Impact of Blackness Preference and Perception on Product Design

By

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Intellectual Property and Publication Statements

The candidate confirms that the work submitted is her own, except where work which has formed part of jointly authored publications has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to the work of others.

The third, fourth and fifth chapters within the thesis have been built on the work from jointly authored publications. The details of the jointly authored publications are as follows:

1. Tao L, Westland S and Cheung V, 2011. Blackness: Preference and Perception. Proceedings of the IS&T/SID's Nineteenth Color and Imaging Conference, 270-275, San Jose (USA).

2. Tao L, Westland S and Cheung V, 2012. Blackness: Preference and Perception (Chroma and Value), Proceedings of the Sixth European Conference on Colour in Graphics, Imaging, and Vision, 253-258, Amsterdam (The Netherlands).

3. Tao L, Westland S and Cheung V, 2012. Studies of Blackness Preference and Perception, Proceedings of the 2012 International Color Association Conference, Taipei (Taiwan).

In all publications, the works were carried out almost entirely by the candidate. The candidate designed and conducted the psychophysical experiment, collected and analyzed the data and wrote the manuscript. Prof. Westland and Dr. Vien modified and made comments on it.

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Abstract

This study investigates our perception of, and preference for, blackness and specifically explores the influence of different cultural backgrounds (notably nationality and gender). Despite black being an important colour it has been studied relatively little compared with, for example, whiteness. Two major questions were considered: whether observers prefer one black to another (blackness preference); and whether observers consider one black sample to be blacker than another (blackness perception). Psychophysical experiments were carried out using paired comparison and ranking methods for male and female observers from UK and China. Blackness perception was found to be invariant to the cultural background of the observer. Whereas the cultural effect was found for the blackness preference results. Male observers preferred darker blacks with a greenish-blue hue whereas female observers preferred lighter blacks with a reddish-blue hue. Differences between the nationality groups were a little less pronounced but Chinese observers (like females) preferred lighter reddish-blue blacks whereas UK observers (like males) preferred darker greenish-blue blacks.

These results are potentially very valuable to designers who may wish to select a black for a product that will be most preferred. This work suggests that different blacks may be optimal for products intended for a mainly male or female audience. However, to what extent can the results from a psychophysical study carried out using abstract coloured squares displayed on a computer be extended to the very practical problem of product design where context may be powerful? This is the third question that was addressed in this thesis. An iPhone product was simulated on-screen using 3-D software and where the colour was varied. Observers were again asked about their blackness preference and perception. The results from the simulation study were almost entirely consistent with those from the earlier work which suggests that the findings from this thesis might have wide applicability to design.

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1. Introduction

1.1. Background

Design is the visual expression of an idea and conveyed in the form of a composition. Forms, colours and their arrangement are the basic essentials of design and colours play a particularly important role (Wong, 1997). There are two ways to classify the design tasks: firstly, it could be classified as original design, adaptive design and variant design. (Otto and Wood, 2001); the second way to categorize design tasks is based on its process operations. Otto and Wood (2001) divided it into mechanical engineering design, architectural design, electrical engineering design, food science design, materials design, furniture design, bridge/roadway design, aerospace design and product design (Otto and Wood, 2001).

Product design is a combination of arts, science and technology (Morris, 2009). The designer may consider the product's appearance, usability, physical ergonomics, marketing, brand development and sales (Morris, 2009). The design of new products can help companies to stand out in the competition. Product design is a series of actions rather than engineering. It needs successful actions for engineering, marketing and so on (Otto and Wood, 2001).

Colour design is a very important component of product design. Colour has the ability to arouse feelings and emotions in people. It plays a great role in decision-making of any customer when they choose what to buy. Research conducted by Elliot and Maier revealed that, when people choose a product, they pay almost 80% attention to colour compared with only 20% attention to the shape or form (Elliot and Maier, 2007). Being a distinctive factor of a product's appearance, colour immediately attracts the attention of a consumer and may arouse a particular emotion. Companies have rediscovered the important role of colour in sales and marketing. According to the study of consumer emotion responses of product, colour is one of the elements that influences the consumer purchase. So understanding consumer response to colour is very important.

Colour emotion is affected by a number of factors such as memory, past experience and intelligence. Certainly culture is one of these factors. Most researchers agree that colour emotion is influenced by culture. This does not mean that the colour will be perceived differently but means that it could represent different things to people who have different cultural backgrounds. Colour perception and preferences are different for different cultural backgrounds. Elliot and Maier (2007) developed a model of colour and its psychological functioning. As they pointed out, colours can carry specific meanings in different contexts; therefore, colour carries different connotative meanings in different cultures (Elliot and Maier, 2007). For example, black is regarded as a symbol of death in most western cultures, but white is always associated with death in China and India.

Black is a powerful colour and important in design. So it is used as the sample colour in this study. Black can produce strong feelings both of love and hate. It is an important colour in our daily life and in manufacturing industry. Moreover, the use of black is particularly important in product design (especially for IT equipment design which is a focus of this study). Black is a colour, albeit one that in its purest form lacks chroma. Many black inks are made by mixing coloured dyes or pigments and can have a perceptible hue. Therefore, there can be slight differences between blacks although they look rather similar. It is interesting to consider, for a range of blacks, which black would be preferred or which black would be considered to be a 'better' black.

In recent years, the importance of black colour has increased for design products. The black colour design of appearance becomes remarkable about IT products and home-use electrical products. So in order to understand the culture differences of using black in product design, iPhone was used as the product model in this study.

1.2. Aims

Several important weaknesses in the literature may be noted. Firstly, there is a great deal of published work that focuses on the perception of whiteness (MacAdam, 1934; Ganz, 1979) but few studies into blackness. In comparison, the assessment of blackness has received relatively little attention. Therefore, in order to understand the different series of black colour, the assessment of blackness will be discussed and explored in this thesis.

Secondly, most research simply seeks to determine whether colour emotion is influenced by culture, but they explore colour preference or colour emotion for colours without context. For example, most researchers used colour chips to investigate the colour preference in the experiment, it may reveal that A is preferred by observers more often than B, but this does not mean that when it used in product design, consumers would prefer A rather than B. Clearly it is complex and the part played by colour in that process requires the consideration of a great many factors.

Therefore, the aims of this study are:

1. This research begins with a hypothesis that differences of colour emotion could exist in different cultures. The first aim of the research is to determine whether this hypothesis is valid or not?

2. The second aim is to explore differences in blackness perception and preference between different cultures and to consider the relationship between blackness perception and blackness preference.

3 The third aim is to explore using blackness colour in product design. Since product design is a very large field, this study is to focus on a particular product (iPhone).

1.3. Overview of Thesis

This thesis is comprised of eight chapters. The outline of the thesis is presented in the first chapter. In this chapter the background, the research motivation and aim are introduced. Chapter 2 reviews the literature which is related to the study. It includes the fundamentals of colour and product design; the earlier psychophysical studies of colour and culture; statistical techniques scaling methods like Thurstone's paired-comparison and the ranking related to this study. The investigation of blackness perception *(which of two black samples observers considered to be closest to a pure black)* and preference *(which of two black samples observers preferred)* according to hue is described in Chapter 3. In this Chapter, a pair-comparison psychophysical experiment is designed; all colour samples are evaluated by hue and analysis carried out based on gender and nationality (Chinese and UK). Chapter 4 explores blackness perception and preference according to chroma and value. In Chapter 5, blackness perception and preference is explored by using a ranking method and seeks to validate and extend the previous findings presented in Chapter 3 and Chapter 4. The application of black colour used in product design is explored in Chapter 6. In order to understand the different series of black colour, iPhone is used as an example model in experiment. The blackness equations are tested in Chapter 7 and finally Chapter 8 presents the conclusion of the study and Chapter 9 introduces further work related to this study.

1.4. Publications

The publications related to this study are listed as below:

1. Tao L, Westland S and Cheung V, 2010. Studies of Blackness. Proceedings of CREATE Conference, Gjøvik (Norway).

2. Tao L, Westland S and Cheung V, 2011. Blackness: Preference and Perception. Proceedings of the IS&T/SID's Nineteenth Color and Imaging Conference, 270-275, San Jose (USA).

3. Tao L, Westland S and Cheung V, 2012. Blackness: Preference and Perception (Chroma and Value), Proceedings of the Sixth European Conference on Colour in Graphics, Imaging, and Vision, 253-258, Amsterdam (The Netherlands).

4. Tao L, Westland S and Cheung V, 2012. Studies of Blackness Preference and Perception, Proceedings of the 2012 International Color Association Conference, Taipei (Taiwan).

2. Literature Review

This chapter gives an introduction of the background knowledge related to the present study. Section 2.1 introduces the colour fundamentals and Section 2.2 explains the colour in product design. Then the early studies on colour psychology and colour emotion are discussed in Section 2.3. Section 2.4 explores the previous studies on black colour design and investigated the psychophysical scaling methods which are used in this study.

2.1. Colour Fundamentals

2.1.1. Introduction

Colour plays an important role in people's visual experiences. One of the earliest colour theories was founded by the Greek philosopher Empedocles (492-431 B.C.). Empedocles pointed out that colour is not the attribute of objects but rather observers perceive colour with their eyes. Later Democritus (460-370 B.C.) developed this idea and stipulated the world was formed by atoms, and followed this with the idea that colour was atomic arrangements. For the first time colour theory evolved from a combination of speculation and observation. But modern "colour theory" as we know it today dates from the 18th century, beginning with a partisan argument around Isaac Newton's colour theory of 1704 (Wikipedia, 2008; Holtzschue, 2006). There is no doubt that colour has a natural character of aesthetic appeal. More significantly, colour can be used to express ideas and psychology, and to convey perception. This section begins with the concept of colour and focuses on the theoretical aspects including the nature of colour through sensation; then traditional colour mixing and colour matching theories are explored; finally colour order systems are discussed.

2.1.2. Colour Definitions

Colour results from perception of people to the objective world. It is the primary factor of human vision and has tremendous expressive qualities. The various physical phenomena, physiological mechanisms and psychological effects combine to affect our perceptions of a colour. Holtzschue pointed out 'Colour is stimulating, calming, expressive, disturbing, impressional, cultural, exuberant, and symbolic' (Holtzschue, 2006). It covers virtually all aspect of life and gives beauty to objects in order to enrich our life. So we can say that black and white images give us the aspect of life, but colours bring the drama into our life.

2.1.2.1. Light and Colour

Colour is essentially an interpretation of light by the eye and brain (Holtzschue, 2006). All things which we see around us are the effect of light and our response to it. Light can help us distinguish one object from another, or from its environment. It is a kind of energy that reaches the optical nerve system of our eyes and is interpreted by our brain as colour (Wong, 1997). So to define colour, the relationship between light and colour needs firstly be understood.

Colour, physiologically, 'is a sensation of light that is transmitted to the brain through the eye' (Feisner, 2006). Light passes into the eye and comes in contact with the retina, the inner lining of the eyeball near the back of the eye (Figure 1). The retina contains rod cells and cone cells which allow the brain to see dimly lit forms. At low levels of lighting only the rods are active, so colour vision is impossible. At higher light levels the cones dominate our visual response. There are three types of cone and each type is responsive to different wavelengths of light. The rods and cones transfer light energy into electrochemical energy and transmit to the brain; in this way we could enjoy colour vision (Feisner, 2006).

Colour can be seen by two different ways, directly or indirectly. Firstly, light can reach the eye directly from a light source, for instance, when we perceive colour on a monitor screen; secondly, when light is reflected from a surface and enters into our eyes, it is called reflected light. Most colours of the physical world are reflected light, for example, printed pages, objects, and the environment (Feisner, 2006).

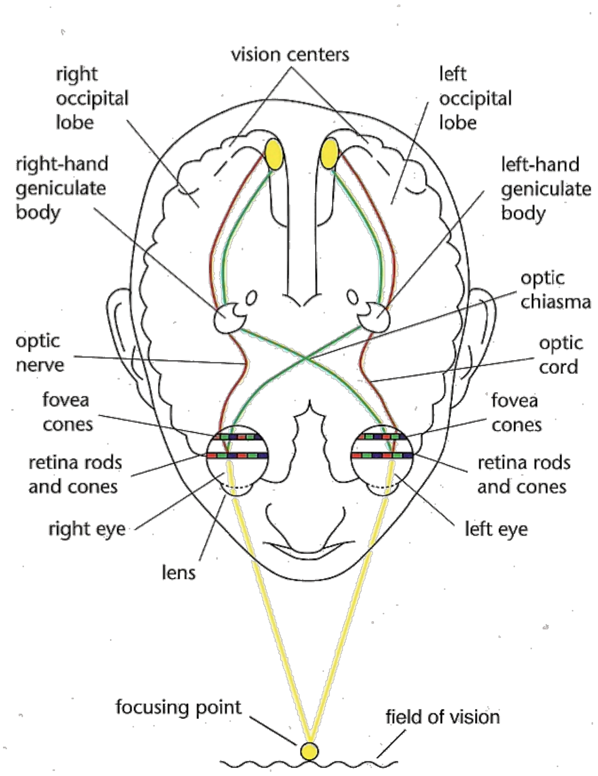
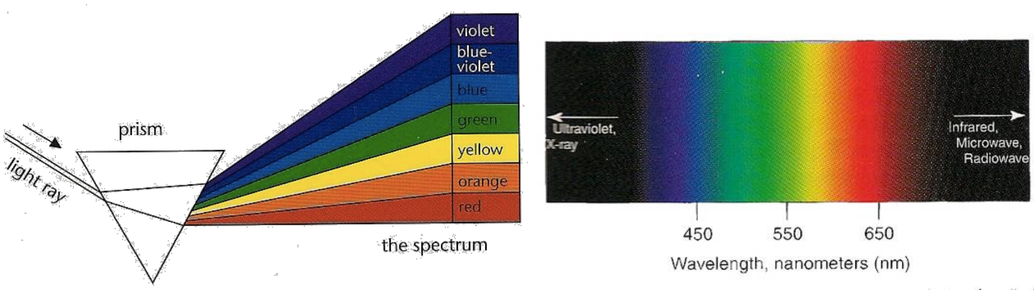


Figure 1. Retino-cortical colour pathways (Feisner, 2006).

Light, the radiation we can see, can be described by its wavelengths. According to the famous experiment of Newton (1642-1727), when sunlight (white light) passes through a prism, it can be split into different wavelengths (red, orange, yellow, green, blue, blue-violet and violet). They are all visible radiation with wavelengths between about 380 and 780 nm (Holtzschue, 2006). Red corresponds to the longest wavelengths (> 630nm) and violet to the shortest. However, radiation includes not only visible radiation, but also radio waves and X-rays, ultraviolet, infrared and microwaves. They are all members of the family of radiation (Figure 2).



The Visible Spectrum **Wavelength**

Figure 2. The electromagnetic spectrum (Feisner, 2006).

2.1.2.2. Perception and Cognition of Colour

The human eyes play an important role in perceiving colour. When light enters our eyes, the energy is transferred into electrical impulses and transmitted to the brain; the brain interprets these signals as colour which we then see (Feisner, 2006).

A schematic diagram of the eye is shown as Figure 3. Light passes through the cornea, the aqueous humor, the organ and the lens, finally striking the retina. The cornea helps to focus on the light waves and provides a protective covering. The aqueous humor, a fluid-like substance, supplies nourishment to the organ (Bleicher, 2005). The retina is the covering near the back of eye and is made up of layers of different cells. It contains two types of receptor cells: rods and cones, named according to their shapes (Bleicher, 2005). Rods are long, thin, and cylindrically shaped and respond to value (light and dark) but cannot distinguish hue (Bleicher, 2005). The purpose of the rods is to allow the brain to differentiate forms. Cones are fat and bulgy shaped and perceive hue. There are more than 100 million rods and 6 million cones in each eye (Bleicher, 2005). The fovea, a most sensitive centre area of the retina which only contains cones, transmits to the brain.

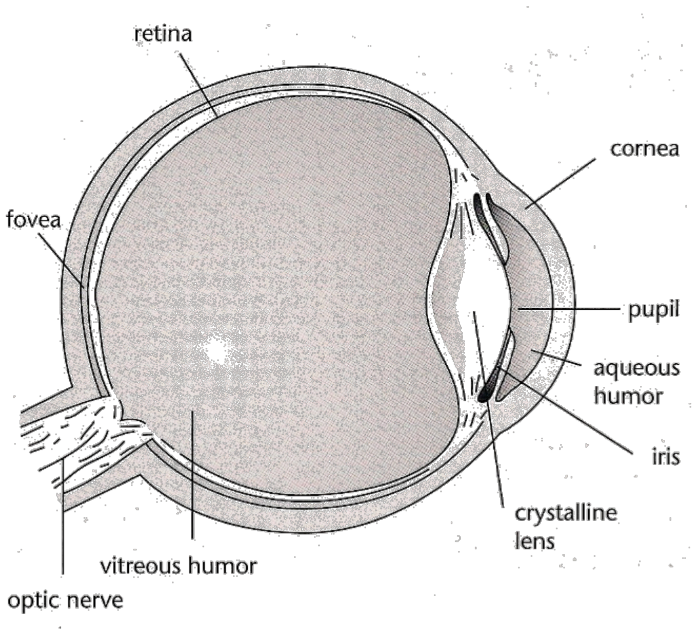


Figure 3. The human eye (Steven, 2005).

2.1.2.3. Conclusion

According to the literature review about the functions of light on colour and organ of the human eye, definitions of colour can be made. Colour can be defined as 'the property of material phenomena perceived by seeing, based on the reflection of light beams of different wavelengths' (Holtzschue, 2006). The wavelength of radiant energy of colour is from 380nm to 720nm (Holtzschue, 2006). This energy can be direct like sunlight or indirect which reflecting from or transmitting through a surface. Light passes through the eye and be processed in the brain which transforms it to colour sensation.

2.1.3. Principles of Colour Mixing and Colour Matching

The analysis above has clearly indicated physical properties leading to colour. Below the basic attributes of colour perception are explored and the important principles of colour mixing and colour matching are described.

2.1.3.1. Colour Mixing

There are two main types of colour mixing: additive colour mixing and subtractive colour mixing (Bleicher, 2005). Additive colour mixing shows different colours that be created of different wavelengths lights; subtractive colour mixing appears when colourants (inks, paints, dyes etc.) are mixed together.

Additive colour is the process of mixing coloured light, such as in theatrical lighting or television (Feisner, 2006). The light is used to describe electromagnetic energy in the visible spectrum which has wavelengths and the process of additive colour mixing takes place in the retina of the human eye. Thus, the energy of the additive combination is the sum of all original beams and the hue of the combination is usually the intermediate of the initial ones (Agoston, 1979). As Figure 4 shows, red, green and blue are the additive primary colours, because these three primary colours can allow the largest gamut of colours to be reproduced. Additive colour mixing is known as a linear process and the famous linearity of additive colour mixing is referred to as Grassman's additive laws.

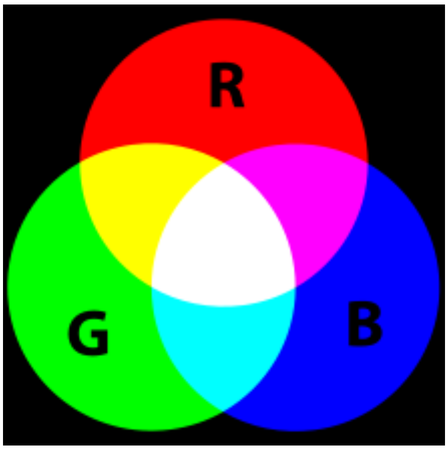


Figure 4. Additive colour mixing (Wikipedia).

Subtractive colour is the process of mixing pigments together, such as we see in painting (Feisner, 2006). It happens when light is selectively removed from a light path by processes such as absorption and scattering. It is mostly related to the methods of creating colours which are based on pigment or dyes. The primaries hues in the subtractive systems are magenta, yellow and cyan which are broadly applied in the printing industry. Mixing magenta and yellow, absorbing green and blue, produces red; mixing magenta and cyan, absorbing green and yellow, produces blue and mixing yellow and cyan, absorbing blue and yellow, generates green.

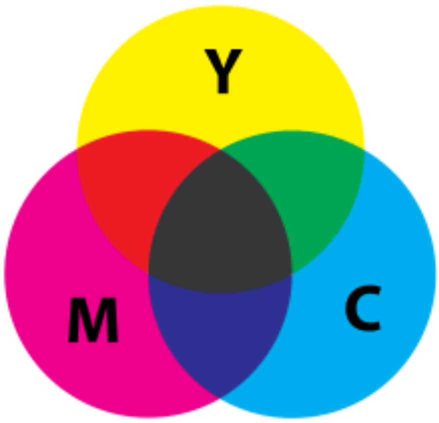


Figure 5. Subtractive colour mixing (Wikipedia).

2.1.3.2. CIE System of Colorimetry

Colour matching research with light was first performed by Newton in the early 1700s (Wikipedia, 2008). He found that white light could be reproduced by combining only blue and yellow wavelengths. In the late nineteenth century, Lovibond developed a device with which he could specify the colour of beer visually using sets of beer coloured glasses (Lovibond, 1887). Later in 1929, the Munsell Book of Colour was produced based on a Maxwell spinning disk, which was known as disk colorimeter (Berns and Billmeyer, 1985). However, significant metamerism may be generated when a visual colorimeter, which is not designed for a specific use, is employed. Thus, the method of using visual colorimetry with a standard observer and a standardised device dates back to the 1920s and was first standardised by the CIE in 1931 (CIE, 1931).

The International Commission on Illumination (CIE) investigated the need for standardisation of colour notations (Feisner, 2006). This exact colour matching system based on lights has been used since 1931. The CIE 1931 system is based on measurements by Guild (1931) and Wright (1928-1929). In this system three primary colours (red, green and blue) were used to match a single wavelength colour (used a 2º field of vision). The CIE RGB functions:

$$I \equiv R[\mathrm{R}] + G[\mathrm{G}] + B[\mathrm{B}] \qquad \text{Equation 1}$$

Where:

I is the stimuli to be matched

R is the value of the (R) primary of wavelength λ_R

G is the value of the (G) primary of wavelength λ_G

B is the value of the (B) primary of wavelength λ_B

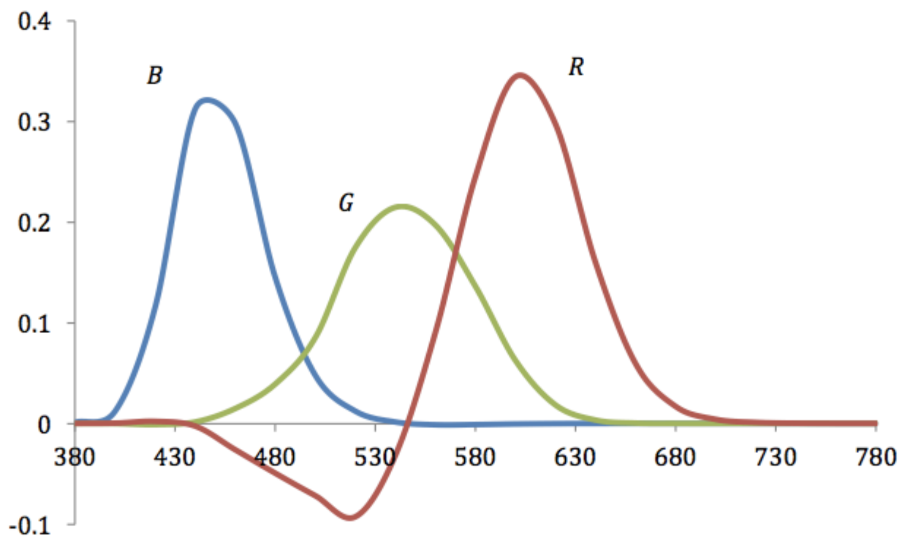


Figure 6. CIE RGB colour matching functions(Berns, 2000).

CIEXYZ

In the CIE colorimetric system, the coordinates of the space are formed by the tristimulus values which means 'amount of three primary lights superimposed to match the perception created by any light' (Kuehni, 2005). The three tristimulus values *X*, *Y* and *Z* are the amounts of what are referred to as imaginary lights. A formula for calculating CIE tristimulus values is:

$X = k\sum E(\lambda)\ \bar{x}(\lambda)\mathrm{P}(\lambda)$

$Y = k\sum E(\lambda)\ \bar{y}(\lambda)\mathrm{P}(\lambda)$ Equation 2

$Z = k\sum E(\lambda)\ \bar{z}(\lambda)\mathrm{P}(\lambda)$

Where:

$E(\lambda)$	is the spectral power distribution of the stimuli at wavelength λ
P(λ)	is the spectral reflectance or transmittance of the stimuli
k	is $100/[\sum E(\lambda)\ \bar{y}(\lambda)]$

$\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ are the colour matching functions for CIE 1931 and CIE 1964

The CIE (1931) colour matching function was derived from experiments which used a 2° viewing angle, but in 1964 the standard observer was changed to 10° vision. Compared with the CIE system in 1931, colour matching should be evaluated two or three times, which means large matching fields relevant to the application could be used in this system. It was a noticeable advantage of the CIE 1964 System. In order to match any real-world stimulus, the CIE system used appropriate calculation to compute the tristimulus values to improved colour matching functions. The range of wavelength is from 360nm to 830nm.

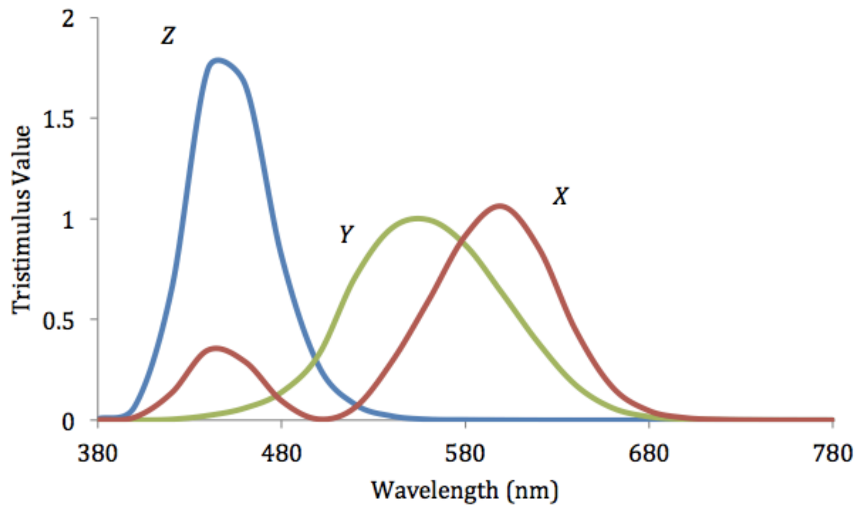


Figure 7. CIE XYZ colour matching functions with standard colorimetric observer (2°)(Berns, 2000).

