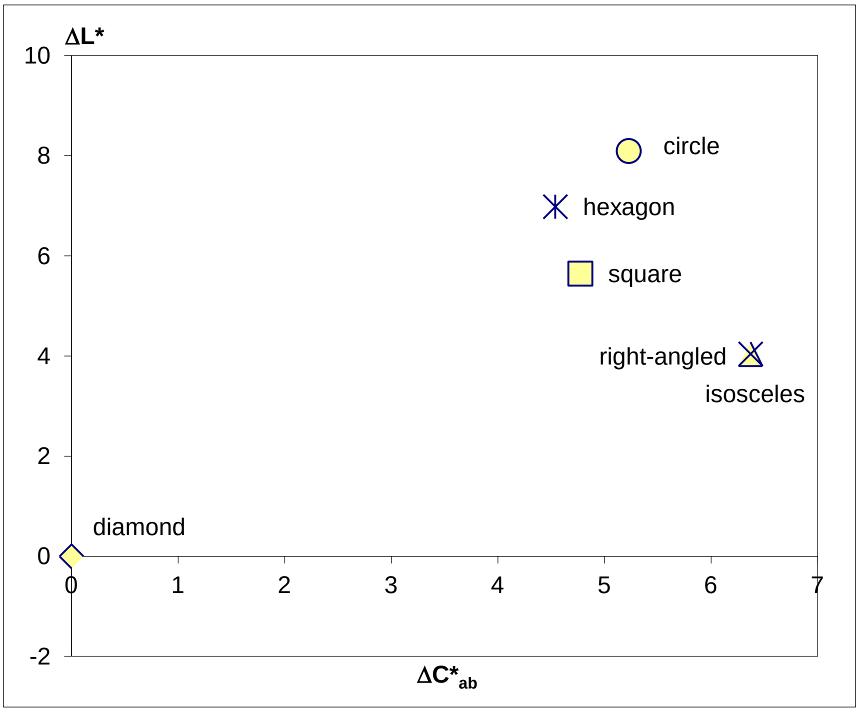


Figure 4-19 Lightness and chroma differences between the test colour and the matches of each shape on blue background.

In the case of lightness induction, the bright background will induce the test patch to appear darker, and the dim background will induce it to be lighter. The diamond, again, showed to be unaffected by the background colours. This reveals that the diamond decreased the effect of simultaneous contrast until it wiped out all the effect, so the test patch appeared the same on different backgrounds.

In all cases, except on red background, the results from all shapes agreed with one another in terms of the direction of lightness induction. On yellow background – the bright background – the test patches in all shapes were induced to have the darker appearance. In the cases of green and blue backgrounds – the dim backgrounds – the test patches were induced to appear lighter. On red background, the hexagon and circle appeared lighter, while the square and both triangles appeared darker. This might be because the brightness of the red background was in between bright and dim. The induction of lightness could go either ways depending on the shape. These results showed that shape had an influence on colour appearance of the test patch.

4.4.3 Total colour differences

The ΔE^*_{ab} values for each shape were averaged from all backgrounds to investigate the influence of shapes on changes in colour appearance due to the colour of the background. The results are depicted in Figure 4-20.