Chromaticity diagram

It is difficult to determine the relationship between different colours in the three-dimensional space. Therefore, a two-dimensional diagram can offer a suitable map, and is derived by plotting *y* and *x*, the proportional amounts of *X* and *Y* known as chromaticity coordinates. The equation to compute chromaticity coordinates *x*, *y* is:

$x = X/(X+Y+Z)$

$y = Y/(X+Y+Z)$ Equation 3

The XYZ primaries lie at x = 1, y = 0; x = 0, y = 1; and x = 0, y = 0 (where z = 1) in the diagram, respectively.

CIELAB

The CIELAB colour space is a colour opponent space with three spatial coordinates: L^*, a^* and b^*. The equations are as below:

$L^* = 116(Y/Y_n)^{1/3} - 16$ if $Y/Y_n > 0.008856$

$L^* = 903.3(Y/Y_n)$ if $Y/Y_n \leq 0.008856$

$a^* = 500[f(X/X_n) - f(Y/Y_n)]$ Equation 4

$b^* = 200\ [f(Y/Y_n) - f(Z/Z_n)]$

Where:

L^*	is lightness
a^*	approximates redness-greenness;
b^*	approximates yellowness-blueness;
X, Y and Z	are the tristimulus values of the stimulus.
X_n, Y_n and Z_n	are the tristimulus values for a reference white.

$f(Y/Y_n) = (Y/Y_n)^{1/3}$ if $Y/Y_n > 0.008856$

$f(Y/Y_n) = 7.787(Y/Y_n) + 16/116$ if $Y/Y_n \leq 0.008856$

$f(X/X_n)$ and $f(Z/Z_n)$ are similarly defined.

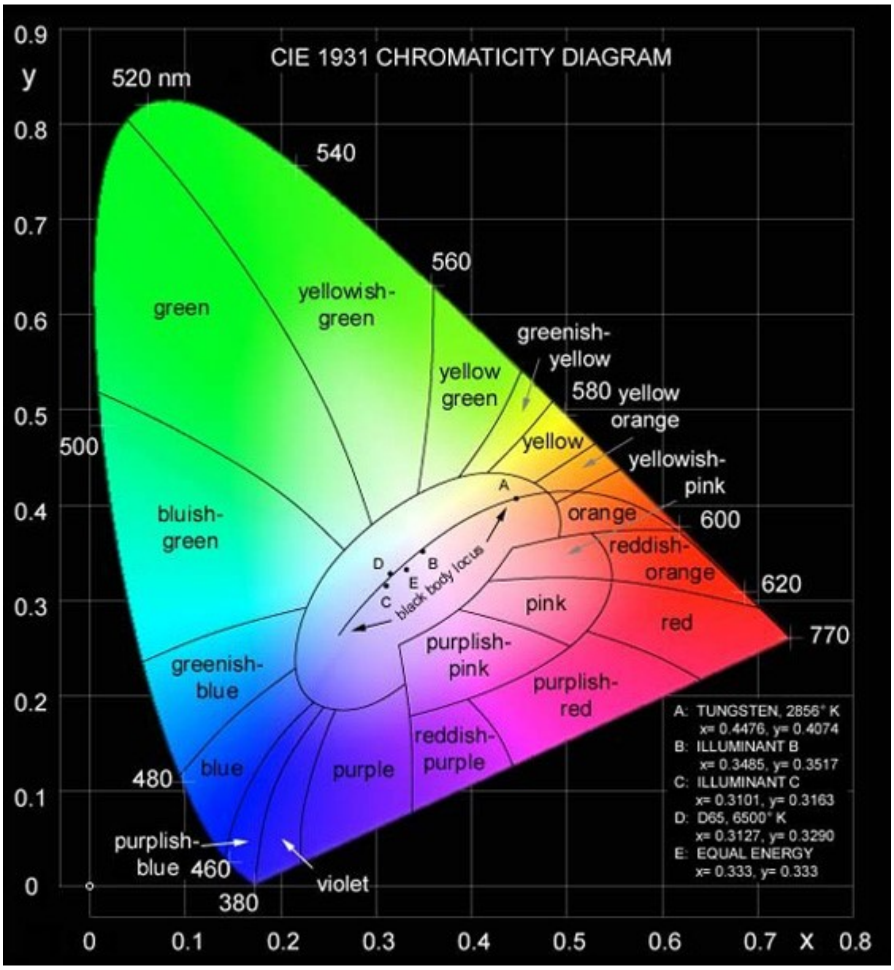


Figure 8. The CIE chromaticity diagram (1931)(Berns, 2000).

2.1.4. Colour Order System

A colour order system evolves from defining a set of visual perceptions (Berns, 2000). Colour order system is widely used to categorise the colour; it arranges colour into a logical order according to certain rules. Dependent on different schemes, there are several types of colour order systems, but the Munsell colour system is particularly important and used as the main colour system in this study. So the Munsell colour system was discussed as following.

The Munsell colour system was developed by Munsell in 1905 (Munsell, 1905). It played a significant role in the colour science theory. This system is not only a numerical system but also a physical exemplification. The Munsell colour system is a three-dimensional diagram which contains three variables: Hue, Value and Chroma (Figure 9). It is classified by 10 hues. First, there are five primary hues of this system—red, yellow, blue, green and purple.

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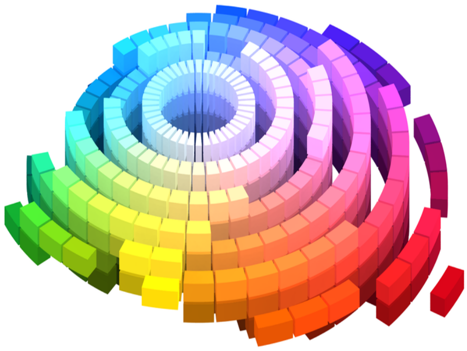


Three-dimensional diagram of the Munsell colour system

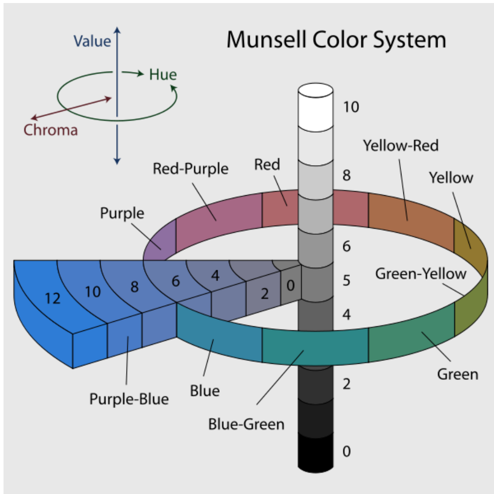


Figure 9. The Munsell colour system.

Hue is defined as 'attribute of colours that permits them to be classed as red, yellow, green, blue, or an intermediate between any contiguous pair of these colours' in Merriam-Webster's Collegiate Dictionary (Kuehni, 2005). The Munsell colour system contains five primary hues (Red, Yellow, Green, Blue, Purple) and five intermediary hues (Yellow-Red, Green-Yellow, Blue-Green, Purple-Blue, Red-Purple). These ten hues are given a name with number 5, then each of these ten hues were divided into 10 steps apart, so there are 100 hues have their numbers. Munsell hue notation (H) is presented by this number and a letter/letters which is taken from the name of the 10 basic hues (Figure 10).

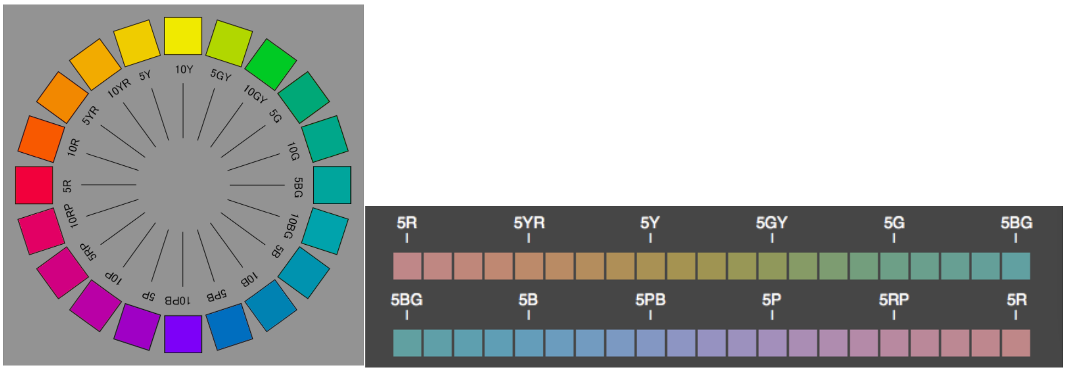


Figure 10. The hues of the Munsell colour system.

'Value refers to the degree of lightness or darkness in any colour' (Holtzschue, 2006). It means the relative luminosity of a colour. A value scale is a series of steps moving between black and white (Holtzschue, 2006). White is the lightest value and black is the darkest (Feisner, 2006). The scale range of lightness in Munsell colour system is divided into 10 equal steps from 0 to 10. Value 0 is used to present the absolute black and absolute white is value 10.

'Chroma refers to the relative purity of a colour' (Holtzschue, 2006). Like value, chroma is linear and progressive. The beginning of a chroma scale is a colour that is hue-intense. The end step is a colour whose hue is weak. The chroma scale ranges in the Munsell system is from 0 for a neutral grey, but the maximal chroma coordinates is depend on which area it is in Munsell colour space.

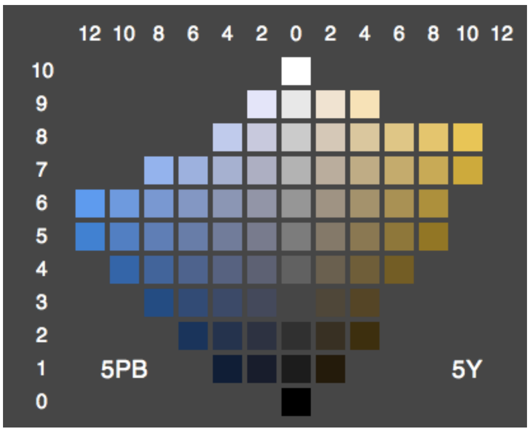


Figure 11. Munsell *value* (vertical) and *chroma* (horizontal); hue 5Y and 5PB (Feisner, 2006).

2.1.5. Conclusion

This section is reviewed the colour fundamentals which related to the study. Colour is usually seen before imagery. According to the different wavelength of light, the physiology of the eye and the brain's reaction could let us identify light as different colour. Due to three classes of photoreceptor of retina, it can induce different sensitivities to the wavelength of light, thus any colour could be defined by three terms. Colour mixing is important to colour specification. There are two types of colour mixing: additive colour mixing and subtractive colour mixing. Colour matching is explored to further understand the properties of the colour system. Colour order systems have been devised to help specification and communication of colour. The Munsell colour system is typically of many colour order systems. Value, chroma and hue are three basic attributes of the Munsell system.

2.2. Colour in Product Design

2.2.1. Introduction

Based on the previous section which introduced colour fundamentals, the focus of this section lies on the relationships between colour, product and consumer. In consideration of this purpose, the subject matter will be discussed in three parts of this section: the principles of the product, consumer emotion response to the product, and the relationship between colour and product.

2.2.2. Definition and Process of Product Design

Product is an important element in marketing which brings value to the target consumer. Ulrich and Eppinger (1995) pointed out product is 'something sold by an enterprise to its customers'. According to marketing theory, product is defined as 'anything that can be offered to a market for attention, acquisition, use, or consumption that might satisfy a want or need' (Kotler and Armstrong, 2010). Thus, product not only refers to tangible objects, for example, computers, mobile phones or fridges, but also includes services, people, organizations, ideas, places, or mixes of these (Ulrich and Eppinger, 1995; Kotler and Armstrong, 2010). Kotler (2010) indicated that product could be finished goods which are produced from raw materials in manufacturing; it also could be the objectives of project management (Kotler and Armstrong, 2010). In a word, product could be a single item, or a grouping of items or services.

Product design is a multidisciplinary procedure which incorporates arts, science and technology. It is a process by which a designer designs a product for a certain purpose. The appearance, usability, physical ergonomics, marketing, brand development and sales should be considered (Morris, 2009). Product design is a series of actions rather than engineering. It needs successful opinions on engineering, marketing and so on (Otto and Wood, 2001). So Morris (2009) defined 'product design' as the process which is focused on the effective production and development of ideas to create a new product.

As early as 1987, Kolb built up a model of reverse engineering and redesign for product design. Kolb's model is divided into three phases: reverse engineering; modelling and analysis; and redesign (Stice, 1987). This model (Figure 12) is based on a current product. At the beginning, the model is focused on an understanding of consumer needs. According to consumer needs analysis, the functional needs will appear and be under discussion with a view to understanding how to satisfy the customers' needs, and then the functional model will be built up. Later Ulrich and Eppinger (1995) defined the product development process as 'the sequence of steps or activities that an enterprise employs to conceive, design, and commercialise a product'. Compared with Kolb's model, they gave a minute description of the design processes. Figure 13 shows five phases of their model. As in Kolb's model, they also pointed out that the target market is the basic functional description for product design. Otto and Wood (2001) pointed out three phases of the design process (Figure 14), then Kotler and Armstrong (2010) developed it and defined the three phases of product design: firstly, to define the core, problem-solving benefits or services that consumers need; secondly product designers need to transfer the core value to an actual objects at the second level; finally, an augmented product around the core value and actual objects should be designed to provide additional services and values (Kotler and Armstrong, 2010) .

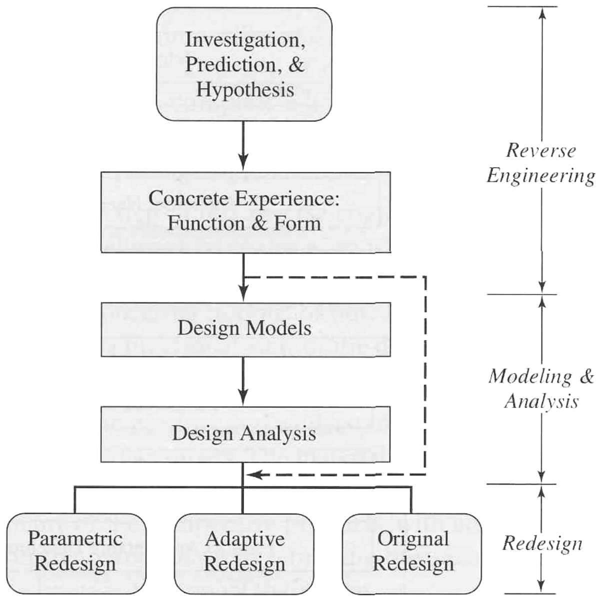
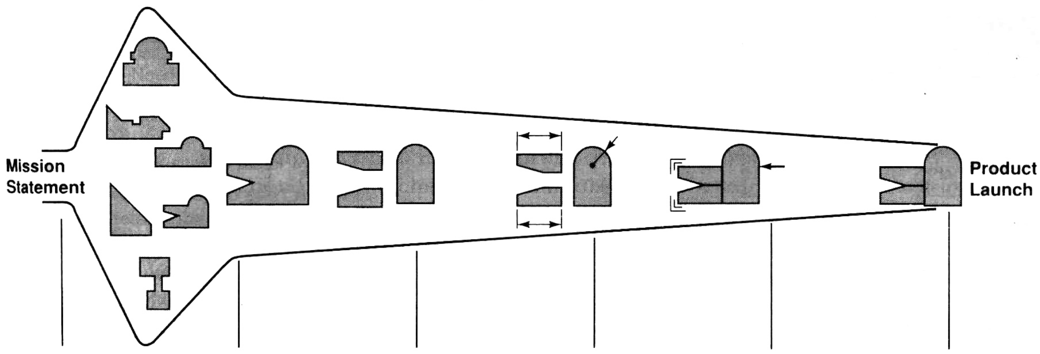


Figure 12. Kolb's product design development model.



	Concept Development	System-Level Design	Detail Design	Testing and Refinement	Production Ramp-Up
Marketing	• Define market segments. • Identify lead users. • Identify competitive products.	• Develop plan for product options and extended product family.	• Develop marketing plan.	• Develop promotion and launch materials. • Facilitate field testing.	• Place early production with key customers.
Design	• Investigate feasibility of product concepts. • Develop industrial design concepts. • Build and test experimental prototypes.	• Generate alternative product architectures. • Define major sub-systems and interfaces. • Refine industrial design.	• Define part geometry. • Choose materials. • Assign tolerances. • Complete industrial design control documentation.	• Do reliability testing, life testing, and performance testing. • Obtain regulatory approvals. • Implement design changes.	• Evaluate early production output.
Manufacturing	• Estimate manufacturing cost. • Assess production feasibility.	• Identify suppliers for key components. • Perform make-buy analysis. • Define final assembly scheme.	• Define piece-part production processes. • Design tooling. • Define quality assurance processes. • Begin procurement of long-lead tooling.	• Facilitate supplier ramp-up. • Refine fabrication and assembly processes. • Train work force. • Refine quality assurance processes.	• Begin operation of entire production system.
Other Functions	• Finance: Facilitate economic analysis. • Legal: Investigate patent issues.	• Finance: Facilitate make-buy analysis. • Service: Identify service issues.		• Sales: Develop sales plan.	

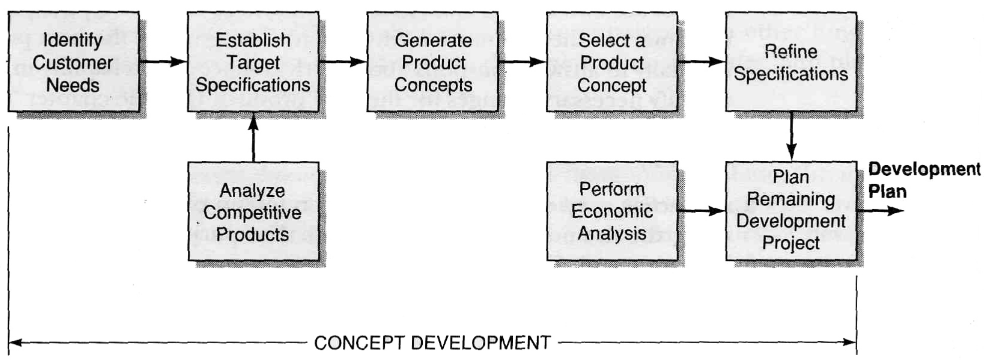


Figure 13. The Ulrich and Eppinger's product design.

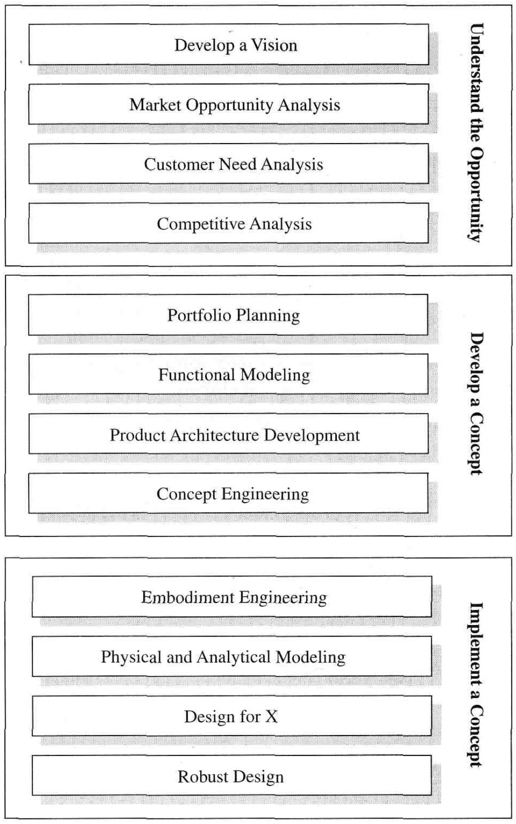


Figure 14. The Otto and Wood product design model (Otto and Wood, 2001).

According to research just discussed, understanding consumer needs is the most basic and important phase in the product design model. Most models use it at the beginning of the product design process. If a product design team wants to stand out from the competitive market, they need to construct customer needs carefully and translate the customer needs into technical terms. So the consumer emotional response of product will be discussed in the next section.

2.2.3. Consumer Emotion Response of Product

A product typically communicates complex emotions to its users through its design and function. Therefore products can evoke certain emotions from its users. However, users are concerned about the function of products rather than their emotional response. But as Demirbilek and Sener (2003) pointed out, whether or not a product can match a concern, it will trigger less or more of these feelings. They also pointed out that people can only feel product emotions when they experience the state associated with it. Then the users categorise products into two groups. They are 'displeasing' and 'pleasing'. The philosophical point of view holds that there are no ‘displeasing’ products, but there are unpleasant emotional responses (Demirbilek and Sener, 2003). Just as Jordan (1996) said, the negative emotional responses include anger, fear and disrespect. Thus it urges the designer to send positive emotional messages to users after examining the target consumers and the environment where they use the products. In brief, the research on product emotional contents can provide the product designer the chance to produce positive emotional elements with a scientifically designed product.

It means that if designers hope to better cater to the psychological needs of its customers, they should try to instil positive emotional contents into products. Therefore, researchers tend to seek these positive emotional elements for products. At the same time they try to achieve the optimal design of emotional content through certain ways.

These views are followed by an important view raised by Jensen (1999) that people’s emotional and psychological needs might be reflected in their dreams. It means a designer needs to understand people’s thoughts and senses. In addition, the preceding researches demonstrate that the consumptive emotional experiences are dictated by different psychological needs, age groups, gender, earnings and educational level and so on (Holbrook and Hirschman, 1982). Furthermore, Jiao (2006) says all of customers’ needs can be defined as psychological needs, which are related with a sense of satisfaction. Consumers gain satisfaction through getting hold of an object or product (Jordan, 1996). So the sense of satisfaction is also put into the four components by Jordan as Figure 15 (Jordan, 1996; Demirbilek and Sener, 2003).

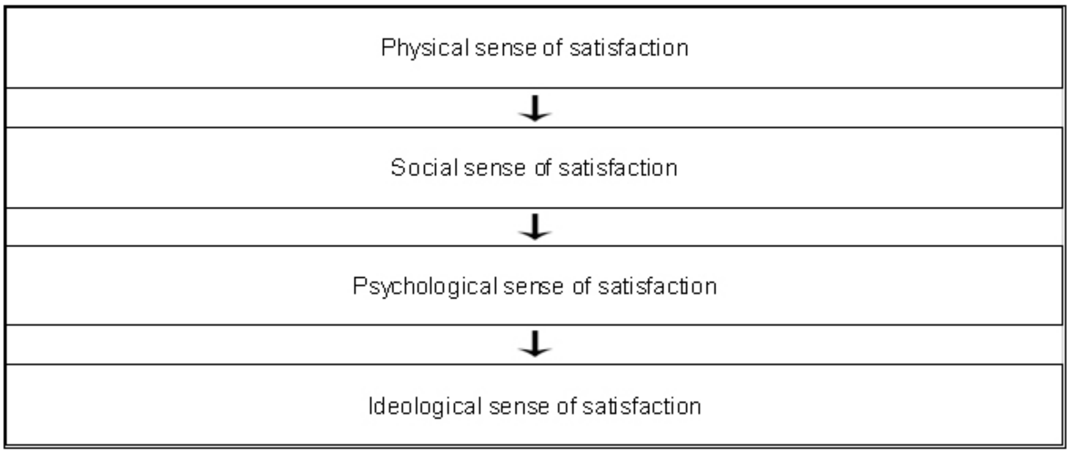


Figure 15. Four components of satisfaction sense (Jordan, 1996).

According to Demirbilek and Sener's study (2003), product emotional content is very much related with human emotions, human attitudes, the emotional response process and the psychological structures toward a product. With the present research, product has a lot of emotions depending on diversified evaluation models. Product emotions are categorised into five groups: social, instrumental, aesthetic, interest and surprise emotions. Furthermore, in studies on different theories and design criteria, researchers indicated that different emotional aspects of products can produce positive results, such as joyfulness, pleasant feelings, interest, excitement and so on. Therefore Demirbilek and Sener (2003) defined that the general product design can produce six characteristics of emotional response type as following: feeling, loveliness, pleasure, familiarity, colour and metaphor.

Colour, as one characteristic of emotional response type, could produce human emotions such as happiness, sadness, inspiration, relaxation, anger. Usually, different colours put together can create phenomenal results in meaning and request. So colours are deemed as psychological and symbolic characteristics (Allgos, 1999). Thus, the designer can use colours to arouse positive emotions. This emotional element will be further analysed and evaluated in the next section.

2.2.4. The Relationship between Colour and Product Design

The relationship between product design and consumer-emotion response were discussed in the previous section. It has been pointed out that colour is one element which influences consumer emotions when they buy products. So this section will explore the relationship between product design and colour which is based on the previous section.

According to the previous section, emotional aspects are very important for successful marketing of products and colours could arouse human-emotion responses and create impulse sales. Danger (1987) pointed out that people may notice colour before they notice shape or form, and a liking for colour is more significant among young people. Reasonable colour use for products is important to stimulate interest of consumers and achieve maximum sales. Thus, it widely used by product designers (Hsiao, 1995). Strong and compelling colours could have several attributes including: attract attention, fulfill the wants of potential customers, create an appeal to specific types of purchaser, enhance design, create an up-to-date image, demonstrate marketing leadership, provide change, support a sales theme, enhance a brand image. For example, Lane (1991) reported that Igloo Products Corporation ascribed the 15 percent market sale increase to the product colour improvement. Thus, how to identity appropriate colours is important in product design.

The selection of the right colour could help a product to do well against fierce competition. Using a systematic method which is based on the marketing to choose a colour of product could develop design. Hsiao (1995) indicated that the colour selection method required to identify a reasonable colour is dependent on the product, the environment of the market and the marketing planning. The environment of the market is a complex factor that includes the type of customer, the target of market, the method of purchase and so on. So how to define the environment of the market and identify the requirement of market is an important process to help designers to identify a colour or a range of colours. A colour selection model was built up by Danger in 1987. The first step of Danger's model is to analyse the characteristics of product, then the attributes and characteristics of colour appropriate to the product and the market were needed to be considered (Figure 16). He pointed out that understanding marketing was the core section of the model, so the specification of market should be considered in the design process. According to this, Danger (1987) built up a process to understand the requirement information of market as shown in Figure 17.

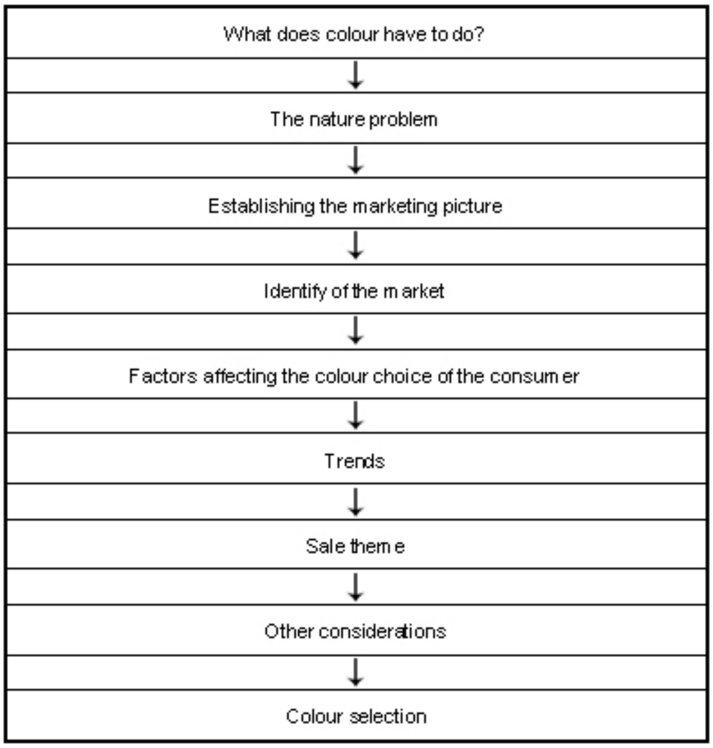


Figure 16. Danger colour selection model (Danger, 1987).

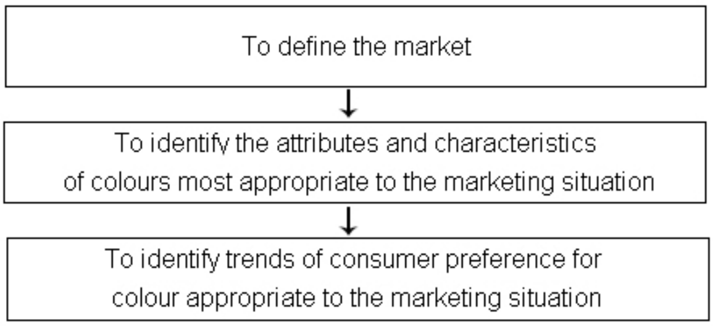


Figure 17. Identify marketing requirement process (Danger, 1987).

2.2.5. Conclusion

Product could be a single item, or a range items or services; further, it could be a tangible object or an incorporeal object. Note, however, that this research is concerned with tangible objects. Product design is a complex process which needs to combine arts, science and technology. The core phase of product design process is to identify marketing requirement and understand consumer emotional needs. According to the study of consumer emotion responses of product, colour is one of the elements to influence the consumer purchase. So, learning colour psychology and emotion could be used to help understand the product colour design. Therefore colour psychology and colour emotion will be discussed in the next section.

2.3. Colour Psychology and Colour Emotion

2.3.1. Introduction

The emotion and affect of product design have increasing attention for last few years. Colour, as one of most important elements in product design, is the focus on this study. So the aim of this thesis is to explore culture differences in colour emotion of product design. The previous two sections discussed colour fundamentals and colour in product design. Therefore, this section introduces colour psychology and colour emotions are described; then characteristics of culture and colour symbolism are discussed.

2.3.2. Colour Psychology and Colour Emotion for Product Design

Colour preference for product design is not just emptiness. It is dependent on the situation and need to develop by designers. Traditionally, colour research has been carried out using abstract colour samples and indicated colour preference without a particular product. So the colour psychology and colour emotion of abstract colour are discussed first.

Many researchers pointed out that colour psychology is influenced by age, sex and national backgrounds (Valdez and Mehrabian, 1994; Boyatzis and Varghese, 1994; Hemphill, 1996, Xin *et al.*, 2004). Colour psychology research contains a very broad category of interests and presents different layers of research methodology. It has been suggested that there are six main research topics in this area, namely: colour reactions as functions of personality and psychopathology; physiological reactions to colour; colour preference; colour effects on emotions; colour effects on behaviour; and reactions to colour concepts (Valdez and Mehrabian, 1994).

Many researchers in the field of psychology have pointed to interesting and basic facts about human dislikes and likes. The belief that colour could have a direct and variable effect on human function was first proposed by the French psychologist Charless Fere in the 1880s who pointed out that red can have an inspiring effect. Perhaps one of the most significant of these early research topics is the research by Max Luscher in the 1940s (Gage, 1999). In the Luscher system there are eight colour samples; dark-blue, blue-green, orange-red, bright yellow, violet, brown, black and grey. Observers would be asked to arrange the colour sample cards in order of preference and this preference order would be used to deduce aspects of the observer's personality. In this research Luchser found that blue is the most generally favourite colour in Europe and subsequent studies have confirmed this. Boyatzis and Varghese (1994) explored children's psychology of colours. They found generally bright colours (such as pink and blue) were more likely to evoke positive effects than dark colours (such as brown and black). By contrast, girls expressed positive emotions to bright colours more than boys. Hemphill (1996) also suggested that adults respond positively (in an emotional sense) to bright colours. In his study, the bright colours were white, pink, yellow, blue, purple and green. The dark colours included black, brown and grey.

The evaluation of emotional response of colour is referred to as colour emotion (Gao and Xin, 2006). It does not mean that colours have special meaning of themselves, but that colour can arouse feelings and emotions in people. However, this psychological impact and emotional response to colour may be dependent on human personality and hence may vary from person to person. Nevertheless, based on average or typical responses, colour can be used to 'communicate ideas and emotions, to manipulate perception, to create, to motivate and influence actions' (Holtzschue, 2006).

More recently there has been growing interest in the relationship between colour and emotional response. Research in this area can be grouped into two kinds: first, where colour preference is evaluated by dimensions of colours, for example, "like" or "dislike," "good" or "bad" etc., and second, where there is a focuses on descriptive dimensions, for example, "warm" or "cool," "light" or "dark," "heavy" or "light" (Lee and Kim, 2007). With respect to the first one of the groups, the major work has focused on using colour preference to find out the connection between personality and colour emotion (Manav, 2007); Guilford had previously suggested that colour preference was connected with value, saturation and hue (Guilford, 1959). In 1941, Eysenck put forward the idea that yellow is the least preferred colour and blue the most preferred one. Hogg also supported that the most preferred colours were blue and purple and the least preferred colours go to yellow among 30 selected colour samples in respect of the scale of value, chroma and hue.

The second group focuses on the descriptive dimensions, for example, "warm" or "cool," "light" or "dark," "heavy" or "light" (Lee and Kim, 2007). In earlier studies, the focus was on the colour emotion of a single colour. The results tried to clarify the function of basic colour attributes on colour preference; for example, hue, value and saturation. Rickers-Ovsiankina paid attention to the emotional significance of colour and found that colours can be divided into two groups if moods related to the colours are taken into consideration: warm colours and cold colours. The colour which could be associated with warm, active and exciting qualities can be categorised as warm. In contrast, cold colours could arouse cold, passive and calming qualities (Birren, 1961). In the continuity of research, the majority of researchers believe that the relationship between colour and emotion is complicated. Manav (2007) pointed out that colour emotion associations rely on preferences. The results of his study demonstrate that people's knowledge and experience of the past could affect colour associations. The study also demonstrated education levels did not make a big difference in colour emotion, probably because none of the subjects has any experience with colour, be it theoretical or practical.

In general, many researches suggested that consumers prefer specific colours in different product categories. Holmes and Buchanan (1984) gave the report about colour preference of consumers for product like automobiles, clothing and furniture and indicated that colour preference is certain depend on the product categories. Pantone (1992) also pointed out that blue, red and black are most popular in fashion design and black colour is most worn colour for dress. However in automobiles industry, consumers prefer blue, grey, white, red and black colours, but beige colour is popular in furniture design (Mundell, 1993). All these researches suggested colour preference need to consider with context in design. Therefore, knowledge of colour preference without a particular product is not enough to help designers in defining the colour for product lines. Rather, to understand colour preferences for different product categories is very important. So in this study, colour preference of the abstract colour will be explored first then a particular product will be brought into the study. Then all studies will focus on colour preference across culture. So culture studies will be introduced in the next section.

2.3.3. Culture Differences and Colour Emotion for Product Design

Culture gives colour its definitions and constructs its codes and values. Our responses to colour are affected by a number of factors. Certainly culture is one of these factors but others include memory, past experience and intelligence. This does not mean that the colour will be perceived differently, but that colour may represent different things to people who have different cultural backgrounds.

Colour has always been used symbolically throughout culture. Elliot and Maier (2007a) developed a model of colour and its psychological functioning. As they pointed out, colour can carry specific meanings in different contexts; therefore, colour carries different connotative meanings in different cultures (Elliot and Maier, 2007a). So the symbolism of colour can be shown to depend upon history, superstition, religion and tradition and can therefore reveal people's feelings and associations. In other word, colour is not only the significance of designers; neither is its biological appearance or the spectacle of nature. It is always related to the culture, because human beings do not live alone but in a rich and complicated cultural context.

2.3.3.1. Culture Definition

Culture is one factor that leads different nations to differences in values and beliefs. It is the system of information shared by a related group of people. Therefore, culture is not the quality of any individual and is always considered to be a property of a community. Donald defined it as 'patterns of doing and thinking that are passed on within and between generations by learning' (Donald, 1991). The

United Nations Educational Scientific and Cultural Organisation (1945) defined it thus: ‘to develop and maintain mutual understanding and appreciation of the life and culture, the arts, the humanities, and the sciences of the people of the world, as a basis for effective international organisation and world peace’. To cooperate in extending and in making available to all peoples for the service of common human needs the world’s full body of knowledge and culture, and in assuring its contribution to the economic stability, political security, and general well-being of the peoples of the world’ (Eliot, 1948). Eliot (1948) also pointed out that ‘the individual culture is dependent on the culture of a group or class, and the culture of the group or class is dependent on the whole society’. Henry Van Til (1869) defined culture as ‘the total human effort of subduing the earth together with its total achievement in fulfilling the creative will of God’. Although culture has been defined from different perspectives by different researchers (such as anthropologists or sociologists) it always reflects the behaviours, beliefs, values, religion and symbols of a group; it is symbolic communication and distinguishes the minds of different groups of people.

2.3.3.2. Cultural Identity

There are two ways to define cultural identity. Firstly, Braziel and Munnur (2003) defined it as ‘in terms of one, shared culture, a sort of collective “one true self,” hiding inside the many other, more superficial or artificially imposed “selves,” which people with a shared history and ancestry hold in common. It is the identity of a group who share the same system of symbols, meanings and standard behaviour. It has also been pointed out that ‘it is a sort of collective treasure of local communities. Like language, it is a description of cultural belonging and has an undisturbed existential possession, an inheritance, a benefit of traditional long dwelling’ (Tomlison, 2003). Castells (1997) propounded cultural identity is the source of people’s meaning and experience. The second definition is very similar with the first one, but it defines cultural identity as ‘a matter of “becoming” as well as of “being”’ (Braziel and Mannur, 2003).

Cultural identifiers include such factors as ‘place, gender, race, history, nationality, language, sexual orientation, religious beliefs, ethnicity and aesthetics’ (Braziel and Mannur, 2003). Social movements have been based on cultural identity positions:

gender, religion, ethnicity, nationality (Tonlinson, 2003). The process of forming the cultural identity for each individual is similar. As a member of some specific culture, each individual must know about its custom, practices, the pattern how its people think and express their mind, what its people believe in and hate and what is the heritage from the ancestors. He/she is undoubtedly influenced by those factors. He/she then makes those components internal parts of his/her life. The so-called self-concept includes what people believe and what they value. The culture is identified with as part of self-concept. In case one has a good understanding of the culture of another, he/she will be in a better position to handle the cultural challenges and differences related to the communication between the two peoples.

How people understand and interpret other people's thinking is influenced by their cultural identities. The pattern people identify themselves in a culture constitutes the central part of one's self-concept. A person's self-concept is composed of many factors some of which (for instance, race, gender or culture) are more basic than others. When a person interacts with other people, these factors play a more important and obvious role in the process. Other factors may be irrelevant unless they are activated under some specific situations. Cultural identity is not stationary and may change with dynamic life. It is unquestionable that a person can identify himself/herself from different perspectives. A man can simultaneously be a husband, a father, a son and a son-in-law, a professor, an employer, a friend and etc. Cultural identity also has many facets. A single or composite measure technique may be used to measure the extension of one's cultural identity. The difference between them is the number of indicators used in the process of measurement.

2.3.3.3. Culture Segmentation

Place, gender, race, history, nationality, language, sexual orientation, religious beliefs, ethnicity and aesthetics are the main factors of culture. According to theories of market segmentation, these factors are included in geographic and demographic segmentation. Geographic segmentation is 'a market segmentation strategy whereby the intended audience for a given product is divided according to geographic units, such as nations, states, regions, counties, cities, or neighbourhoods' (Kotler and Armstrong, 2010). It is a simple form of market segmentation. In demographic segmentation, it contains age, family size, family life cycle, gender, income, occupation, education, religion, race, generation, nationality, and social class.

Geographic	
World region or country	Western Europe, Middle East, Pacific Rim, China, India, Canada, Mexico, North America
Country region	East Asia, South Asia, North Asia
City or metro size	Under 5,000; 5,000–20,000; 20,000–50,000; 50,000–100,000; 100,000–250,000; 250,000–500,000; 500,000–1,000,000; 1,000,000–4,000,000; over 4,000,000
Density	Urban, suburban, exurban, rural
Climate	Northern, southern
Demographic	
Age	Under 6, 6–11, 12–19, 20–34, 35–49, 50–64, 65+
Gender	Male, female
Family size	1–2, 3–4, 5+
Family life cycle	Young, single; married, no children; married with children; single parents; unmarried couples; older, married, no children under 18; older, single; other
Income	Under \$20,000; \$20,000–\$30,000; \$30,000–\$50,000; \$50,000–\$100,000; \$100,000–\$250,000; \$250,000 and over
Occupation	Professional and technical; managers, officials, and proprietors; clerical; sales; craftspeople; supervisors; farmers; retired; students; homemakers; unemployed
Education	Primary school or less; some secondary school; secondary school graduate; some college; college graduate
Religion	Jewish, Muslim, Hindu, Buddhist, other
Race	Asian, Hispanic, Black, White
Generation	Baby boomer, Generation X, Millennial
Nationality	South American, British, French, German, Italian, Japanese

Figure 18. Geographic and demographic segmentation (Kotler and Armstrong, 2010).

2.3.3.4. Culture and Colour

Colour associations may be unstable because of cultural differences and changes. Colour meaning and preferences are different for different cultural backgrounds, and therefore in colour studies of this nature the question of how to define culture is very important. Certainly, nationality, gender, religion and age group often are taken into consideration by researchers. This study will focus on the gender effect and nationality effect of colour emotion for product design. Thus, the next section explores the existing research of gender and nationality difference of colour emotion.

Many researchers have pointed out that there are differences between genders in preference for colours. As early as 1897 Jastrow reported that men preferred blue to red (contrary to women's preferences)(Khouw, 2000). Later, Eysenck found that blue had a lower affective value for men than women, and yellow had a lower affective value for women (Eysenck, 1941). Women have been shown to have a shrewder insight on colour than men because men have a tendency to prefer achromatic colours (Guilford and Smith, 1959). They noticed that the colour tastes of women are more sensitive and various. Furthermore, McInnis and Shearer (1964) commented that women pay more attention to colour than to shades. They also suggested that 49% of males and 55% of females preferred dark colours and 44% of males and 24% of females liked warm colours (McInnis and Shearer, 1964). Likewise, Plater pointed out that women preferred weaker chroma than men (Plater, 1967). The researchers also found that there are gender differences between male and female in colour identification. In the research of Thomas, Curtis, and Bolton (1978), the name lists of colour samples produced by 72 Nepalese people have considerable differences between male and female. Females always wrote down more names of colour than male did (Thomas *et. al*, 1978). Likewise, Greene (1995) also carried out a study on colour identification. Observers were asked to name 21 colour samples and the results showed that women know more colour details than men (Greene, 1995). In more recent research Radeloff (1990) proposed that more women than men have a favourite colour. Radeloff found that there was no sensible difference between male and female in the preference of light and dark colour, but almost all women preferred soft colours to bright colours (men were opposite) (Radeloff, 1990).

Does many nationality differences exist on colour emotion and psychology? Sato (2000a) found some nationality differences. In their studies, grey colour was associated with cool by Hong Kong observers, but green was associated with coolness by Taiwan observers. Later, a study which explored colour preference between British and Chinese was carried out by Xin *et al.* (2004). In this study, 20 colour chips was presented and observers were asked to rate colours on 10 different emotions. The results indicated some differences between the Chinese and British preference scale. Chinese observers like colours which they rated as clean, fresh, and modern colour. However, British observers showed no such pattern. Osgood (1960) pointed out that colour associations could be the reason that influences colour emotion. The emotions associated to colour have a strong national component. Colour is always used as a symbolism throughout culture. To understand what this really means, it is an effective way to start from explaining the relationship between the colour and people emotion response. So a cross-cultural study of colour meaning was carried out in 1973 (Adams *et al.,* 1973). Data for eight colour samples from 23 different nationalities about the meaning of colour were collected; later, Ou (2007) explored colour semantics including colour meanings and colour associations use special word-pairs to describe the characters of colours, such as warm-cool, light-dark, passive-active, soft-hard and so on; subsequently, McCandless developed a colour chart of colour meaning in different nationality in 2009 (Figure 19). The chart encompasses 10 different nationalities and 62 colour emotion. It is clearly shows the different colour emotion in different nationalities.

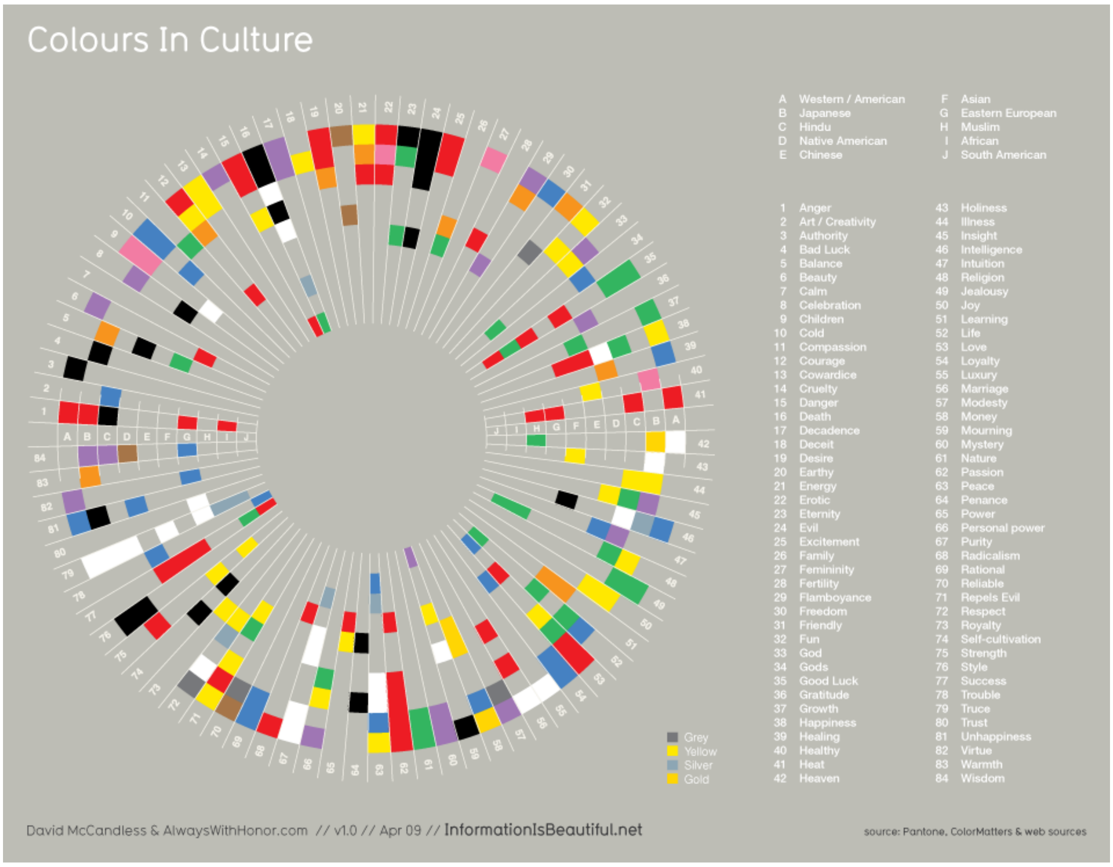


Figure 19. Colour in culture chart (McCandless, 2009).

2.3.4. Conclusion

In spite of the common sense of colour influence on humans, colour psychology and colour emotions are not completely universal and may vary from one person to the next. In their respective reports, most researchers agreed that colour psychology is cultural as well as being influenced by gender and age. In cross-cultural communication, different nations with different cultural backgrounds or people of the same nations with the same backgrounds but belonging to different social groups or social classes have different perceptions of its meaning. So colour emotion can not be studied without consideration of time and place, or of a specific cultural context. By the same token, any history of colours must first of all be a social history. The social history make the colour have its meaning. Colour is endowed with different meanings against different gender, national backgrounds and aroused the association of people.

2.4. Research Focus, Research Questions and Methodology

2.4.1. Introduction

In this thesis a decision was made to focus on one colour rather than to attempt to explore colour relationships for all colours. A number of previously published studies have looked at many different colours but their analysis of cultural differences tend to be quite shallow; in this study a more detailed analysis of a single colour will be carried out. Black was chosen as the colour for this study partly because it is of particular importance in product design especially in IT and mobile computing devices (such as the iPhone). Therefore, blackness preference *(which of two black samples observers preferred)* and blackness perception *(which of two colour samples observers considered to be closest to a pure black)* are carried out in this study. First, the symbolism of black is discussed, and then the fundamentals of black colour and recently research on blackness are explored. At the end the research question and the methodologies are presented.

2.4.2. Colour Symbolism of Black

When black is on its own, it also can arouse strong feelings. Like other colours, it could be arouse in us both positive/negative emotions and associate with symbolic meaning. So the symbolism of black is discussed as below.

Black is a multi-dimensional colour in terms of its symbolism. It means classic, but it also represents death and evil in some cultures while it is associated with fertility and life in others. Black is also of great importance in modern design and in technology (Tao *et al.*, 2010). 'It is used in Western cultures for funerals. It has an air of intelligence (graduation robes), marked with rebellion (the bad guy), shrouded in mystery (space). It typically symbolised absence, modernity, power, sophistication, formality, elegance, wealth, mystery, style, evil, (such as in films) death (in Western cultures), fear, emptiness, darkness, seriousness, conventionality, rebellion, anarchism, unity, sorrow, professionalism, and slimming quality (fashion)' (Wright and Rainwater, 1962). Therefore, black can produce strong feelings both of love and hate. For example, its positive emotions in Japan were clearness, tightness, and sharpness, while negative emotions are darkness and heaviness (Saito, 1996).

In world popular culture, black has long been associated with evil and hell. Frank and Gilovich (1988) pointed out that black could be associated with evil and death. There was a deadliest disease in Europe called Black Death between 1384-1350. The sign of this disease is that the sufferer's skin would become blacker and darker. It is believed this is the reason the disease had its name (Rosemary, 1999). Therefore, European people always associated black colour with the death image. Since the eleventh century, black became associated with the colour of hell in the Europe. In the bible, black is always associated with an oppressive and punitive quality, and this may be the source of the association. According to the Bible, black is the original colour and appears ahead of other colours. It said 'in the beginning, God created the heavens and the earth. The earth was without form and void: darkness was upon the face of deep' (Pastoureau, 2008). In the Bible, it was believed that 'in black no life is possible, for the symbolism of colours black already appears as void and deathly' (Pastoureau, 2008). Other mythologies develop this image to describe or explain the origin of the world. For example, 'in Greek mythologies, hell is always dark. In the underground world everything is black and frozen' (Tao *et al.*, 2010). Nyx, goddess of the night, is the mother of Aether and Hemera, Goddess of the day and atmosphere. She always wears black clothes and drives a four-horse chariot of the same colour. She also gave birth to the goddess of sleep, dreams, anguish, secrets, discord, distress, old age, misfortune and death. So death is always closely associated with the colour black; similarly, 'black is the main colour of Roman hell and represents death. Black was used in objects, offerings and paintings in Roman funeral rites from the beginning of the Republic' (Tao *et al.*, 2010). People wore black clothes as mourning clothes in funerals in

Europe from the second century B.C. (Pastoureau, 2008). As in Europe, black colour also means dark and evil in Chinese, Japanese and Egypt culture. In Japan, black is associated with mystery, the night, the supernatural and death. Japanese believed that wear black colour could be jinxed in the 10th and 11th century.