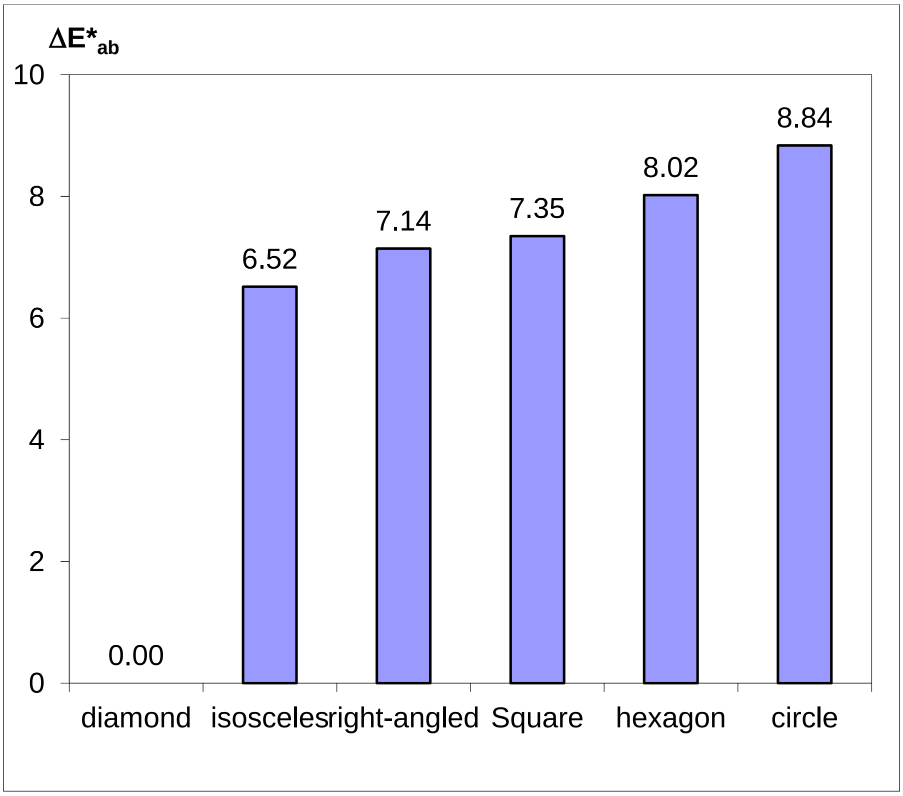


Figure 4-20 Total colour differences averaged from all backgrounds for each shape.

The results showed that the circle induced more changes than the other shapes, while the diamond wiped out all the effects of background colour. The descending order of shape contribution to the colour changes was as follows: circle, hexagon, square, right-angle triangle, isosceles triangle, and diamond.

4.5 Comparison between different backgrounds

Figure 4-21 shows the ΔE^*_{ab} results between the test colour in various shapes and their matching colours on different backgrounds. The results showed that both shape and background contributed to the changes in colour appearance of the test colour, as colour differences were varied when either one of these factors changed.

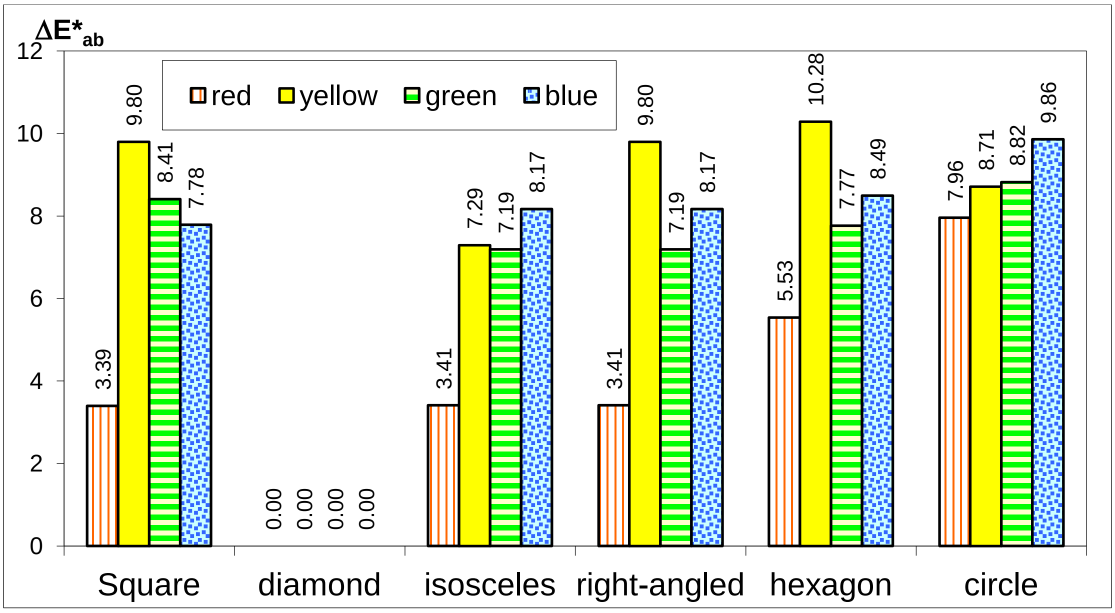


Figure 4-21 Total colour differences for each shape on each background.