In contrast, black also has positive meanings. For example, black colour also means being fertile and fecund in Egypt culture. First, 'it symbolises the fertile aspect of the earth in Egypt, because it is the colour of silt deposited (Pastoureau, 2008). Every year when the Nile River is in a beneficial flood, it deposits a layer of mud on the fields. It enriches the field and brings a wealth of crops, thus benefits the Egyptian people. Second, it means the rebirth in Egypt. Anubis (Figure 20) is an embalmer god and a Protector god to protect the dead. He always show himself up as a whole Jackal or half human and half Jackal with the black skin (Pastoureau, 2008). Otherwise the deified kings and queens, ancestors of the pharaoh were also generally represented with black skin (Pastoureau, 2008). In Chinese mythology, black is always used as the colour of the heaven emperor, because black is the symbol of the north. In Chinese mythology, blue, red, yellow, white and black compose the traditional unique Chinese colour system (Figure 21). This system is a veneer of Chinese civilisation and its influence permeates into all mythology and entire historical epoch. They are represented in form of the five elements of Chinese Yin-Yang theory. In this system every colour has its own connotation. Black colour indicates the north. And the god of this locality is named as black tortoise. Its image is a snake specifically coiling around the tortoise (Peng, 2008). The north, like the zenith of the Arctic, is the centre of the universe. People cannot see the star with our naked eyes, the whole thing is dark. So people think that black has a mystical power. Thus black becomes the most desirable colour in the Yin-Yang theory. As the colour of the dark sky, black is all-embracing colour and transcends the multicolour. Therefore, artists often use black ink to present an ever-changing world in Chinese ink painting. In addition, black represents honesty, fair, fortitude, valour and generosity in Chinese Opera. There are eleven basic colours in Chinese opera: red, purple, black, white, blue, green, yellow, pink, gray, gold and silver. People who have these qualities always used black facial makeup. Black masks not only indicate a rough and bold character, but also are associated with a fair and unselfish personality. For example, in opera Zhang Fei (a famous general in Three Kingdoms Period) has a black cross butterfly face, Li Kui (a famous rebel) and Bao Gong (also named Bao Zheng who is the courageous and unprejudiced judge of the Song Dynasty) (Zheng, 2008) also use black as the main colour of their face marks' (Tao *et al.*, 2010).

Figure 20. The image of Anubis.

Figure 21. The five fundamental colours of the traditional Chinese system.

2.4.3. Fundamentals of Black Colour

Black is achromatic and darkest colour (Holtzschue, 2006) It is often considered as a lack of colour and is "achromatic" or hue-less. Black is an amazing colour and it is a good partner for the designer, it could be used in anything you want, and supplied a great contrast and drew people's attention. Moreover, the use of black is particularly important in product design. Many blacks are made by mixing coloured dyes or pigments so there can be slight differences between blacks although they look rather similar. So it is important to consider which black would be a better black to use in design.

As early as Neolithic times, black was one of the first colours used in painting. People used black pigments made from burning bones or grinding a powder of manganese oxide to draw bulls or other animals between 18,000 and 17,000 years ago (Pastoureau, 2008). Then in the Middle Ages, black became one essential element of the most influential invention. A new high quality black pigment was created and entered into market. Royalty, the clergy, judges and government officials of most Europe began to wear blacks in the 14th century. Later, black was widely used in fashion in the 18th and 19th centuries. The invention of new and economical black pigment meant that quality black colour were available for the general public. Therefore black colour is widely used in business dress of the upper and middle classes. In 20th and 21st centuries, black is a symbol of individuality and intellectual. It also associated with punk; it was symptomatic of punk fashion at the end of 20th century.

Despite the importance of black, there have been relatively few studies into blackness preference and blackness perception. By contrast with a great number of researches in whiteness perception, even the blackness perception has received more attention than blackness preference, few studies in blackness perception have been done so far. As early as 1970, Bode *et al.* explored the quantification of blackness using black print pastes. He pointed out that bluish blacks were the best black but did not have the experimental data. In this study, he also found that add a small amount of blue ink could improve the appearance of blacks. Later, a study, which explored the effect of hue on blackness, was carried out by North Carolina State University. In this study, using the Munsell colour system, bluish to greenish blacks were found to be 'better' blacks (Haslup, 2012). Westland (2006) invited 25 observers ranked 100 colour samples and calculated blackness index (Equation 5). Thus,

$$B_W = 8.6542 - 0.2583L^* - 0.0052a^{*2} + 0.0045b^{*2} \qquad \text{Equation 5}$$

Then Cho (2012) carried out a psychophysical experiment which contained 39 observers and 77 colour samples and proposed a blackness index (Equation 6). Thus,

$$B_C = 3.02 - 0.05\, \{(L^*)^2 + 0.89(a^*+2)^2 + 0.36\, (b^* -33)^2\}^{1/2} \qquad \text{Equation 6}$$

She also tested Westland blackness index and pointed out that the predictive performance is 0.36 for Westland's model and 0.94 for her new model. Therefore these two equations were also tested in this study.

2.4.4. Research Questions

This study will focus on the colour black and the impact of blackness perception and preference on product design. Four psychophysical experiments will be described in this thesis that investigate aspects of observer preference and perception for black colours. The first experiment investigates the effect of hue on blackness perception and preference; the second experiment investigates the effect of chroma and value on blackness perception and preference; the third experiment uses a different psychophysical technique to validate findings from the first two studies; finally, psychophysical studies are carried out using a particular product (the iPhone) in order to explore the design context of blackness perception and preference in which three-dimensional models of iPhone of differing black colour are presented to observer using 3-D software.

The psychophysical experiments seek to address three main research questions. The first question concerns the relationship between the observers' perception of blackness and their preference for blackness. In blackness perception the issue is typically which of two black samples observers consider to be closest to a pure black; in blackness preference the issue is which of two colour samples observers would prefer. The second question concerns the robustness of blackness preference and perception findings; specifically, whether they are invariant to changes in gender and nationality (Chinese and UK). The third question explores the relationship between the blackness preference and perception findings which were obtained in the absence of any particular context (i.e. the stimuli were black squares on a grey background) and corresponding findings when there is a strong product context (in this case, the iPhone).

2.4.5. Methodology

The key methodology in this thesis needs to be able to scale visual stimuli. One of the fundamental problems in psychophysics is 'the assignment of numerical values to the individual members of a set of stimuli, with respect to some physical attribute of the stimuli, and with respect to the mental responses which they evoke' (Engledrum, 2000). In this case the attribute of the stimuli that is being judged is blackness; two aspects of blackness are resolved – that is blackness preference and blackness perception. A common problem for the psychophysicist is to derive the best possible set of numerical responses which made by an observer or by a group of observers. Not only are these responses to be arranged in their correct subjective order, as determined from the consensus of comparisons by all observers, but they also need to calculate the numerical response values (i.e. interval scale data). Thurstone described the paired comparisons method to reach this objective (Thurstone, 1927b).

A great number of different techniques exist that allow scaling including paired comparison and ranking (Engledrum, 2000). Engledrum has prepared a flowchart which succinctly describes when various methods are appropriate (Figure 22). The first step is define whether there is confusion or not in the sample set (this is concerned with how close the stimuli are to each other; if they are sufficiently separate – in the psychophysical dimension – then there will be no confusion). The second step relates to the number of stimuli in the set.

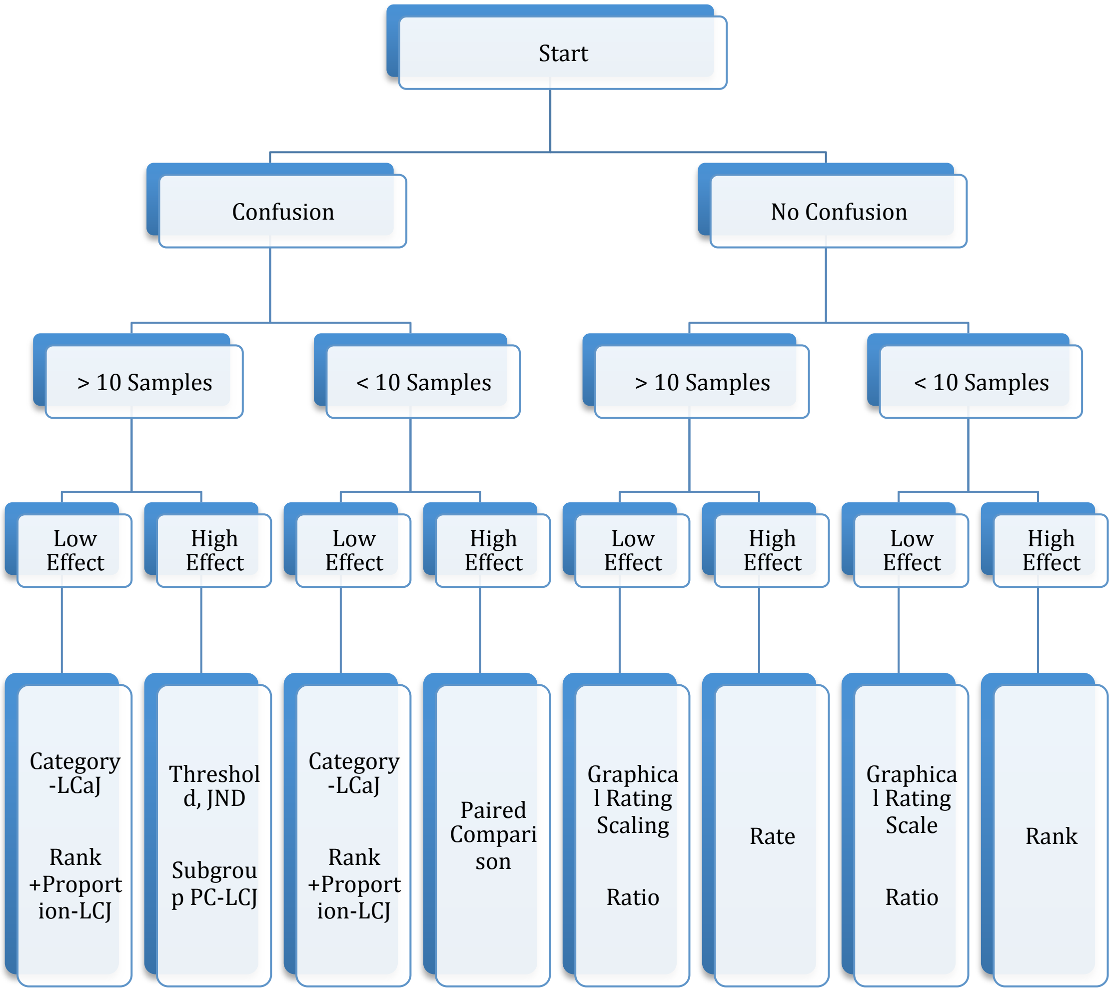


Figure 22. A process of how to select a suitable scaling method(Engledrum, 2000).

According to Engledrum's method of selecting the scaling method the paired comparison and ranking methods were chosen for this study. These two methods are important psychophysical scaling methods that use to explore the colour experiment data especially for colour preferences and have been used in a wide series of studies (Terwogt and Hoeksma, 1995; Ou *et al.*, 2004a, b & c; Ling *et al.*, 2006b; Franklin *et al.*, 2010). There are three advantages to the paired comparison scaling method. First, this scaling method can discover more detail of individual preferences. Second, even if the differences between stimuli are small, this method can easily make the distinction more precise. Third, these two scaling method (paired comparison and ranking) can provide data not only about the difference of individual preference, but also show the points of similarity. In the paired comparison method, the colour stimuli are presented to the observers in pairs and the observers are asked to select one from each pair according to the research questions. The paired comparison experiment is the main technique used in this thesis and is the basis of the first two experiments. The ranking method is used in the third experiment, in part as a means of validating the findings from the paired comparison method. In the ranking method, observers are presented with a set of the colour stimuli and asked to put them in order from most preferred to least.

Most paired comparison and ranking scaling experiments are used Thurstone's statistical method. So the statistical models for analysis paired comparison and ranking will be discussed as below.

2.4.5.1. Paired Comparison

This section presents the basic paired-comparison data collection method and discusses Thurstone's law of comparative judgment that is used as data analysis method in this study.

As early as 1860, Gustav Fechner first introduced the paired comparison method and this method has be generalised and used frequently in the scaling field (David, 1988; Engeldrum, 2000; Torgerson, 1958). In 1927, psychometrician Thurstone improved a scientific way to use pair comparison (Thurstone, 1927). He referred to these procedures by the law of comparative judgment. This was consistent with, and built upon, contemporary psychophysical theory by researchers such as Ernst Heinrich Weber and Gustav Fechner. Thurstone showed that the technique can be used to order a set of items according to preference or importance and, crucially, according to an interval scale. In the paired comparison experiment, the data collection method of paired comparison experiment is to present a set of stimuli in pairs to an observer and asks them to select one of the two stimuli which has the most characteristics that the experiment is to investigate.

2.4.5.2. Ranking Method

The ranking method is a procedure which first modelled by Bartleson (1984). This method is usually used in the psychophysical experiment that contains more than five stimuli and all stimuli can be showed at once. In a ranking scaling experiment, the observer is asked to rank the stimuli in order according to an attribute defined by the research questions.

Therefore, the ranking order of all stimuli is to be given by observers and all stimuli could regard like to compare with other stimuli in pairs (Thurstone, 1931). Thus it is possible to convert the ranking data into a frequency matrix like paired comparison. For example, there are four stimuli {A, B, C, D} and first observer ranked them as C, D, B and A. Transfer this ranking to pair comparison, from left to right gives, C>D, C>B, C>A, D>B, D>A and B>A. Total six pair comparisons are done and could be converted them into a frequency matrix like table 1. Then the frequency matrix could convert to the scale value by using same analysis method like paired comparison.

Table 1. The comparisons of four stimuli.

	A	B	C	D
A	S_A-S_A	S_B-S_A	S_C-S_A	S_D-S_A
B	S_A-S_B	S_B-S_B	S_C-S_B	S_D-S_B
C	S_A-S_C	S_B-S_C	S_C-S_C	S_D-S_C
D	S_A-S_D	S_B-S_D	S_C-S_D	S_D-S_D

	A	B	C	D
A		1	1	1
B	0		1	1
C	0	0		0
D	0	0	1	

2.4.6. Methods and Equations Used to Determine Scale Values

2.4.6.1. Thurstone's law of comparative judgments

According to the methodology of paired comparison and ranking that was used in this research, Case V of Thurstone's law of comparative judgments (Thurstone, 1927a) has been used as the psychophysical method to obtain scale values.

$$S_i - S_i = x_{ij}(\sigma_i^2 + \sigma_j^2 - 2r_{ij}\sigma_i\sigma_j)^{1/2} \qquad \text{Equation 7}$$

Where:

S_i, S_j — are the scale values of stimuli i and j;

x_{ij} — is the normal deviate corresponding to the proportion of the times that stimulus *i* is judged greater than stimulus *j*;

σ_i, σ_j — are the deviation of stimuli *i* and *j*;

r_{ij} — is the correlation between values of discriminal processes corresponding to stimuli i and j;

2.4.6.2. Analysis Method

As Thurstone indicated that with *n* stimuli, the full set of *n*(*n*-1)/2 pairs need to be compared. For example, if there are *n*=4 items which defined as {A, B, C, D}, the following six pairs need to be considered: (A B), (A C), (A D), (B C), (B D) and (C D). A comparison matrix is constructed for the stimuli {A, B, C, D}. At the beginning of the experiment the entries of the comparison matrix are all set to zero. Each time an observer made a response the appropriate entry in the matrix is incremented by 1. Such as, if the observer is viewing pair (A B) and prefers sample B then the entry for B-A is incremented. Value 1 can be put in the appropriate row and column in the comparison matrix and accumulated to indicate the frequency by which each stimulus is preferred to others (see Table 2).

Table 2. The comparisons of four stimuli.

	A	B	C	D
A	A-A	B-A	C-A	D-A
B	A-B	B-B	C-B	D-B
C	A-C	B-C	C-C	D-C
D	A-D	B-D	C-D	D-D

Consider that we have *n* stimuli and *k* observers and the *n* stimuli are judged in pairs. Each of the *k* observers is asked to indicate which stimulus of a pair produces the stronger response (according to some agreed criterion). The preference ratio is defined as the ratio of actual to possible number of times that one stimulus is judged rated better or greater than the other) – for each pair considering all *k* observers' responses. Thurstone's law indicates that the response differences in units of standard normal deviates are the estimates of the scale values for the stimuli (Morrissey, 1955). The procedure outlined derives interval scale data from the preference ratios.

Table 3. Preference ratios for the corresponding comparisons in Table 2. E.g. P(B>A) is the preference ratio, the number of times that B is preferred to A in this case.

	A	B	C	D
A	P(A>A)	P(B<A)	P(C<A)	P(D<A)
B	P(B>A)	P(B>B)	P(C<B)	P(D<B)
C	P(C>A)	P(B>C)	P(C>C)	P(D<C)
D	P(D>A)	P(B>D)	P(C>D)	P(D>D)

Once all observations have been made and the comparison matrix is complete, each entry in the comparison matrix is converted into a preference ratio by dividing by $(n\text{-}1)k$ since each sample was compared with each of the other *n-1* samples by each of the *k* observers. The preferences ratios are in the range 0-1. The preference ratios are converted to generate a corresponding table of units of standard normal deviates by calculating the inverse of the standard normal cumulative distribution (the *normsinv* function in Excel). The columns of the table are then averaged to generate estimates of the scale values (Morrissey, 1955).

2.4.6.3. Confidence interval

Case V of Thurstone's Law of Comparative Judgments is widely used as the method to determine the data which get from the paired comparison experiment, but how to determine confidence interval or p-value in this method is missing. Therefore, many researchers tried to explore the confidence interval and p-value of Thurstone's law. First, they tried to calculate the error metrics by using Thurstone's law, but this seems to be at a cost of losing the inherent simplicity of Thurstone's original formulation. Later Morovic (1998) presented an equation (equation 8) to estimate confidence intervals.

$$CIs = 1.96\ \frac{\sigma}{\sqrt{N}} \qquad \text{Equation 8}$$

Where:

N is the number of observations

But Zolliker (2010) tested this equation and indicated this equation could only used when the stimuli number is smaller than 5. Moreover, the equation that derived by Morovic is missing dependency on the number of stimuli. Therefore Montag (2006) tried to use Monte Carlo simulations to investigate the estimated error. He gave an equation that not only depends on the number of observation but also depends on the number of stimuli.

$$E_e = b_1(n - b_2)^{b_3}(N - b_4)^{b_5} \qquad \text{Equation 9}$$

Where:

b_1 = 1.76, b_2 = -3.08, b_3 = -0.613, b_4 = 2.55 and b_5 = -0.491

But Zolliker (2010) also pointed out that the equation of Montag cannot be used if the number of stimuli is two, because the b_4 is bigger than 2. Moreover he also indicated that all these equations are based on their specific data. So it is difficult to estimate the confidence interval and p-value when using the Thurstone's Case V in paired comparison experiment. Therefore the confidence interval and p-value will not considered in Chapters 3, 4 and 6. However, in the case of the ranking experiments, the confidence interval could be analysed. The significant differences (*p* value) between nationality and gender will be determined by using SPSS software. Appendix V shows *p* values of the ranking experiment.

2.4.6.4. Individual Differences

The scale values in this thesis are calculated from all of the observer data pooled together. It is not possible to calculate scale values for individual observers using this method, unless each observer was to repeat the experiment many times. Therefore it is not easy to explore the observer variability of the scale values. However, in the case of the ranking experiments, one way to look at observer variability is to look at the variability in rank order selected by each of the 26 observers. Appendix V shows the significant differences within each group. It is evident that despite small variations between observers, broadly speaking they rank the samples in a consistent manner.

3. Blackness: Preference and Perception (Hue)

3.1. Introduction

This chapter explores the preference and perception of different black hues using psychophysical experimentation. Data collection and analysis were used by the paired comparison method in this study. The reason for this method was discussed in the previous chapter (detailed information can be found in Section 2.4.5). In the psychophysical experiment, two comparative studies were carried out. Firstly, observers were asked to indicate which of two black samples they preferred. This is referred to later as blackness preference. Secondly, observers were asked to indicate which of two black samples they considered to be closest to a pure black. This is referred to later as blackness perception. All colour samples were evaluated by hue and analysis was carried out based on gender and nationality (Chinese and UK).

3.2. Experimental Methods

3.2.1. Definition of Stimuli

3.2.1.1. Colour Stimuli

The stimuli was a colour set with 13 colour samples: ten chromatic colours and three achromatic colours. Ten chromatic colour samples were chosen from the Munsell system to represent the varying regions of the hue at nominally the same levels of saturation and value and used the darkest colour in each hue of the Munsell system (the hues are denoted as B, BG, G, GY, Y, YR, R, RP, P and PB). Thus, in the Munsell system, the colour samples were all represented at different hues and V/C=1/2[1] (Figure 23). One of the neutral samples had the same value as the chromatic samples and the other two were lighter and darker respectively. The Munsell notations and systematic colour names are shown in the Table 4. All

[1] In the Munsell system, each colour is represented by a hue, by a value (essentially lightness and denoted by V) and by a chroma (denoted by C).Thus, V/C = 1/2 is a colour with value 1 and

colours were arranged on a neutral grey (R=133, G=133, B=133) background on a screen.

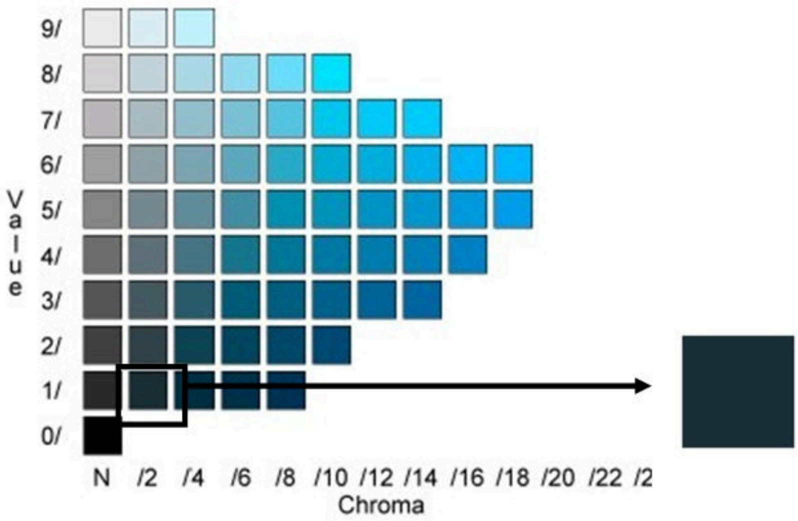


Figure 23. An example Munsell page showing the position of one of the samples used in the experiment with Value 1 and Chroma 2. The neutral samples (N0, N1 and N2), used in the experiment, can also be seen.

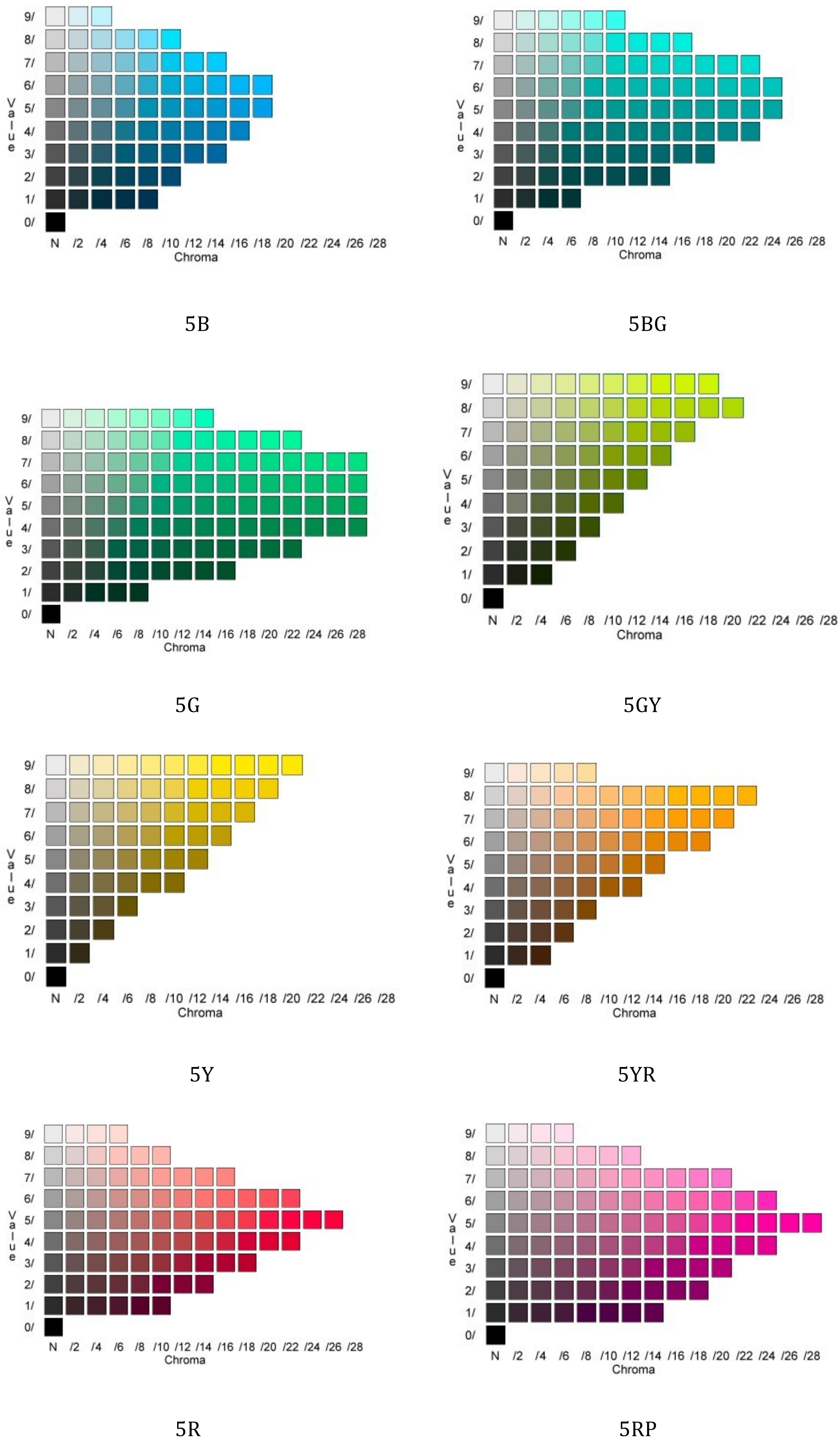
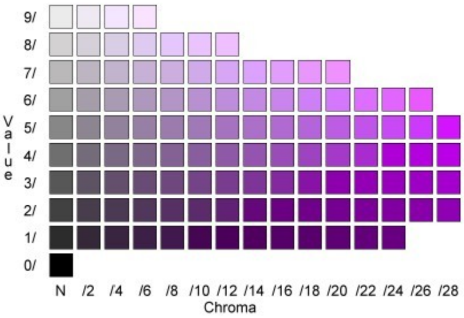
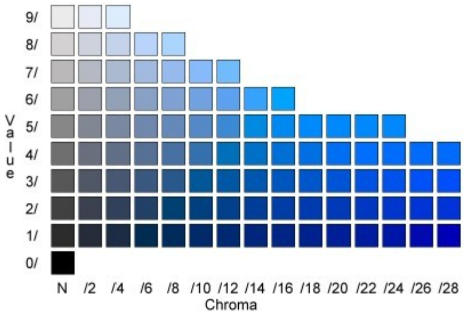


Figure 24. The main hues in experiment of The Munsell system



5P



5PB

Figure 24. The main hues in experiment of The Munsell system (continued).

Table 4. Munsell notations, visual representations and target RGB values of Munsell samples used in the experiment.

Hue	Stimuli	RGB		Hue	Stimuli	RGB
N0		[R = 0 G = 0 B = 0]		**N1**		[R = 34 G = 34 B = 34]
N2		[R = 52 G = 52 B = 52]		**5B**		[R = 19 G = 36 B = 43]
5BG		[R = 20 G = 36 B = 37]		**5G**		[R = 24 G = 36 B = 31]
5GY		[R = 31 G = 35 B = 24]		**5Y**		[R = 40 G = 33 B = 16]
5YR		[R = 47 G = 30 B = 23]		**5R**		[R = 48 G = 28 B = 32]
5RP		[R = 45 G = 28 B = 40]		**5P**		[R = 41 G = 30 B = 45]
5PB		[R = 28 G = 34 B = 46]				

3.2.1.2. CRT

A CRT monitor was used for the experiment. The CIE values of all colour samples were measured by a colorimeter which according to the white [R = 255 G = 255 B =255] point in same screen (Table 5). As can be seen in Figure 25 the ten chromatic colours are distributed around (and are almost equi-distance from) the reference white in CIELAB colour space. The samples are not uniformly distributed but this does not imply that CIELAB is not uniform. The decision was taken to calibrate the display (that is, to ensure that it is used in a stable condition throughout the experiment) but not to characterise it. Display characterisation (see Westland and Ripamonti, 2004) would involve constructing a model that relates device RGB values to some device-independent representations of the stimuli (such as CIE values). However, display characterisation does not allow representation of colour stimuli on the display with zero error; small errors in the characterisation model could result in quite large visual differences with regard to the dark samples used in this study. Therefore, an sRGB model has been assumed and the sRGB values have been used to display the colours without compensation for properties of the display; However, the actual CIELAB values of the stimuli that were displayed as measured (Figure 25).

Table 5. CIELAB colour coordinates as measured experimentally.

Sample	L*	a*	b*	X	Y	Z
N0	10.23	1.37	1.71	0.89	0.95	1.11
N1	32.89	0.68	2.62	5.62	6.16	7.35
N2	40.89	-1.34	2.69	8.63	9.71	11.72
5B	32.73	-4.43	-4.66	5.17	6.10	9.41
5BG	31.92	-7.93	0.00	4.66	5.80	7.61
5G	32.51	-10.36	5.62	4.67	6.02	6.41
5GY	31.92	-6.65	11.42	4.82	5.88	4.94
5Y	32.24	-4.62	18.69	5.00	5.92	3.62
5YR	30.70	3.64	12.22	5.12	5.37	4.30
5R	31.83	8.92	3.56	5.92	5.77	6.63
5RP	32.02	10.61	-2.98	6.13	5.84	8.52
5P	32.65	8.04	-6.22	6.14	6.07	9.87
5PB	32.83	-0.99	-6.32	5.47	6.14	10.01

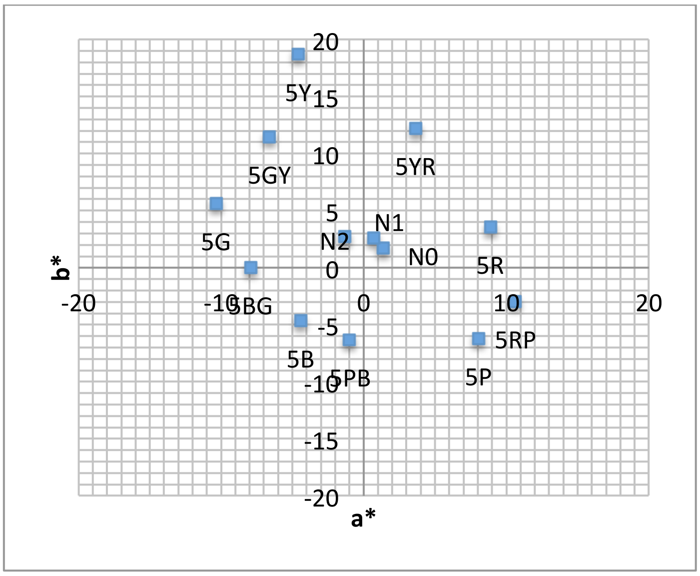


Figure 25. The a* b* plots of 13 black samples.

3.2.2. Observers

Forty observers (24 female and 16 male) participated in this experiment, including twenty observers from China (12 female and 8 male) and twenty (12 female and 8 male) observers from UK. All of these observers passed the Ishihara Test for colour blindness before participating in the experiment and were therefore assumed to have normal colour vision.

3.2.3. Experimental Procedure

The colour stimuli were presented to all observers on computer screen GUI written in MATLAB. The stimuli were displayed on a neutral grey (R= 133, G= 133, B=133) background and were each 8 cm × 8 cm and viewed from approximately 90 cm (a visual field size of 15°) in a dark room. Each stimulus was defined by sRGB values and no additional colour management was employed (however, the actual colours displayed were subsequently measured).

The stimuli were presented to the observers in pairs (see Figure 26 for example). The experiment was carried out in two phases. First, the observers were asked to choose which stimuli (of a pair) they prefer (this is referred to as blackness preference); second, they were asked to choose which stimuli was the closest to a pure black (referred to as blackness perception). Note that the two phases were not inter-leaved; rather, the observers judged all the pairs in phase 1 (blackness preference) and then, were presented with the pairs of colour samples again and asked to judge according to phase 2 (blackness perception). Observers were asked to indicate their choice by pressing the button below the colour samples (Figure 26) after which the next pair of colour samples would be displayed.

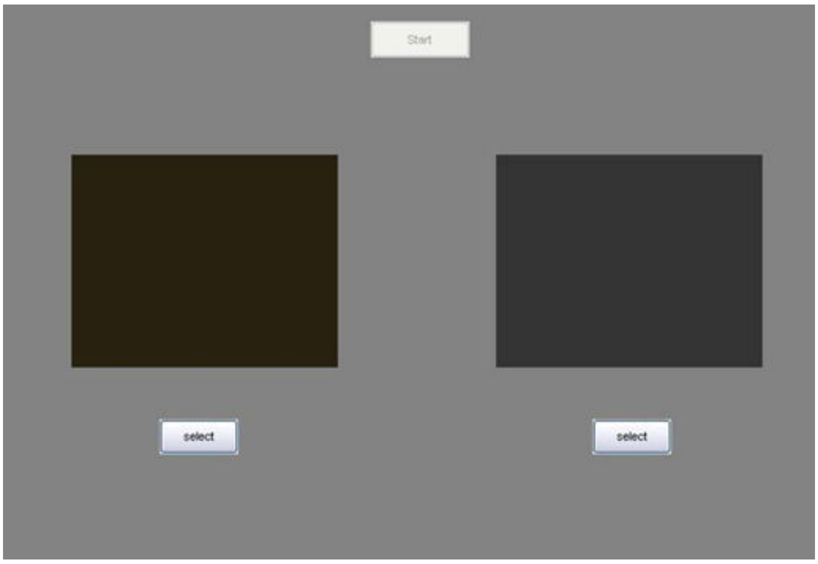


Figure 26. The GUI used in the experiment.

3.2.4. Paired-Comparison Method

Paired-comparison techniques are particularly used in colour psychophysical experiments. Thurstone showed that the technique can be used to order a set of items according to preference or importance and, crucially, according to an interval scale.

Section 2.4.5 describes why the complete pair-wise comparison procedure was used in this study. However, in short, the use of paired comparison compared to, for example, categorical judgement, is very accurate and maximises the possibility of detecting cultural differences that could be subtle. The method is quite time consuming for the observers however.

Thus, the stimuli were presented in pairs and the observer was forced to choose one of a pair over the other according to two phases of this psychophysical experiment.

- ✧ Phase 1: Observers were asked to indicate which of two colour samples they preferred. This is referred to as *blackness preference*.

- ✧ Phase 2: Observers were asked to indicate which of two black samples they considered to be closest to a pure black. This is referred to as *blackness perception*.

The term complete is used to indicate that every sample was compared with every other. Therefore for the 13 samples there were 78 paired comparisons for each of 40 observers that participated meaning that there were 3120 (78 pairs × 40 observers) total observations for each of the two phases.

3.3. Data and Results

3.3.1. Blackness Preference

This section considers the blackness preference of observers with particular emphasis on the effect of hue. In the first phase of the experiment observers were asked to indicate which of a pair of two blacks they preferred.

Table 6 displays the scale values of colour stimuli according to blackness preference. It divided into three groups: nationality (Chinese and UK), gender (male and female) and all pooled together. These represent an interval scale and positive, larger scale values are most preferred with negative values being least preferred. Figure 27 illustrates the scale values for blackness preference. In the chromatic colour set, samples 5B, 5PB and 5RP are ranked in the first three places and samples 5GY, 5Y and 5YR are ranked at the bottom. Thus, on average, observers like purplish and bluish blacks but dislike the blacks which contain yellow hues. In achromatic colour set, the scale values of three samples are nearly equal.

Table 6. Scale values for colour preference.

Sample	UK	Chinese	Male	Female	All
N0	-0.07	0.12	0.09	-0.01	0.03
N1	0.06	-0.05	0.07	-0.04	0.01
N2	0.08	-0.02	-0.13	0.14	0.03
5B	0.49	0.31	0.54	0.32	0.40
5BG	0.37	0.06	0.35	0.14	0.22
5G	0.12	-0.16	0.06	-0.06	-0.01
5GY	-0.18	-0.39	-0.03	-0.47	-0.28
5Y	-0.70	-0.70	-0.59	-0.77	-0.68
5YR	-0.69	-0.49	-0.51	-0.66	-0.58
5R	-0.07	-0.21	-0.34	-0.02	-0.13
5RP	0.10	0.61	-0.01	0.57	0.33
5P	0.04	0.54	-0.12	0.57	0.28
5PB	0.48	0.38	0.65	0.31	0.42

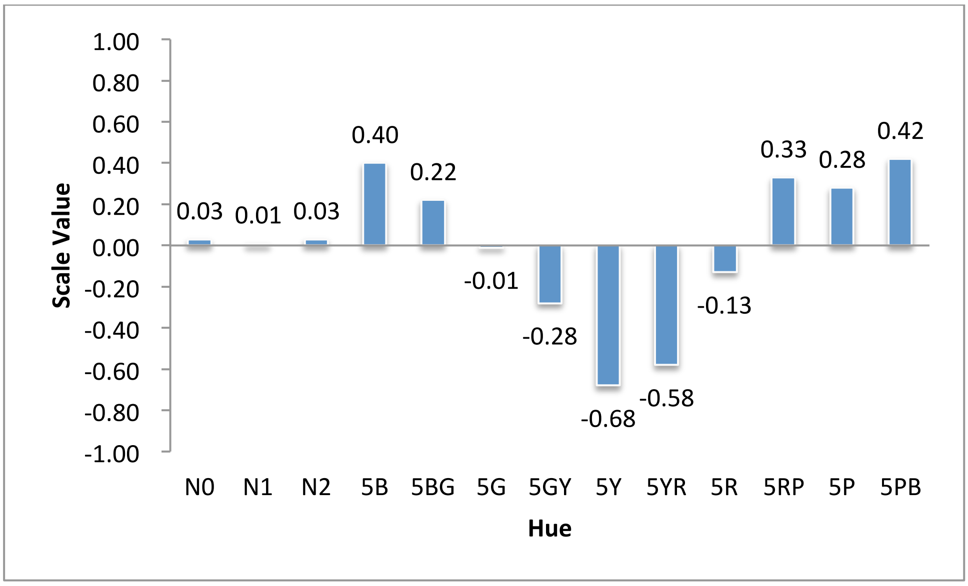


Figure 27. Scale values for blackness preference (all observers).

Interestingly, however, observers prefer the bluish blacks to the chromatically neutral blacks (even N0 which is darker than the chromatic colours). The general order of preference of colour samples in different nationality groups is illustrated in Figure 28. It shows that both Chinese and UK observers commonly preferred bluish and purplish blacks and disliked yellowish blacks. Samples 5B, 5PB have a high preference score for both groups (5B = +0.49, 5PB = +0.48 for UK; 5B = +0.31, 5PB = +0.38 for Chinese). Samples 5Y, 5GY and 5YR are the least preferred samples in both groups (5Y = -0.70, 5GY = -0.18 and 5YR = -0.69 for UK; 5Y = -0.70, 5GY= -

0.39 and 5YR = -0.49 for Chinese). Compared with the UK observers, Chinese observers ranked samples 5RP, 5P and 5PB in the first three places (5RP = +0.61, 5P = +0.54, 5PB = +0.38). However, samples 5B, 5BG and 5PB were clearly the favourite blacks for UK observers (5B = +0.49, 5BG = +0.37, 5PB = +0.48). Both sets of observers prefer bluish blacks; however, the Chinese observers have a preference for reddish blue-blacks whereas the UK observers have a preference for more neutral or greenish blue-blacks. Generally, there was more variance in the scale scores for the UK observers than for the Chinese observers.

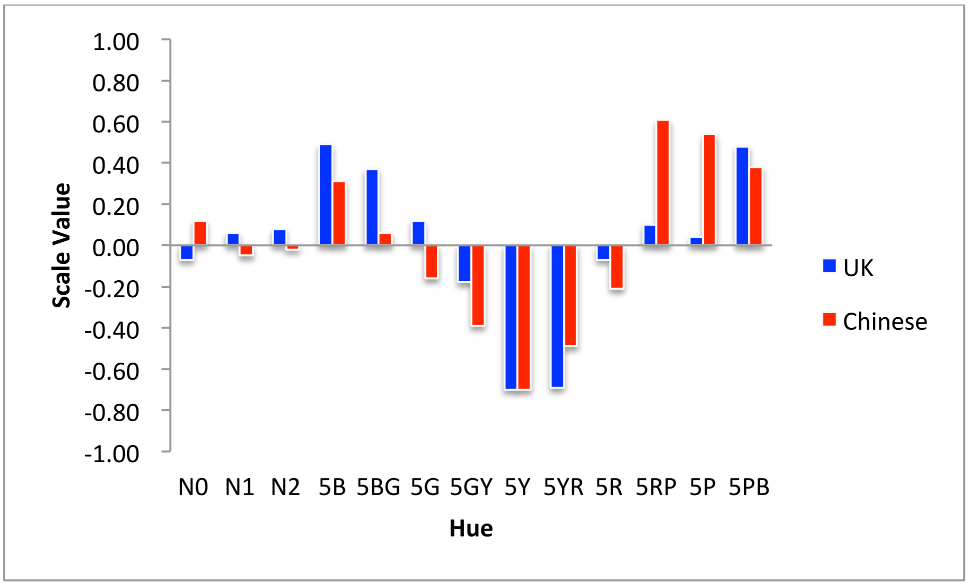


Figure 28. Scale values for colour preference scaling according to nationality (UK vs. Chinese).

Figure 29 shows the differences for colour preference according to gender. Both male and female like bluish and purplish colour samples. The colours which contain blue and purple tone all have high scores. For example samples 5B, 5BG, and 5PB (5B = +0.54, 5BG = +0.35, 5PB = +0.65 for male; 5B = +0.32, 5BG = +0.14, 5PB = +0.31 for female). Moreover, both male and female do not like yellowish black, sample 5Y was ranked as lowest colour sample: 5Y = -0.59 for male and 5Y = -0.77 for female. Despite the common opinions between male and female, there also have some differences attitudes. Female do not like yellow tone, any colour sample which contains yellow tone was ranked at the bottom place (5GY = -0.47, 5Y = -0.77, 5YR = -0.66). But male seems do not like reddish colour because the scores of samples 5R, 5YR and 5RP are the lowest three places in chromatic colour set exclude 5Y(5R = -0.34, 5YR = -0.51, 5RP = -0.01). Compared with males, sample 5RP has a high score in female group (5RP = +0.57) and shared first place with sample 5P in chromatic colour samples. Then as Figure 29 indicated male ranked three colours which contain blue tone in first three place in chromatic colour set (5B = +0.54, 5BG = +0.35, 5PB = +0.65). But the colours which contain purple tone such as sample 5RP, P and 5PB have a high scores in female group (5RP = +0.57, P = +0.57, 5PB = +0.31). Therefore, though both male and female groups like bluish and purplish black, there is a tendency for females to slightly prefer reddish blue-blacks or purples more than the males group.

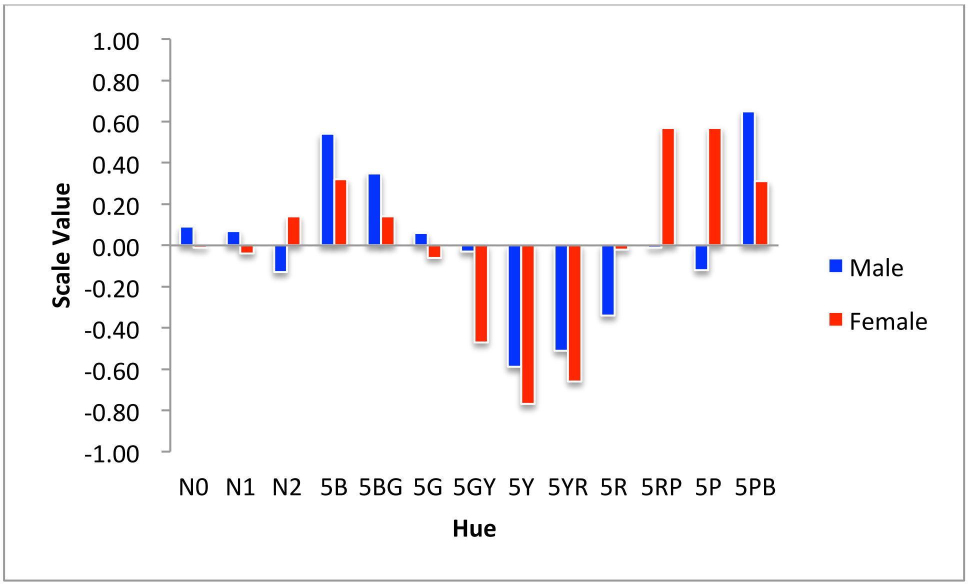


Figure 29. Scale values for colour preference according to gender (male vs. female).

Figure 30 and Figure 31 could indicate there are culture differences in colour preferences. The correlation coefficients (r) for nationality and gender are 0.75 and 0.61 respectively. This could indicate that colour preference could be influenced by the culture, and that gender has a greater effect on colour preference than nationality.

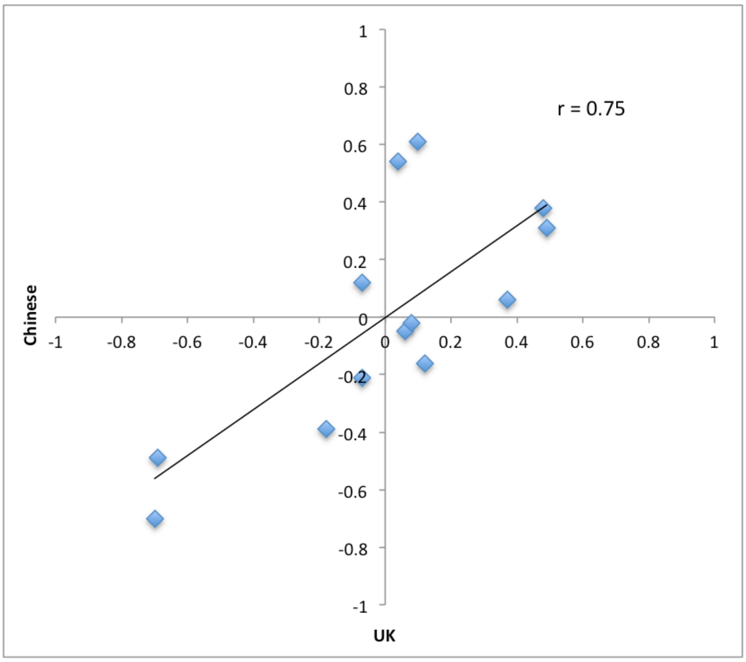


Figure 30. Correlation coefficient for colour preference scaling according to nationality (UK vs. Chinese).

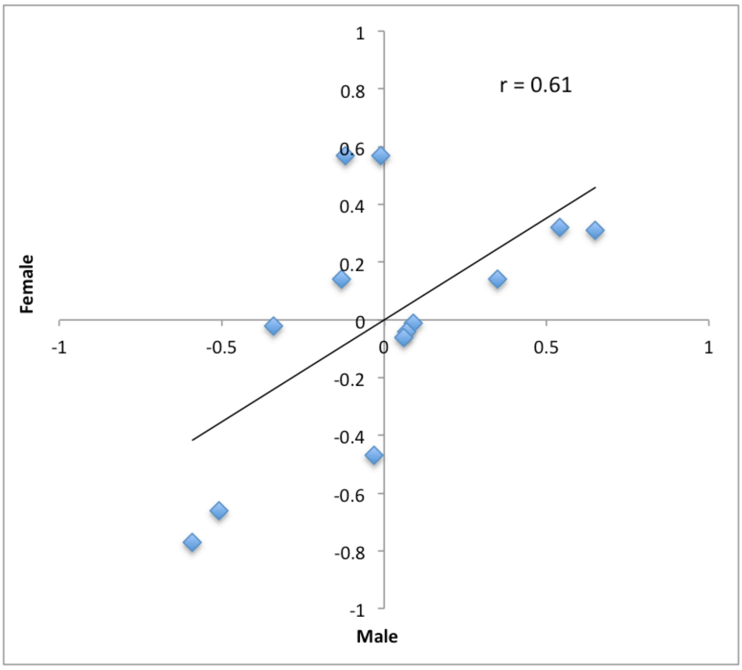


Figure 31. Correlation coefficient for colour preference according to gender (male vs. female).

3.3.2. Blackness Perception

Section 3.2.1 considered the blackness preference of observers with particular emphasis on the effect of hue. The results indicated that there were some differences between UK and Chinese observers and also between male and female observers. Moreover gender had a greater effect on colour preference than nationality. In this section the results of the blackness perception (where the observers were asked which of two black samples they judged to be closest to a pure black) are analysed.

Table 7 displays the scale value of stimuli according to the selection of colour perception which shows by nationality (Chinese and UK), gender (Male and Female) and pooled over all observers. The greater and more positive the scale values the more the sample was judged against the criterion of being pure black. Figure 32 shows the scale values of colour samples more intuitively. It indicates that sample N0 has the highest scale value (+2.15) of all the samples. This result means that people considered sample N0 to be the nearest colour to pure black. This result is expected, because this sample has little hue and is the darkest colour sample. So if observers chose sample N0 as the nearest colour to pure black, that means the observers exactly have general understanding about what black it is. It is interesting to find that in the chromatic colour set, sample 5PB with is in first place and samples 5R and 5Y were considered to be the least black of all the stimuli. This result is agreed with researches of Bode (1979) and Haslup (2012).

Table 7. Scale values of colour samples according to the 'pure black' criterion (all observers).

Sample	UK	Chinese	Male	Female	All
N0	2.15	2.15	2.15	2.15	2.15
N1	0.96	0.80	0.94	0.83	0.85
N2	-0.48	-0.49	-0.54	-0.45	-0.48
5B	-0.11	-0.22	-0.08	-0.26	-0.17
5BG	-0.14	-0.12	-0.20	-0.08	-0.13
5G	0.01	-0.20	-0.01	-0.15	-0.10
5GY	-0.18	-0.26	-0.10	-0.31	-0.22
5Y	-0.61	-0.45	-0.47	-0.56	-0.52
5YR	-0.44	-0.37	-0.35	-0.44	-0.40
5R	-0.61	-0.57	-0.67	-0.52	-0.58
5RP	-0.50	-0.47	-0.57	-0.43	-0.48
5P	-0.41	-0.29	-0.49	-0.27	-0.35
5PB	0.36	0.44	0.36	0.45	0.38

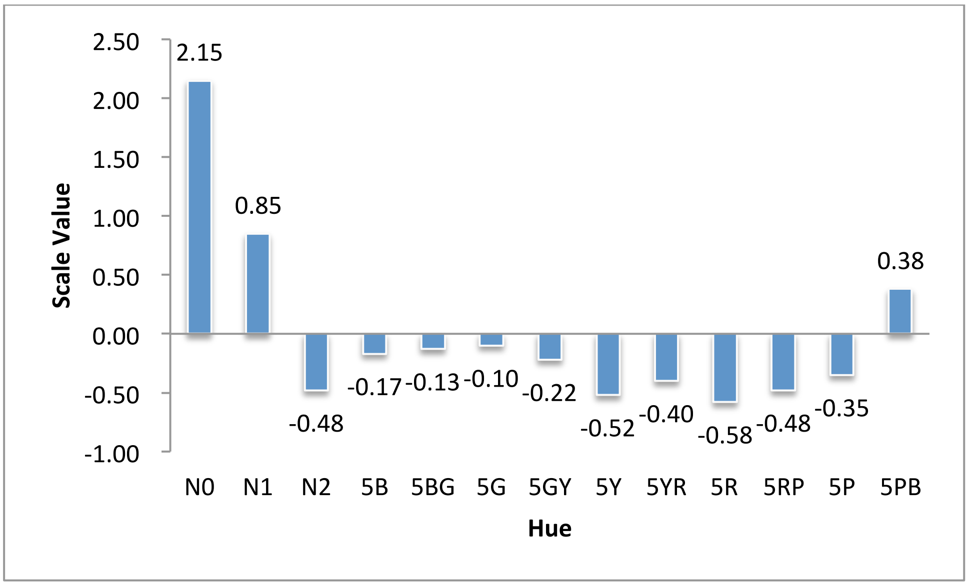


Figure 32. Scale values of colour sample according to the 'pure black' criterion (results pooled over all observers).