To compare the results from different background colours, the colorimetric values averaged from all shapes for the given background were calculated. The ΔE^*_{ab} values were then calculated between the averaged values and the test colour, to reveal the induction by the background regardless of the shape. The results are depicted in Figure 4-22.

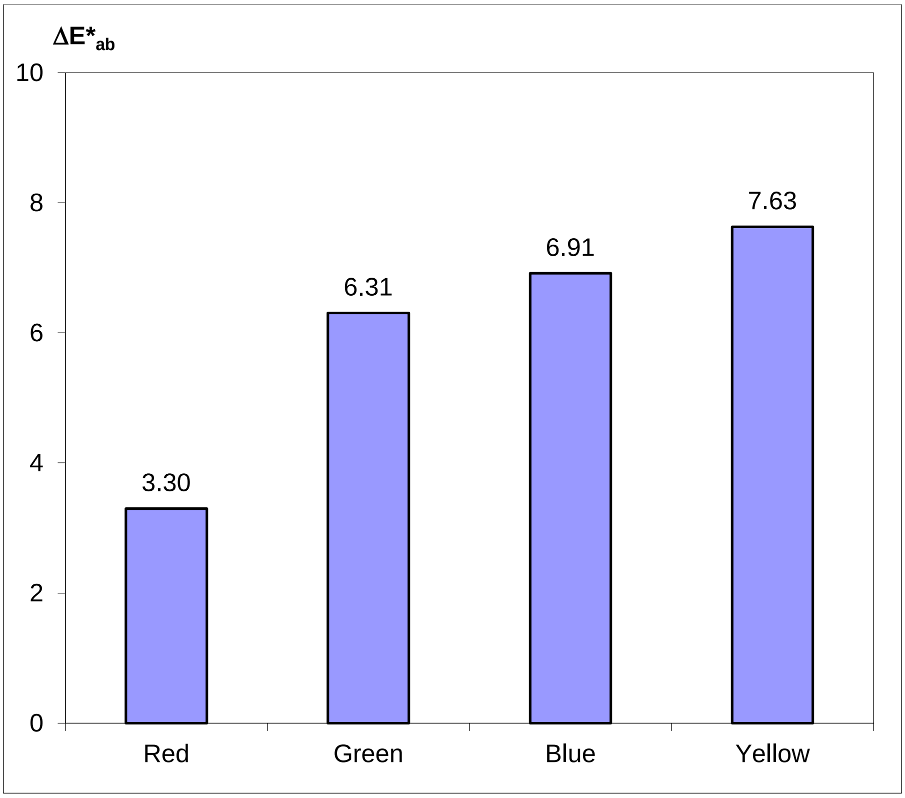


Figure 4-22 Total colour differences between the colour averaged from all shapes and the test colour for each background.

It was found that yellow background induced the most changes, while the red background the least. However, these results depended on the levels of chroma and lightness of the colours used in the study. The background colour with high intensities of chromaticness and lightness will induce higher degree of colour changes.

CHAPTER V

CONCLUSIONS

5.1 CONCLUSIONS

This research aimed at investigating the effect of shape of colour samples on the level of chromatic induction of the background colour.

Forty Thai observer (20 males and 20 females) ranging in age from 20-28 years old, with an average of 24.3 ± 1.6 years, took part in visual experiments. Each observer matched colour appearance of square samples presented on a grey background with that of test samples with different shapes on a chromatic background. All samples were shown on a CRT monitor. Six shapes were included in this study. They were circle, square, diamond, isosceles triangle, right-angled triangle and hexagon. Four chromatic backgrounds were red, green, yellow and blue. The differences between colours of the test and the matching samples were quantified by CIE total colour difference, ΔE^*_{ab}.

5.1.1 Effect of Background

The results showed that the colour of the background had an effect on colour appearance of the sample. The appearance of the sample changed towards the opponent hue of the background colour. For example, on red background, the grey sample appeared greenish. This reveals that the effect of simultaneous contrast occurred in this study. The levels of chromatic and lightness induction were different for different backgrounds. In this study, it was found that yellow background induced the most colour changes on the sample, while red background induced the least. The background with high intensity of lightness and/or chroma will induce high changes in lightness and/or chroma on the sample.