Figure 33 shows the scale results according to nationality (China and UK) and displays the results more intuitively. N0 is considered to be the most black and 5R is considered to be the least black in both Chinese and UK observer group. Besides, in achromatic colour set, both Chinese and UK observers put the three achromatic colour samples in the same order (N0 = +2.15, N1 = +0.80, N2 = -0.49 for Chinese; N0 = +2.15, N1 = +0.96, N2 = -0.48 for UK). In the chromatic colour set, sample 5PB is considered to be the blackest colour by both Chinese and UK observers (5PB = +0.44 for Chinese; 5PB = +0.36 for UK). However, sample 5PB ranks third place which only next to samples N0 and N1 in all stimuli. As Figure 33 indicates, almost colour stimuli has same ranking place in Chinese and UK observer groups, which means there are little differences in blackness perception between the UK and China populations.

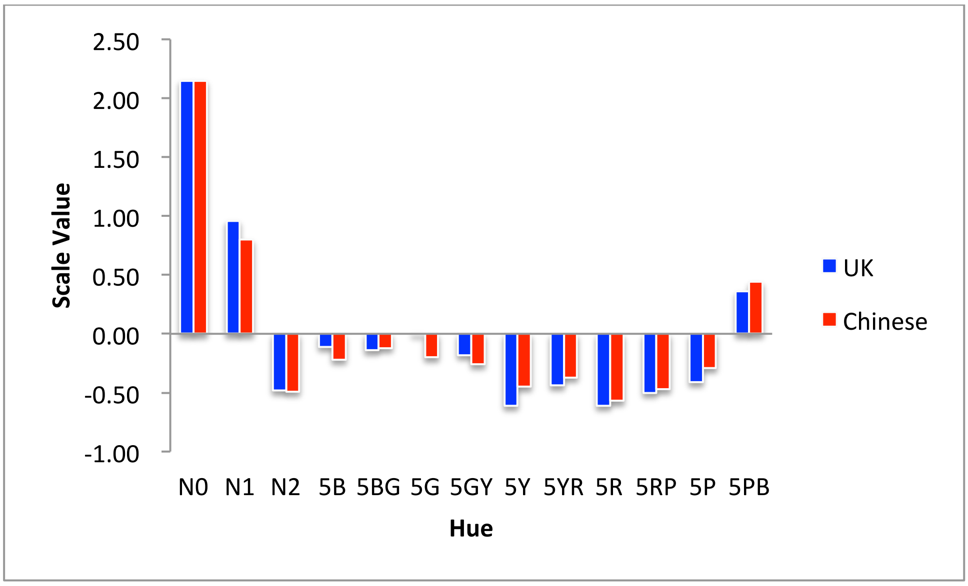


Figure 33. Scale values of analysis of colour samples closest to pure black by scaling according to nationality (UK vs. Chinese).

Figure 34 allows a direct comparison between male and female observers (combining the data from the two nationalities). Both male and female considered that samples N0, N1 and 5PB are three blackest colours. That means if do not consider samples N0 and N1 these two achromatic colour, sample 5PB is in the first place in all chromatic colours. A closer examination of the results suggests that both male and female observers do not rate samples N2 (achromatic colour) and 5R (chromatic colour) as being very black (5R = -0.67, N2 = -0.54 for male; 5R = -0.52, N2 = -0.45 for female) (Figure 34). Although results from female and male observers are broadly correlated, there are some larger differences compared to when we considered the effect of nationality (the correlation coefficient (r) is 0.98 but for the nationality comparison is 0.99). Such as, males give sample 5R a lowest score as -0.67, but females think sample 5Y (5Y= -0.56) is least close to pure black. But in general, both male and female did not rate yellowish (5Y = -0.56, 5YR = -0.35 for male; 5Y = -0.56, 5YR = -0.44 for female) and reddish (5R = -0.67, 5RP = -0.57 for male; 5R = -0.52, 5RP = -0.43 for female) colours samples as being very black. So these results could suggest that there does not have a significant influence on blackness perception according to gender.

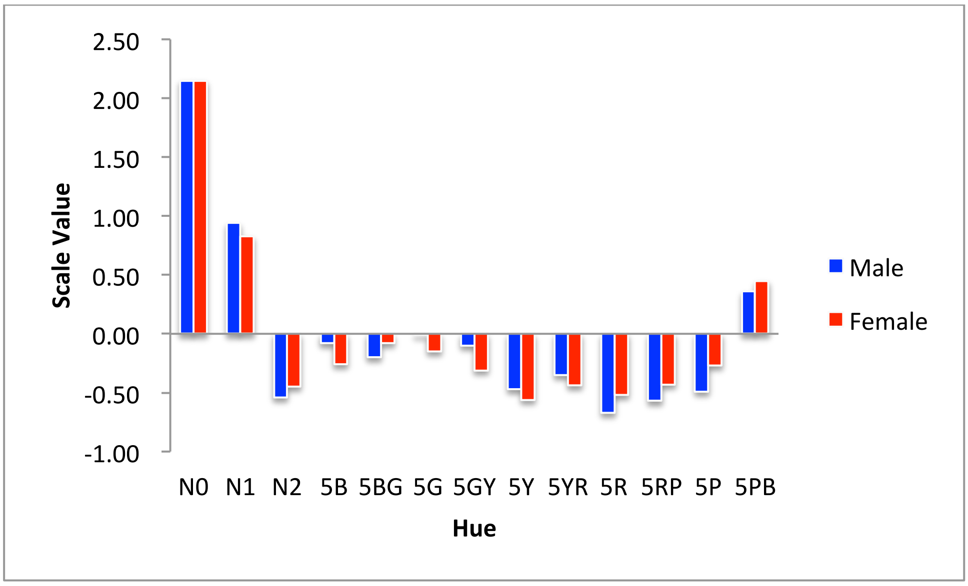


Figure 34. Scale values for colour samples closest to pure black by scaling according to gender (male vs. female).

The correlation coefficient (r) for the nationality of blackness perception is 0.99 (Figure 35). This seems to suggest that there are little differences in blackness perception between the UK and China populations. Similarly, the correlation coefficient for the gender of blackness perception is 0.98 (Figure 36). According to this, neither nationality nor gender seems to have a significant influence on blackness perception. Regardless of cultural background, there is a common understanding of what is black.

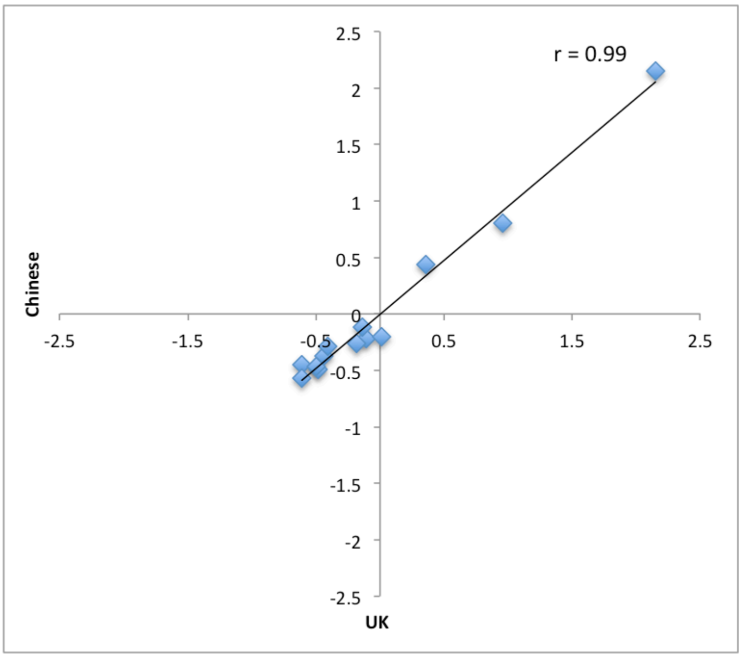


Figure 35. Correlation coefficient of analysis of colour samples closest to pure black by scaling according to nationality (UK vs. Chinese).

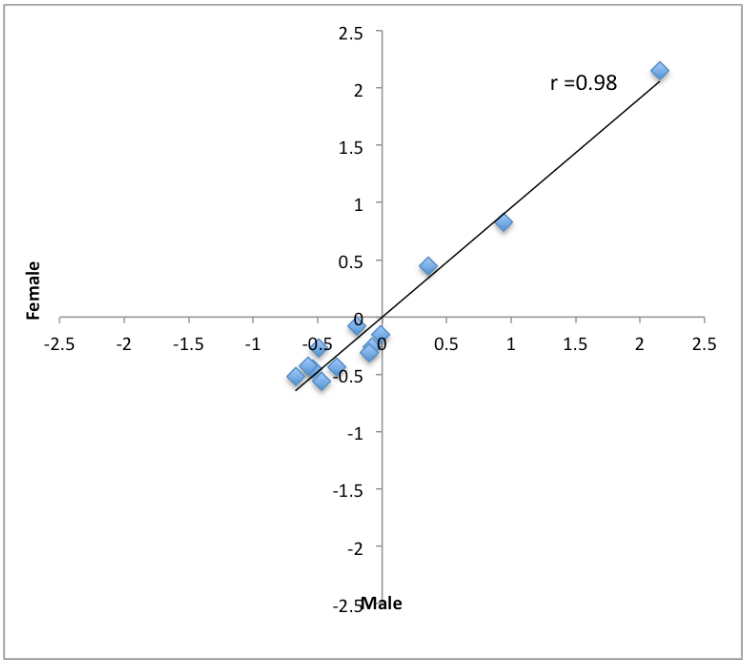


Figure 36. Correlation coefficient for colour samples closest to pure black by scaling according to gender (male vs. female).

3.4. Conclusion

This chapter sought to investigate the relationship between blackness perception and blackness preference according to hue using a psychophysical experiment. Two factors, gender and nationality, were investigated.

For blackness preference, when observers were asked about which blacks they preferred, the results illustrated both nationality and gender differences. The correlation coefficient for the nationality comparison was 0.75 and for the gender comparison was 0.61. This could suggest that there are systematic differences between nationality and gender groups. Indeed, it seems that both Chinese and female observers prefer reddish blue-blacks (purples) compared with UK and male observers who had more of a preference for neutral or greenish blue-blacks. Note that the numbers of male and female participants were the same (12 females and 8 males) in the two nationality groups.

For blackness perception, when observers were asked about which black is closest to pure black, neither nationality nor gender differences exhibited a significant impact on the results. Observers demonstrated a common understanding about what is black. For example, the scale values of each sample are derived from observers from Chinese and UK observers were strongly correlated. The correlation coefficients (r) for the nationality and gender comparisons were 0.99 and 0.98 respectively.

It is no surprise that sample N0 was considered the most black sample and was also the more preferred black since it was the darkest and least chromatic of the samples. However, the results for the stimuli of chromatic colour set which varied in hue but had same chroma and value were interesting to explore. Samples 5PB and 5B were preferred blacks compared to samples 5Y, 5GY and 5YR. In fact, although the blackness perception experiment revealed sample N0 to be the blackest sample, the blackness preference experiment revealed that several chromatic samples (notably 5PB and 5B, but also some others) were preferred to N1. Therefore it would seem that observers have a strong preference for bluish and purplish blacks and a lesser preference for yellowish blacks.

The preference for bluish blacks is consistent with general studies on colour preference; for example, Hogg (1969) found that that blue and purple are the most preferred hues and yellow is the least; similar findings have been found by other researchers (Palmer and Schloss, 2010).

4. Blackness: Preference and Perception (Value and Chroma)

4.1. Introduction

There are three dimensions of colour: hue, value and chroma. The previous chapter focused on hue and the results suggested that neither nationality nor gender had a high impact on blackness perception. However, the results showed that colour preference for blackness could be influenced by nationality particularly (and by gender to a bigger extent). Interestingly there was also a difference between blackness perception and blackness preference. Though most observers perceived the darkest and least chromatic samples to be the most black, these samples were not judged to be the most preferred blacks. Most observers expressed a strong preference for bluish blacks and a lesser preference for yellowish blacks.

This chapter focuses on value and chroma. The psychophysical experiments in this chapter explore blackness preference and blackness perception for observers from different nationality and different gender groups for samples which varied predominantly in value and chroma.

4.2. Experimental Methods

4.2.1. Definition of Stimuli

4.2.1.1. Colour Stimuli

The stimuli of this psychophysical experiments was a colour set with 29 chromatic colours which taken from the Munsell colour system. Three samples which with Munsell V/C = 1/2, V/C = 1/4 and V/C = 2/2[2] (Figure 37) were chosen from each of

[2] In the Munsell system, each colour is represented by a hue, by a value (essentially lightness and denoted by V) and by a chroma (denoted by C). Thus, V/C = 1/2 is a colour with value 1 and chroma 2. V/C = 1/4 is a colour with value 1 and chroma 4. V/C = 2/2 is a colour with value

the main ten Munsell hues (R YR Y GY G BG B PB P RP). Because Munsell V/C = 1/4 is unavailable in Y hue, only 29 samples were used and displayed in a neutral grey (R=133, G=133, B=133) background on a CRT computer screen. The RGB values of the colour samples are displayed in Table 8.

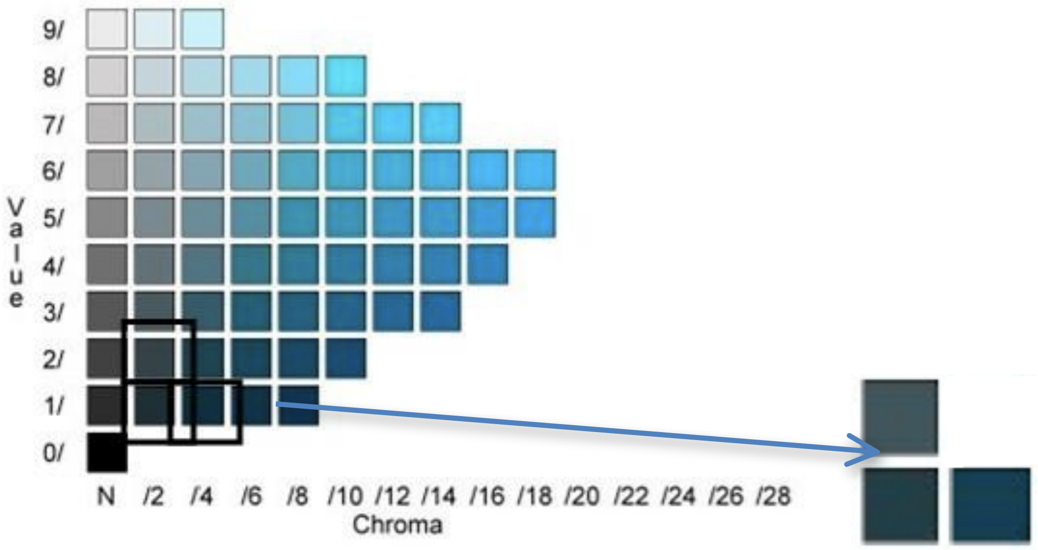


Figure 37. An example Munsell page showing the position of the samples used in the experiment with Value 1 and Chroma 2; Value 1 and Chroma 4; Value 2 and Chroma 2.

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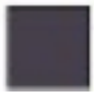
2 and chroma 2.

Table 8. RGB values of Munsell samples used in the experiment.

Hue	V/C = 1/2	V/C = 1/4	V/C = 2/2
5B	[R=19 G=36 B=43]	[R=0 G=38 B=52]	[R=39 G=55 B=61]
5BG	[R=20 G=36 B=37]	[R=0 G=39 B=41]	[R=39 G=55 B=55]
5G	[R=24 G=36 B=31]	[R=0 G=39 B=27]	[R=42 G=55 B=49]
5GY	[R=31 G=35 B=24]	[R=23 G=28 B=0]	[R=49 G=54 B=42]
5Y	[R=40 G=33 B=16]	-	[R=58 G=52 B=37]
5YR	[R=47 G=30 B=23]	[R=57 G=24 B=5]	[R=65 G=49 B=41]
5R	[R=48 G=28 B=32]	[R=57 G=22 B=32]	[R=67 G=47 B=49]

Table 8. RGB values of Munsell samples used in the experiment (continued).

5RP	[R=45 G=28 B=40] 	[R=52 G=23 B=44] 	[R=65 G=47 B=56] 
5P	[R=41 G=30 B=45] 	[R=45 G=26 B=52] 	[R=58 G=49 B=63] 
5PB	[R=28 G=34 B=46] 	[R=21 G=34 B=56] 	[R=47 G=52 B=65] 

4.2.1.2. CRT

As in Chapter 3 the approach taken was to use the sRGB colour values to display the samples and then to measure the CIE values of the actual colours that were displayed. The CIE tristimulus values of each colour on-screen were carefully measured using a Minolta CS100 colorimeter. The white of the display was used in subsequent calculations of CIELAB values for the samples. Table 9 shows the CIE values of colour samples with value 1 and chroma 2 as measured by colorimeter which according to the white point in same screen. Similar to Table 9, Table 10 displays the CIE values of colour samples with value 1 and chroma 4 and Table 11 displays the CIE values of colour samples with value 2 and chroma 2 as measured experimentally. Then Figure 38 shows the 29 colour samples used in the experiment as plotted in CIELAB a*b*. As measurement of all sample sets, the difference in L* between V/C = 1/2 and V/C = 1/4 was not significant but the difference in L* between V/C = 1/2 and V/C = 2/2 are quite large; Same as that, the differences between V/C = 1/2 and V/C = 2/2 is large too. That means V/C = 2/2 is the lightness colour samples. As measurement of all sample, the V/C = 1/4 is the most chromatic colour samples.

Table 9. CIELAB colour coordinates as measured experimentally (V/C = 1/2).

Hue	V/C = 1/2					
	L*	a*	b*	X	Y	Z
5B	32.73	-4.43	-4.66	5.17	6.10	9.41
5BG	31.91	-7.93	0.00	4.66	5.80	7.61
5G	32.51	-10.36	5.62	4.67	6.02	6.41
5GY	32.13	-6.62	11.46	4.82	5.88	4.94
5Y	32.24	-4.62	18.69	5.00	5.92	3.62
5YR	30.70	3.64	12.22	5.12	5.37	4.30
5R	31.83	8.92	3.56	5.92	5.77	6.63
5RP	32.02	10.61	-2.98	6.13	5.84	8.52
5P	32.65	8.04	-6.22	6.14	6.07	9.87
5PB	32.83	-0.99	-6.32	5.47	6.14	10.01

Table 10. CIELAB colour coordinates as measured experimentally (V/C =1/4).

Hue	V/C = 1/4					
	L*	a*	b*	X	Y	Z
5B	30.23	-10.84	-10.90	3.98	5.21	10.04
5BG	30.64	-17.14	-2.99	3.70	5.35	7.83
5G	30.08	-20.72	7.11	3.35	5.16	5.11
5GY	30.41	-18.65	31.83	3.55	5.27	1.51
5Y	-	-	-	-	-	-
5YR	29.48	9.30	30.23	5.15	4.96	1.51
5R	30.05	19.10	2.08	6.13	5.15	6.24
5RP	29.93	19.50	-8.30	6.12	5.11	9.04
5P	30.84	14.50	-12.76	6.03	5.42	11.04
5PB	31.53	1.14	-14.11	5.20	5.66	11.96

Table 11. CIELAB colour coordinates as measured experimentally (V/C = 2/2).

Hue	V/C = 2/2					
	L*	a*	b*	X	Y	Z
5B	40.80	-6.61	-3.50	8.04	9.66	14.08
5BG	40.00	-7.71	0.64	7.59	9.26	11.91
5G	40.54	-9.83	6.28	7.61	9.53	10.24
5GY	40.14	-6.39	10.05	7.78	9.33	8.81
5Y	41.24	-2.38	13.66	8.68	9.89	8.30
5YR	40.99	2.95	10.44	9.14	9.76	9.14
5R	40.78	5.23	5.19	9.29	9.65	10.75
5RP	40.89	7.30	-0.87	9.58	9.71	13.08
5P	40.58	5.09	-5.80	9.18	9.55	14.90
5PB	41.20	-1.37	-4.54	8.77	9.87	14.82

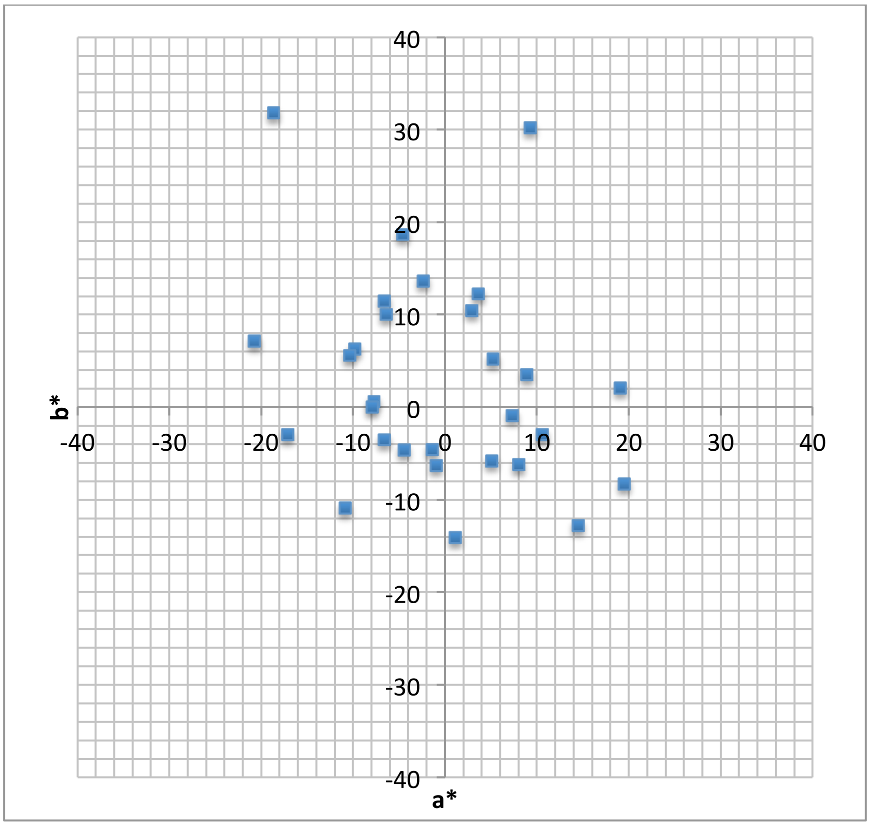


Figure 38. The 29 colour samples in CIELAB a*-b* spaces.

4.2.2. Observers

Twenty-five observers were invited to take part in this experiment; 13 observers were from China and 12 observers were from UK. There were 13 female (7 from China and 6 from UK) and 12 male (6 from China and 6 from UK) observers. All of these observers passed the Ishihara Test for colour blindness before the experiment and were therefore assumed to have normal colour vision.

4.2.3. Experimental Procedure

As in the previous chapter, all stimuli used in this experiment were 8 cm × 8 cm and presented to the observers on a neutral grey background (R=133, G=133, and B=133) in pairs. Each stimulus was defined by RGB values and no additional colour management was employed (however the actual colours displayed were subsequently measured). All observers were presented with colour stimuli on a CRT monitor at a viewing distance of 90 cm and a visual field size of 15° and using the same computer in a dark room.

There are two phases in this psychophysical experiment. In the first phase, blackness preference was considered. The observers were asked to indicate which colours they prefer. In the second phase, blackness perception was explored. The observers were asked to indicate which blacks are close to a pure black. Observers were asked to judge all stimuli in phase 1 firstly, and then all stimuli were presented again and observers were asked to judge according to phase 2.

The paired comparison method was used in this psychophysical experiment. The stimuli were presented to the observers in pairs (Figure 26; Chapter 3). Observers press the select button under one of the samples to indicate their choice. After they press the select button, the next pair of colour samples was displayed.

In Chapter 3 a complete paired-comparison experiment was carried out. However, in this chapter the aim is to explore blackness preference and perception according to value and chroma. Therefore, hue was not considered in this experiment. So the colour samples were only compared with the colour samples which contain the same hue in pairs, but not compare across hues[3]. Thus three paired comparisons were carried out for each hue (Figure 39). Therefore for ten hues, 30 paired comparison were done, then 25 observers were invited to attend the experiment, that means there were 750 (30 pairs × 25 observers) total observations for each of the two phases.

[3] It would have been possible to carry out a complete paired-comparison paradigm and this issue is discussed again at the end of this chapter.

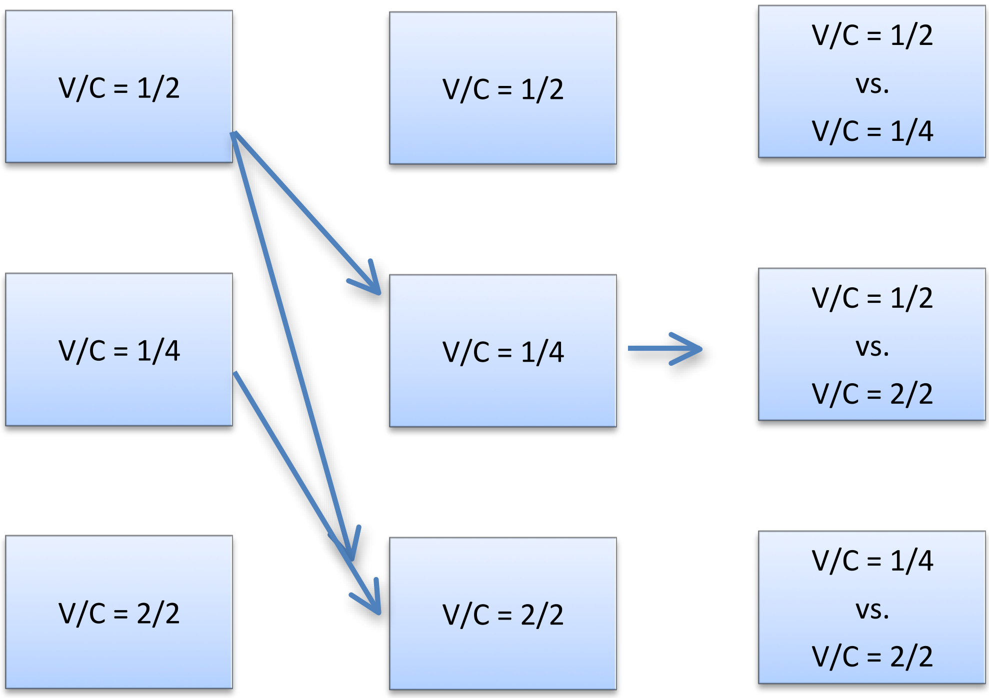


Figure 39. The paired comparison method used in the experiment.

4.3. Data and Results

4.3.1. Blackness Preference

There are two phases in this psychophysical experiment: blackness preference and blackness perception. In this section, the results of blackness preference (which related to which of a pair of colour samples observers preferred) are analysed.

Table 12 shows the scale values of colour sample which in different value and chroma (V/C = 1/2, V/C = 1/4 and V/C = 2/2) according to nationality (UK and Chinese). The greater and more positive the scale value, that means observers more prefer. Figure 40 illustrates the scale values of colour sample in different nationality group. Chinese observers preferred V/C = 1/2, but UK observers ranked V/C = 1/2 as the least prefer blacks. V/C = 2/2 has a highest preference score for UK observers, but it has the lowest score in Chinese nationality group respectively. So the positions of V/C = 1/2 and V/C = 2/2 are complete reversed (V/C = 1/2 is -0.06, V/C = 2/2 is +0.10 for UK and V/C = 1/2 is +0.10, V/C = 2/2 is -0.08 for Chinese). This result could suggest that Chinese observers like the darker and less chromatic samples and British observers like the lightest ones.

Table 12. Scale values for colour preference according to UK and Chinese (results pooled over all hues).

V/C = 1/2	**UK**	-0.06
	Chinese	0.14
V/C = 1/4	**UK**	-0.04
	Chinese	-0.07
V/C = 2/2	**UK**	0.10
	Chinese	-0.08

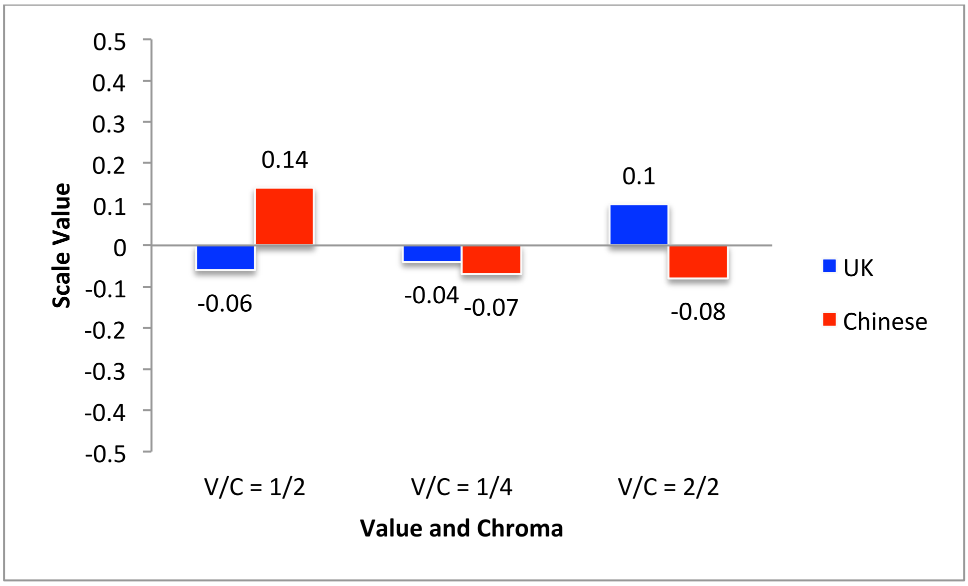


Figure 40. Scale values for colour preference according to nationality (results pooled over all hues).

Table 13 shows the scale values for colour preference scaling for UK and Chinese in each hue. It displays the scale values of colours samples which with V/C = 1/2, V/C = 1/4 and V/C = 2/2 in each different ten hues according to UK and Chinese observers in detail.

Table 13. Scale values of colour preference according to UK and Chinese in each hue.

Hue	V/C = 1/2		V/C = 1/4		V/C = 2/2	
	UK	Chinese	UK	Chinese	UK	Chinese
5B	-0.37	-0.07	0.29	0.69	0.08	-0.32
5BG	0.00	-0.10	-0.55	0.55	0.55	-0.37
5G	0.00	0.37	-0.55	-0.53	0.55	0.39
5GY	0.24	0.32	-0.92	-0.45	0.69	0.39
5Y	0.11	0.14	-	-	0.00	-0.07
5YR	-0.14	0.39	0.21	0.29	-0.07	-0.39
5R	-0.32	0.18	0.55	-0.08	-0.22	0.15
5RP	0.15	1.49	0.00	-0.92	-0.15	0.71
5P	-0.32	0.00	0.60	0.55	-0.29	-0.29
5PB	0.00	0.29	-0.14	-0.32	0.14	0.32

Figure 41 indicates the general order of preference of colour samples in different nationality groups in each hue. The blue bars show the results of UK observers and the red bars illustrate the results of Chinese observers. There are three sections in each hue. As indicated in Figure 41, 5G, 5GY and 5P has similar range in both groups. Almost all observers preferred V/C = 2/2 in 5G and 5GY hue sets, then in 5P hue set V/C = 1/4 is ranked as first place. These results could suggest that observers like lightness colour sample in 5G and 5GY, but prefer more chromatic colour in 5P hue. However there was a large difference for 5BG, 5R and 5RP between Chinese and UK groups. Figure 41 shows, in 5BG Chinese preferred V/C = 1/4 but disliked V/C = 2/2, but the results for UK observers were contrary to Chinese (V/C = 1/4 is lowest one and V/C = 2/2 is highest one). This means Chinese observers prefer more chromatic colour sample in 5BG and UK observers prefer the lightness colour sample.

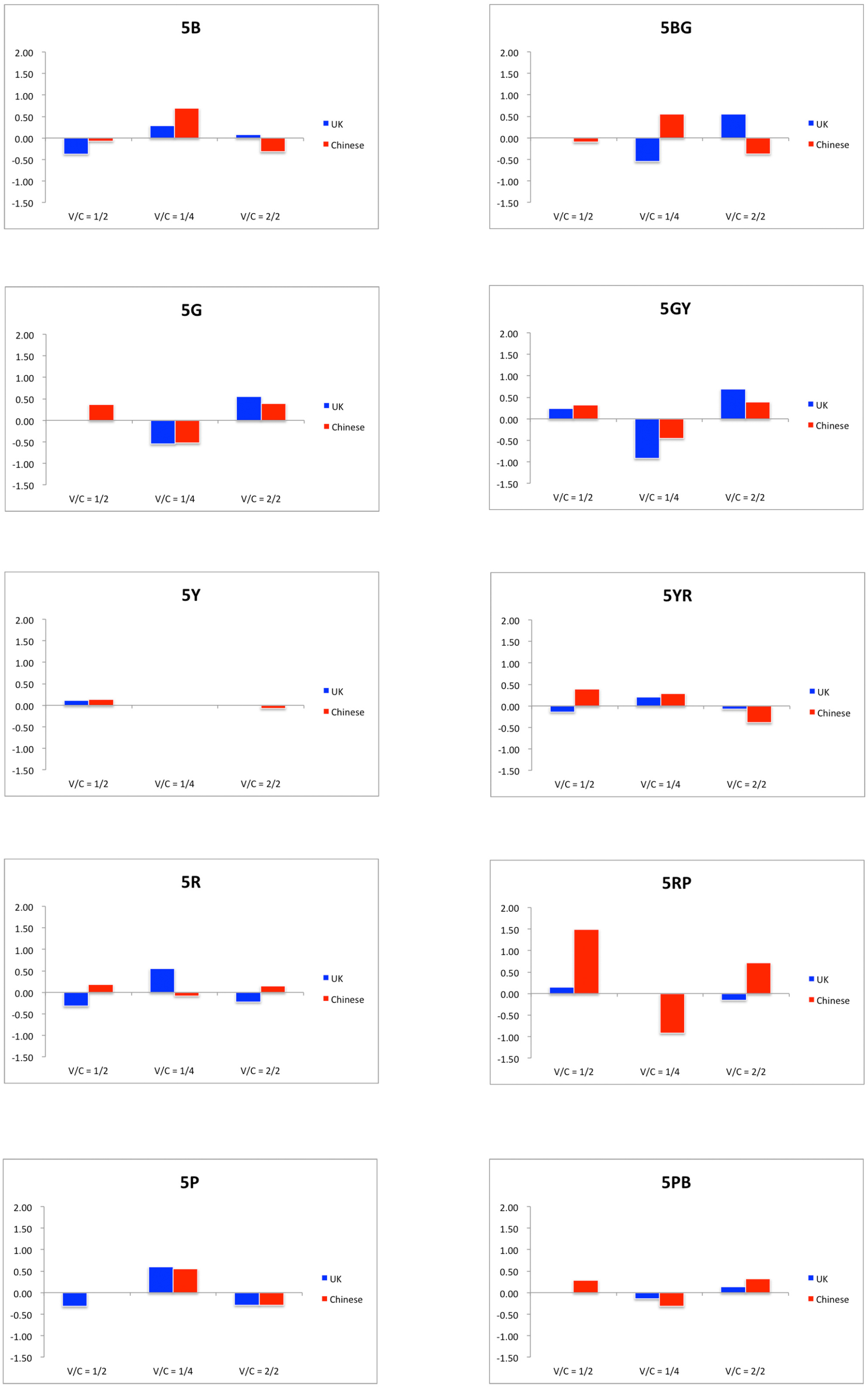


Figure 41. Scale values for colour preference according to UK (blue bars) and Chinese (red bars) observers in each hue.

Table 14 shows the scale values for male and female groups pooled over all hues. As Figure 42 illustrates females gave similar scores for all colour sections. V/C = 1/2, V/C = 1/4 and V/C =2/2 have very close scores (V/C = 1/2 is -0.01, V/C = 1/4 is -0.02 and V/C = 2/2 is +0.02). V/C =2/2 is a little high than others and V/C = 1/4 is a little bit lower. However, males preferred V/C =1/2 (+0.13) and disliked V/C = 1/4 (-0.08). As Figure 42 shows, both females and males do not like V/C = 1/4. The V/C = 1/4 colour samples always have lowest scores of three sections. But male ranked V/C = 1/2 colour samples at first place, female gave the highest scores to V/C = 2/2. These results could suggest that males like darker and less chromatic blacks and females like lightest blacks.

Table 14. Scale values for colour preference according to male and female (results pooled over all hues).

V/C = 1/2	**Male**	0.13
	Female	-0.01
V/C = 1/4	**Male**	-0.08
	Female	-0.02
V/C = 2/2	**Male**	0.08
	Female	0.02

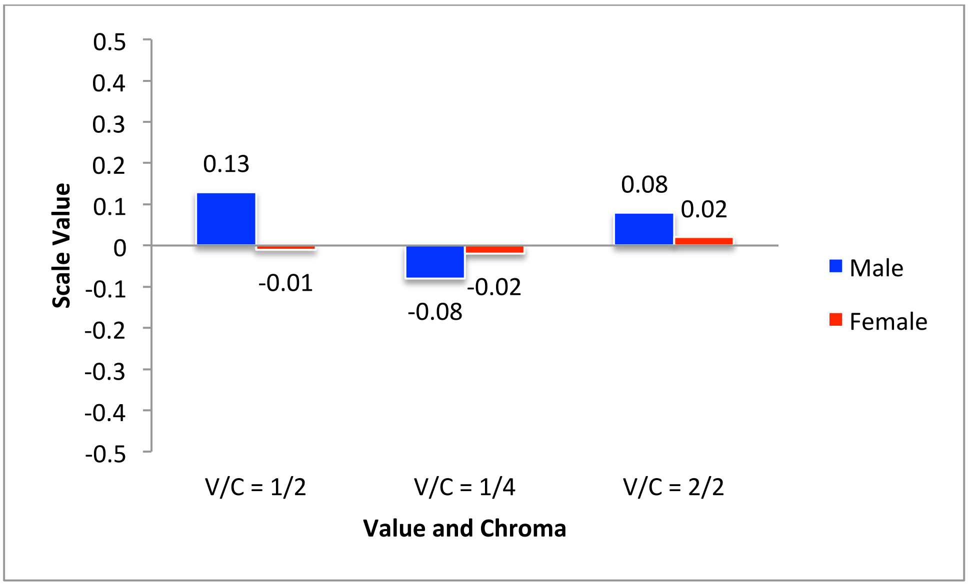


Figure 42. Scale values for colour preference according to male and female (results pooled over all hues).

Table 15 shows the scale values for colour preference according to different gender groups (male and female). For each hue, the scale values of colour samples which with V/C = 1/2, V/C = 1/4 and V/C = 2/2 were displayed in detail.

Table 15. Scale values for colour preference according to male and female in each hue.

	V/C = 1/2		V/C = 1/4		V/C = 2/2	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**
5B	-0.26	-0.23	0.46	0.36	-0.20	-0.14
5BG	0.08	-0.18	-0.17	0.17	0.08	-0.11
5G	0.34	0.06	-0.85	-0.40	0.51	0.31
5GY	1.34	0.06	-2.84	-0.42	1.51	0.35
5Y	0.84	-0.08	-	-	-0.84	0.08
5YR	-0.11	0.17	0.46	-0.06	-0.35	-0.12
5R	-0.08	-0.11	0.17	0.17	-0.09	-0.06
5RP	0.56	0.36	-0.71	-0.23	0.15	-0.14
5P	-0.25	-0.14	0.60	0.42	-0.35	-0.29
5PB	0.43	-0.06	-0.85	0.06	0.43	0.00

Figure 43 shows scale values for colour preference in each hue according to gender. The results indicated that V/C= 2/2 has a high score and V/C= 1/4 has a low score in 5G and 5GY hue selections both in male and female group. It also indicated both male and female liked V/C = 1/4 in 5B, 5P and 5R hue selections. This could suggest that almost observers prefer more colourful samples in 5B, 5P and 5R hues. Recalled the finding in blackness preference which varied in hue, these three hues are ranked at higher places. This could be the reason why more colourful more preferred in these three hues. But as the Figure 43 shows, people also have different perspectives between male and female. For example, females gave the lowest scores to V/C = 1/2 and the highest scores to V/C = 1/4 in 5BG and 5PB sections, but males preferred V/C = 2/2 and disliked V/C = 1/4. In 5Y hue selection, the results between male and female are the exact opposite. Male preferred V/C = 1/2 and disliked V/C = 2/2, but female gave a higher score to V/C = 2/2 than V/C = 1/2.

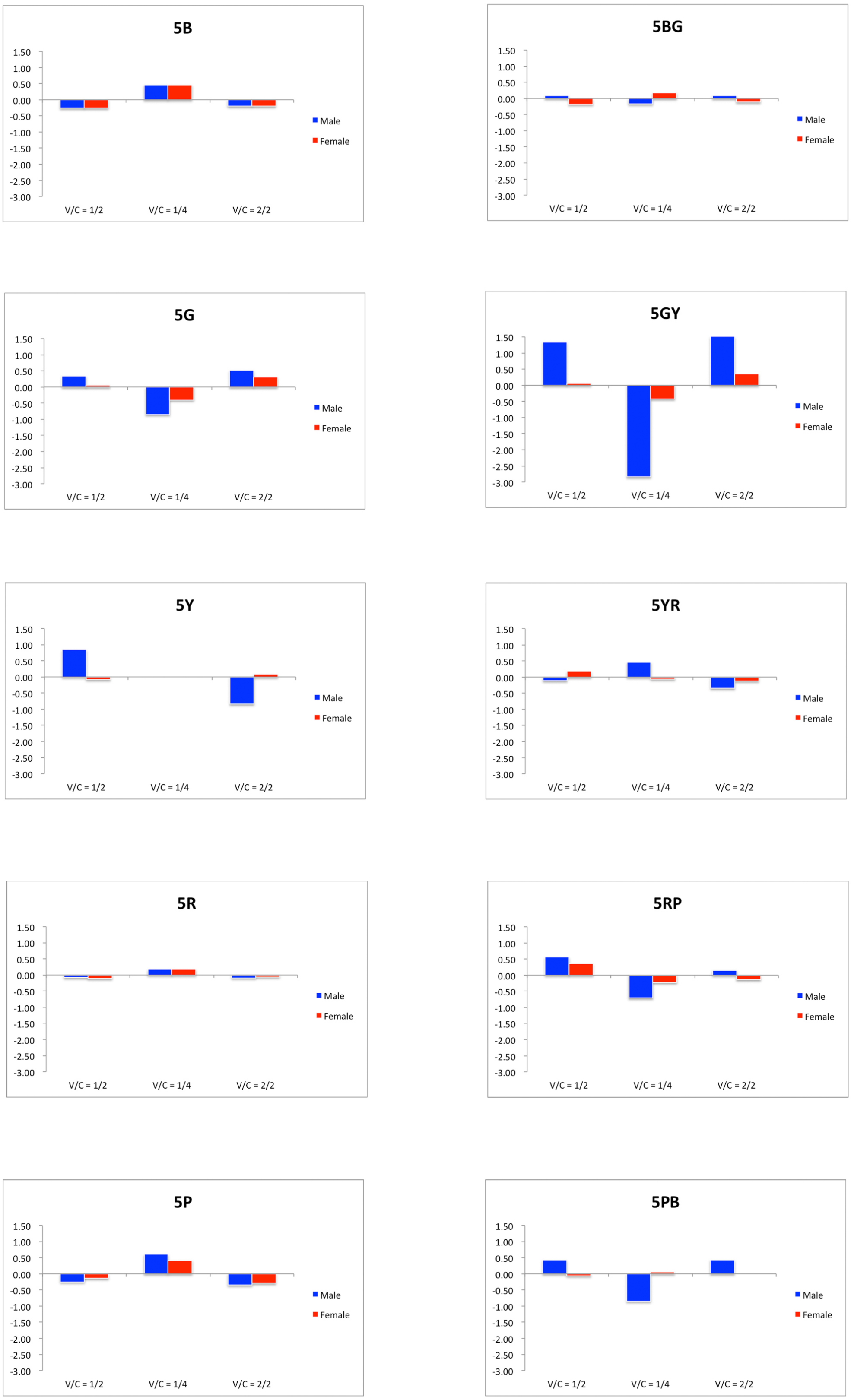


Figure 43. Scale values for colour preference according to male (blue bars) and female (red bars) in each hue.

Figures 44 and 45 indicate that culture differences play an important role in colour preferences. The correlation coefficients (r) for nationality and gender are 0.30 and 0.61 respectively. This could indicate that colour preference is influenced by culture, and that nationality has a greater effect on colour preference than gender. The results indicated when observers were asked about colour preference, the results were very different. These results are consistent with previous research which discussed the gender and nationality difference of colour preference according to hue.

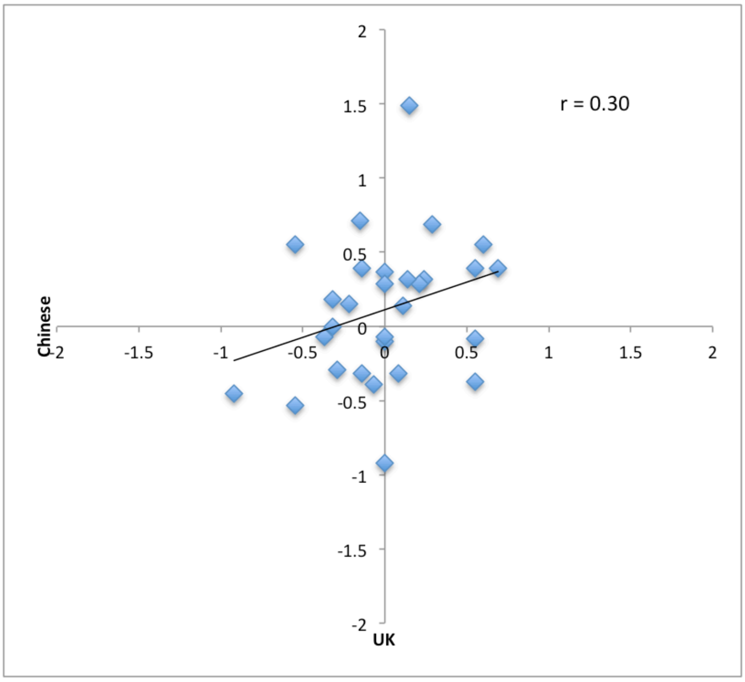


Figure 44. Correlation coefficient for colour preference scaling according to nationality (UK and Chinese).

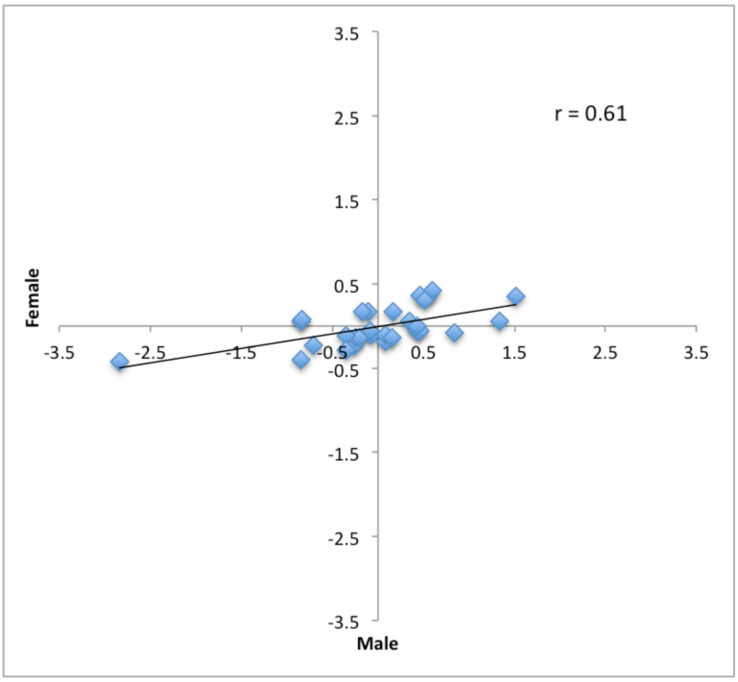


Figure 45. Correlation coefficient for colour preference according to gender (male and female).

4.3.2. Blackness Perception

In this section the results of the blackness perception phase are analysed. That means observers were asked which of two black samples they judged to be closest to a pure black.

Table 16 shows the scale values of colour sample in different values and chroma groups and those results are according to the nationality. The greater and more positive the scale values means it was considered to be closet to the pure black. Figure 46 illustrates that all scale values are similar in different groups. Colour samples with value 1 and chroma 2 ranked in the first place (2.84 for British and 2.14 for Chinese); then the colour samples with value 2 and chroma 2 ranked second (-1.21 for British and -0.49 for Chinese); Last colour samples with value 1 and chroma 4 is considered to be the least blackness colour sample (-1.64 for British and -1.65 for Chinese). This result indicates that people considered darker and less chromatic blacks to be the nearest colour to pure black and when samples more colourful, they considered to be least black.

Table 16. Scale values of blackness perception according to UK and Chinese (results pooled over all hues).

V/C = 1/2	**UK**	2.84
	Chinese	2.14
V/C = 1/4	**UK**	-1.64
	Chinese	-1.65
V/C = 2/2	**UK**	-1.21
	Chinese	-0.49

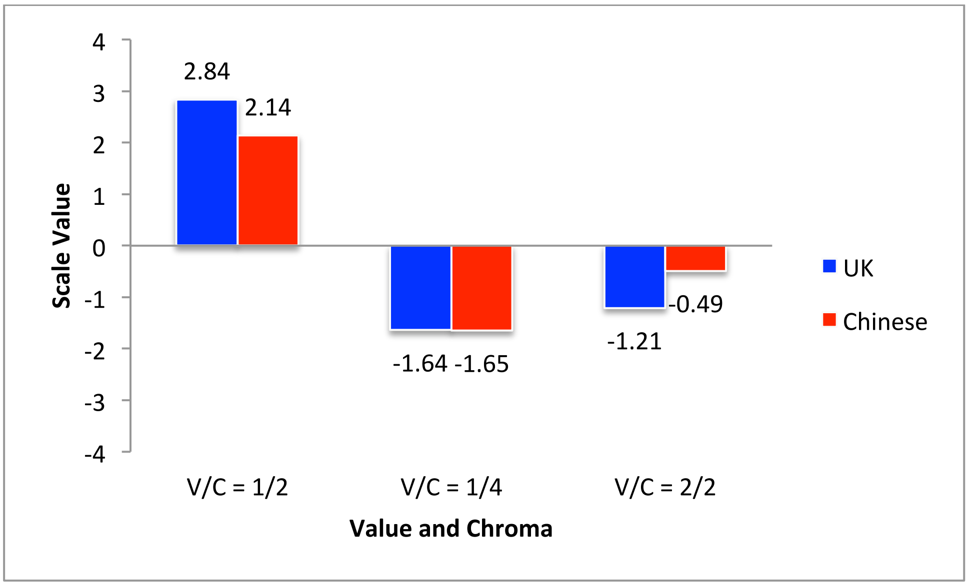


Figure 46. Scale values of blackness perception according to UK and Chinese (results pooled over all hues)

Table 17 shows the scale values for colour perception scaling for UK and Chinese. It displays the scale values of colours samples which with V/C = 1/2, V/C = 1/4 and V/C = 2/2 in each different hues according to UK and Chinese observers in detail.

Table 17. Scale values of blackness perception according to UK and Chinese in each hue.