5.1.2 Effect of shape

In comparison with the square, the results showed that shape had an impact on colour appearance of the sample in a way that it could change the intensity of simultaneous contrast. The diamond always reduced the effects of simultaneous contrast. In other words, the diamond made the background have less effects on colour appearance of the sample. In this study, the diamond cancelled out all the effects of simultaneous contrast, so the same sample appeared the same on different backgrounds. Overall results showed that the haxagon and circle increased the colour changes of the sample due to the background colour, while the triangles slightly decreased the changes.

5.1.3 Colour changes due to shape and background.

Both shape and background contribute to the changes in colour appearance of the sample. In most cases, the background induces the opponent colour on the sample. This phenomenon is known as simultaneous contrast. In some cases, when the sample is small, the opposite effect occurs – the colour of the background bends with the sample, this phenomenon is called spreading. However, the results in this study showed that all shapes except the diamond exhibited the effects of simultaneous contrast. The test sample appeared more chromatic with the opponent hue of the background colour. The diamond, on the other hand, did not show this effect, nor did it show the spreading effect. The physical size of the diamond was not smaller than the triangles, yet their results were different. The cause of these differences could be from the perception of size, not the physical one. This finding confirms that both shape and size have an impact on colour appearance.

5.2 SUGGESTIONS

The future study colud investigate these factors:

1. The effects of chroma and hue of the test colour.
2. The effects of different levels of chroma and lightness of background colour.
3. The effects of the area and size of the shape.

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Appendix

TABLE A-1 The colorimetric values of matching colours on red background.

Matching colours on red background					
Step	L*	a*	b*	C^*_{ab}	h_{ab}
8	45.61	-2.88	1.20	3.12	157.33
7	43.18	-2.81	1.71	3.29	148.66
1	44.55	-2.95	1.29	3.22	156.41
2	42.25	-5.38	1.94	5.72	160.19
3	43.71	-6.06	2.36	6.50	158.74
4	45.57	-8.21	-0.10	8.21	180.71
5	48.75	-9.49	-0.42	9.50	182.56
6	48.80	-8.93	-3.78	9.70	202.95

TABLE A-2 The colorimetric values of matching colours on yellow background.

Matching colours on yellow background					
Step	L*	a*	b*	C^*_{ab}	h_{ab}
8	43.42	-3.46	2.41	4.21	145.17
7	47.33	-3.80	2.46	4.53	147.10
1	44.55	-2.95	1.29	3.22	156.41
2	40.72	-0.69	-4.50	4.55	261.24
3	39.68	0.25	-6.59	6.60	272.15
4	38.06	0.25	-6.02	6.02	272.41
5	39.61	-0.08	-5.30	5.30	269.11
6	40.96	-0.48	-4.56	4.58	263.95

TABLE A-3 The colorimetric values of matching colours on green background.

Matching colours on green background					
Step	L*	a*	b*	C^*_{ab}	h_{ab}
8	51.20	-4.86	1.02	4.97	168.11
7	50.38	-5.37	3.72	6.53	145.31
1	44.55	-2.95	1.29	3.22	156.41
2	51.37	-1.00	0.15	1.01	171.20
3	50.29	-0.34	-4.27	4.29	265.49
4	49.93	1.05	-2.63	2.83	291.79
5	50.33	2.45	-2.59	3.57	313.46
6	49.59	1.97	-2.75	3.39	305.65

TABLE A-4 The colorimetric values of matching colours on blue background.

Matching colours on blue background					
Step	L*	a*	b*	C^*_{ab}	h_{ab}
8	45.21	-2.10	-0.79	2.25	200.67
7	43.26	-1.56	-2.00	2.53	231.94
1	44.55	-2.95	1.29	3.22	156.41
2	48.59	-5.32	7.98	9.59	123.68
3	50.19	-4.99	6.25	7.99	128.62
4	51.53	-5.69	5.27	7.76	137.20
5	52.64	-5.81	6.13	8.45	133.46
6	50.61	-5.80	8.74	10.49	123.59

VITA

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