Hue	V/C = 1/2		V/C = 1/4		V/C = 2/2	
	UK	Chinese	UK	Chinese	UK	Chinese
5B	2.84	2.84	-1.10	-1.39	-1.74	-1.45
5BG	2.84	2.84	-1.65	-1.76	-1.20	-1.08
5G	2.84	2.84	-2.84	-1.90	0.00	-0.95
5GY	2.84	2.84	-1.88	-1.90	-0.96	-0.95
5Y	1.42	1.02	-	-	-1.42	-1.02
5YR	2.84	2.84	-2.84	-1.76	0.00	-1.08
5R	2.84	2.84	-2.84	-1.76	0.00	-1.08
5RP	2.84	2.84	-1.42	-1.45	-1.42	-1.39
5P	2.84	2.84	-1.28	-1.39	-1.57	-1.45
5PB	2.84	2.84	-2.84	-1.76	0.00	-1.08

Figure 47 shows scale values for colour perception according to nationality in different hues. All scale values in different hue of Chinese and British are very similar. It could suggest that there are no difference between the UK and China. Observers considered that colour samples with value 1 and chroma 2 are closet to the pure black. Then colour with value 2 and chroma 2 ranked in second place in most hue groups, which means more colourful then less blackness. But 5B and 5P show the difference rank. Colours with value 1 and chroma 4 are considered blacker than colours with value 2 and chroma 2, which means the more colourful, the more blackness in 5B and 5P. According to the previous chapter, blacks that contain blue and purple hues are considered to be close to the pure black. This could be the reason why the more colourful, the more black in 5B and 5P.

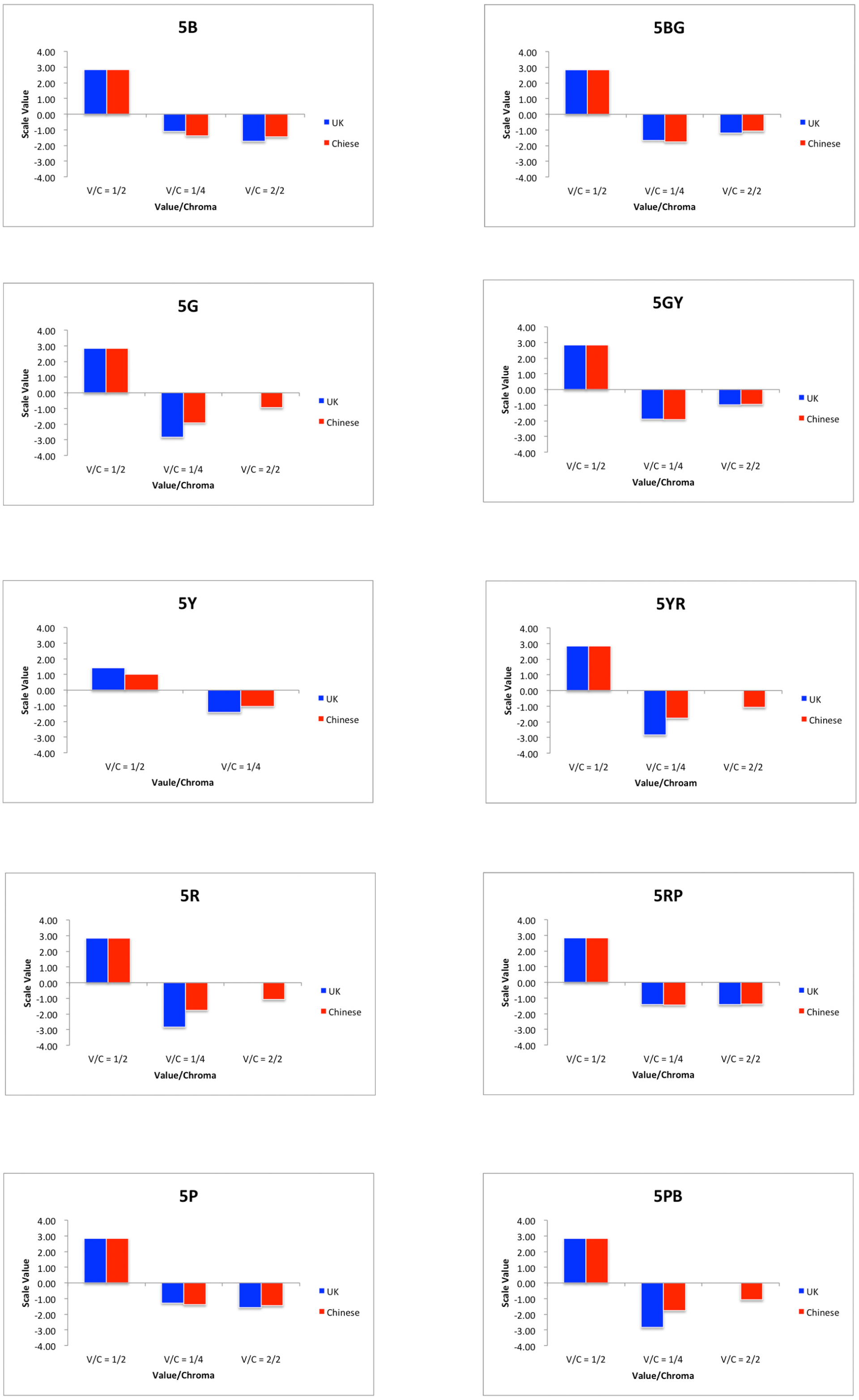


Figure 47. Scale values of blackness perception according to UK (blue bars) and Chinese (red bars) in each hue.

Table 18 displays blackness perception according to genders. As Figure 48 indicates that both male and female considered that the colour samples with value 1 and chroma 2 is the most blackness and the colour samples with value 1 and chroma 4 is the least blackness colour sample. This results could suggest that either male or female considered that the darker and less colourful samples is nearest to a pure black and the results also indicated if colour samples is more colourful, then it ranked as the less black.

Table 18. Scale values of blackness perception according to male and female (results pooled over all hues).

V/C = 1/2	**Male**	2.84
	Female	2.16
V/C = 1/4	**Male**	-1.65
	Female	-1.64
V/C = 2/2	**Male**	-1.19
	Female	-0.52

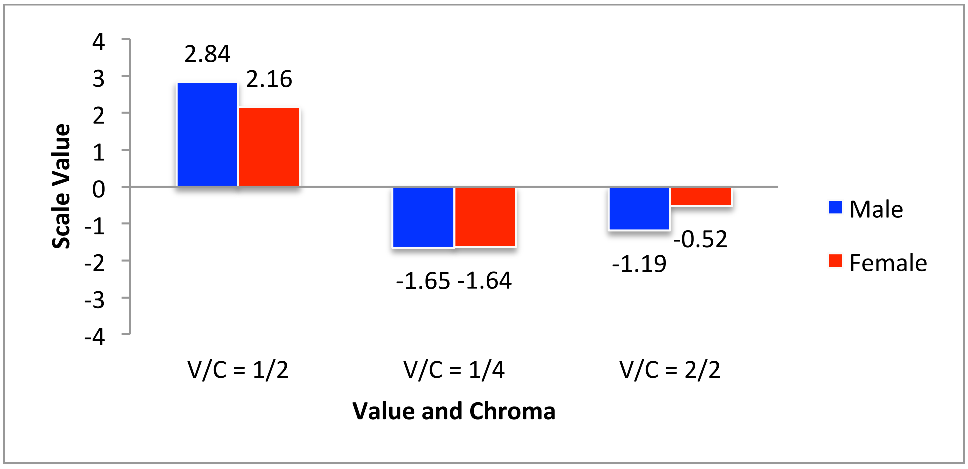


Figure 48. Scale values of blackness perception according to male and female (results pooled over all observers)

Table 19 shows the scale values for colour perception according to different gender groups (male and female). For each hue, the scale values of colour samples which with V/C = 1/2, V/C = 1/4 and V/C = 2/2 were displayed in detail.

Table 19. Scale values of blackness perception according to male and female in each hue.

Hue	V/C = 1/2		V/C = 1/4		V/C = 2/2	
	Male	Female	Male	Female	Male	Female
5B	2.84	2.84	-1.14	-1.34	-1.70	-1.51
5BG	2.84	2.84	-1.60	-1.79	-1.25	-1.05
5G	2.84	2.84	-2.84	-1.92	0.00	-0.92
5GY	2.84	2.84	-2.84	-1.79	0.00	-1.05
5Y	1.42	0.37	-	-	-1.42	-0.37
5YR	2.84	2.84	-2.84	-1.79	0.00	-1.05
5R	2.84	2.84	-2.84	-1.79	0.00	-1.05
5RP	2.84	2.84	-1.51	-1.45	-1.34	-1.39
5P	2.84	2.84	-1.25	-1.39	-1.60	-1.45
5PB	2.84	2.84	-2.84	-1.79	0.00	-1.05

Figure 49 indicated the scale values for colour perception according to gender in each hue, and there are no differences compared to when we considered the effect of nationality. Thus, the result suggests that both male and female observers rate V/C = 2/2 is blacker than V/C = 1/4 in most hues except 5B and 5P. But in general, same as the results of colour perception according to nationality, gender does not have a significant influence on blackness perception.

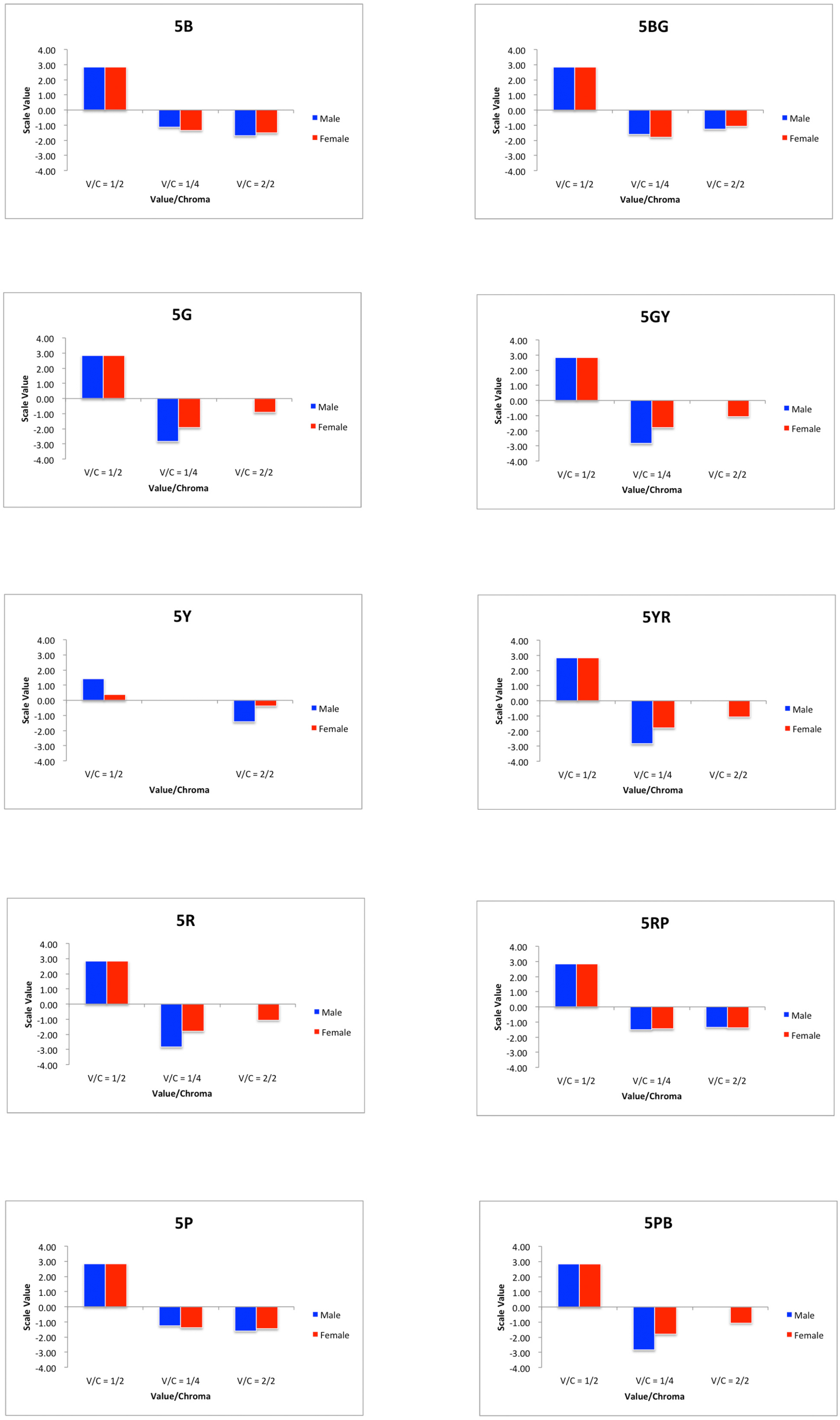


Figure 49. Scale values of blackness perception according to male (blue bars) and female (red bars) observers in each hue

Figures 50 and 51 show the correlation coefficient is 0.96 for the nationality and 0.95 for the gender. It indicates that neither culture nor gender have a significant influence on blackness perception. These results are consistent with previous research which discussed the gender and nationality difference of colour perception according to hue.

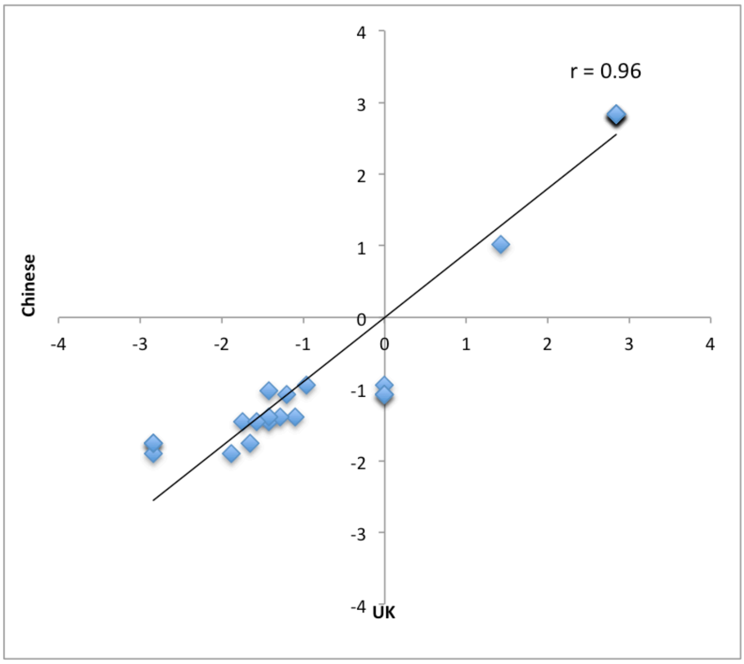


Figure 50. Correlation coefficient of analysis of colour samples closest to pure black by scaling according to nationality (UK and Chinese).

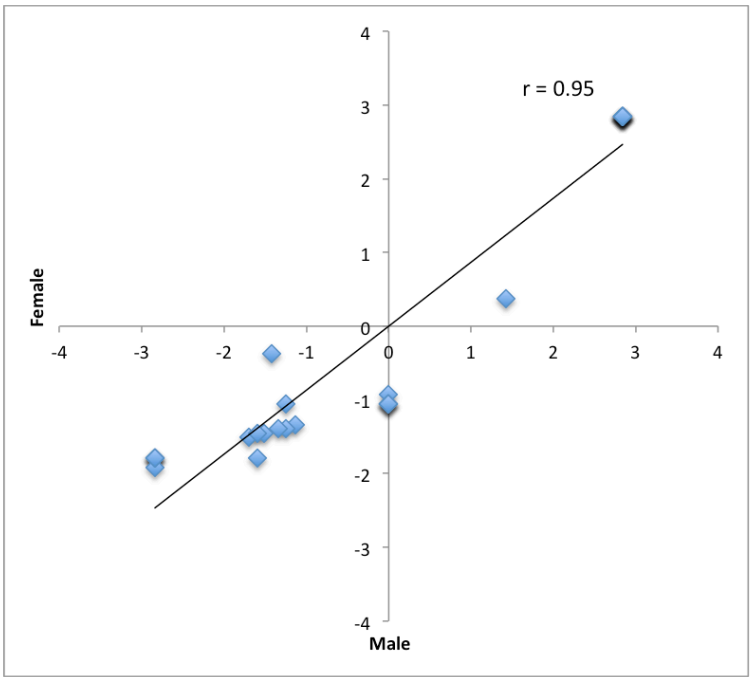


Figure 51. Correlation coefficient for colour samples closed to pure black by scaling according to gender (male and female).

4.4. Conclusion

This study was to investigate the effects of nationality and gender on blackness perception and blackness preference varied in value and chroma.

For blackness preference, the correlation coefficient for the nationality is 0.30 and for the gender is 0.61. This could suggest that there could be differences between nationality and gender groups. Chinese and male groups preferred darker and less chromatic colour set, but UK and female observers like lightest and less chromatic colours.

For blackness perception, neither nationality nor gender differences had a significant difference. The scale values from observers in nationality and gender groups were strongly correlated. The correlation coefficients (r) for the nationality and gender comparisons were 0.96 and 0.95 respectively. All observers considered that colours with value 1 and chroma 2 is most blackness and colours with value 1 and chroma 4 is the least.

The results from this chapter are consistent with those from Chapter 3. Both chapters reveal cultural differences in blackness preference but not in blackness perception. Further work is required to confirm this tentative finding using more observers and other method. One reason for this is both chapters relied upon the paired-comparison technique and it is important to cross-validate the findings using a different psychophysical technique. In addition, in this chapter an incomplete paired-comparison paradigm was employed and the results were compared across different groups. Therefore Chapter 5 further explores aspects of blackness perception and preference but using the ranking psychophysical technique.

5. Blackness: Preference and Perception (Hue, Value and Chroma)

5.1. Introduction

This chapter further investigates blackness preference and perception. Chapters 3 and 4 measured blackness preference and blackness perception for samples that varied in hue, value and chroma. The paired-comparison method was used in the psychophysical experiments described in these chapters. Findings from both chapters indicated little effect of gender or nationality on observers' perception of blacks. However, there was evidence of a cultural effect on colour preference.

In order to validate and extend the previous findings of Chapter 3 and Chapter 4, the ranking method was used in this chapter to further explore blackness preference and perception for samples that varied in hue, value and chroma.

5.2. Experimental Methods

5.2.1. Definition of Stimuli

5.2.1.1. Colour Stimuli

In order to validate the previous findings, the same colour samples used in Chapter 3 and Chapter 4 are also used in this experiment. Therefore, a set of 29 colour samples, comprising of three samples (Munsell V/C = 1/2, V/C = 1/4 and V/C = 2/2) for each of ten hues (R YR Y GY G BG B PB P RP) were taken from the Munsell colour system. As noted in Chapter 4, for the Y hue only two samples were available so that the total number of samples used was 29 rather than 30. All colour samples were displayed on a neutral grey (R=133, G=133, B=133) background on a CRT computer screen.

5.2.1.2. Observers

Twenty-six observers (14 from China and 12 from UK) were invited to attend this experiment. There were 10 males (5 from China and 5 from UK) and 16 females (9 from China and 7 from UK). All of these observers passed the Ishihara Test for colour blindness before participating in the experiment and were therefore assumed to have normal colour vision.

5.2.2. Experimental Procedure

The ranking method was used in this study. The colour samples were 3 cm × 2 cm and presented to the observers on a neutral grey background (R=133, G=133, B=133) at the same time. Colour samples were displayed on a CRT monitor using a GUI written in MATLAB. Each stimulus was defined by sRGB values and no additional colour management was employed. All observers viewed the samples on a CRT computer screen in a dark room at a distance of 90 cm.

The experiment was carried out in two phases. In Phase 1, observers were asked to put all of the colour samples in order from like to dislike (blackness preference). Then in phase 2, observers were asked to arrange the colour samples in order of which one is the closest to a pure black (blackness perception). These two phases were independent. Observers were asked to judge all stimuli in phase 1 firstly, and then all stimuli were presented again and observers were asked to judge them again according to phase 2. In this experiment, observers were able to move the samples on the GUI using the mouse after pressing the start button.

The ranking scaling method was used in this psychophysical experiment. The stimuli were presented to the observers at the same time (Figure 52). After pressing the start button at the top of the screen, observers were able to move the samples on the GUI using the mouse to indicate their ranking order.

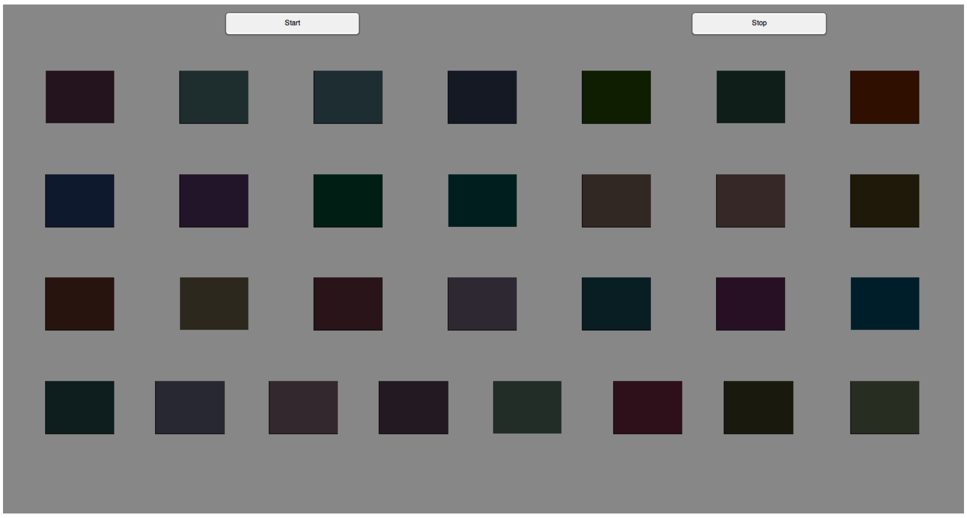


Figure 52. The GUI used in the experiment.

5.2.3. Ranking Method

The ranking method was taken in this experiment because of the large number of stimuli and to provide data using a technique different to that used in the previous two chapters. For the 29 colour samples, if the paired-comparison method was used, then a total of 409 observations would be required in each phase by each observer (this might result in observers losing motivation during the task and making random choices). According to the ranking method the observers arrange the stimuli in order, from best to worst, according to an attribute defined by the instructions. The rank-order data were collected and used to calculate interval scale values. The process of ranking method could consider to an inherently comparison of all samples with each other (Thurston, 1931). Thus the ranking data can be converted to a proportion matrix as in the paired-comparison experiment. For example, consider four stimuli A, B, C, D. If an observer ranked them in the order B, C, D, and A then this can effectively be converted to pair-wise comparisons thus: B>C, B>D, B>A, C>D, C>A and D>A. Therefore, the proportion matrix can be generated and from this the interval scale values can be calculated as explained earlier.

5.3. Data and Results

5.3.1. Blackness Preference

Two phases were used in this psychophysical experiment: blackness preference and blackness perception. In this section, the results of blackness preference are analysed. Figure 53 shows the ranking orders of all colour samples from like to dislike (left to right). It indicated that observers like purple and blue tone but dislike yellow tone. The colour samples, which contained purple and blue tone, are always placed in the left part； but the yellowish blacks are always placed in the right part. The reddish and greenish blacks are in the middle of the line. Furthermore, observers preferred darker and less chromatic purplish and bluish blacks. The colour samples with V/C = 1/2 ranked higher in purplish and bluish blacks, however in reddish and greenish blacks, observers seems prefer colourful or lighter colour samples. In order to validate and extend the previous finding in Chapters 3 and 4, blackness preference and blackness perception that varied in hue and varied in value/chroma are discussed as below.

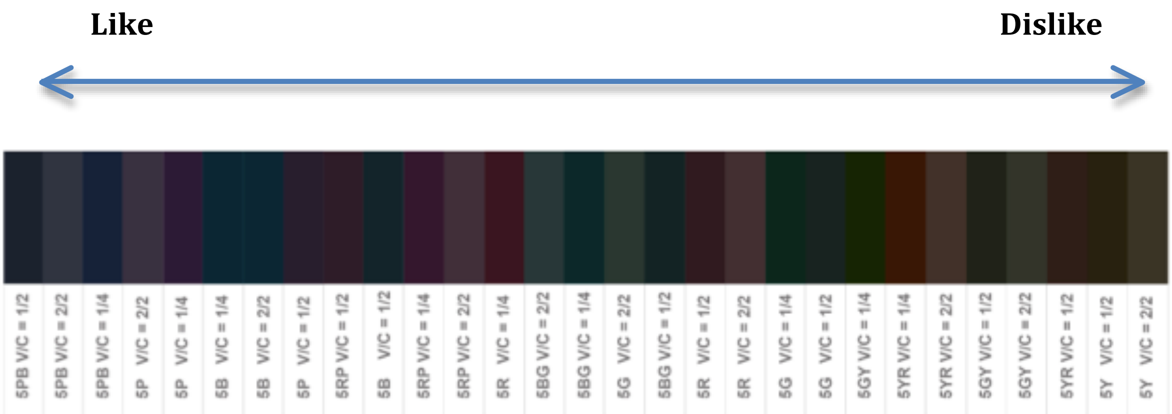


Figure 53. The ranking orders of colour samples.

5.3.1.1. Blackness Preference According to Hue

Blackness preference according to hue is first considered and validated the previous finding in Section 3.3.1.

Table 20 shows the scale values of the colour sample of various hues according to blackness preference pooled over all observers. The colours are divided into ten groups according to hue, and for each hue there are then three samples (V/C = 1/2, V/C =1/4 and V/C =2/2). As before, more positive scale values indicate that the samples were more preferred. The data from Table 20 are plotted in Figures 54, 55 and 56.

From Figure 54 (where V/C = 1/2) it is evident that the reddish blues (5PB, 5P and 5RP) are ranked in the first three places with yellowish blacks (5Y and 5YR) ranked as least preferred. Section 3.3.1 also indicated that observers preferred bluish and purplish blacks and disliked yellowish blacks. Figures 55 and 56 show similar data for V/C = 1/4 and V/C = 2/2. The sequence is nearly the same as in Figure 54 which suggests that the preference for bluish blacks is invariant to small changes in value and chroma. This result is consistent with the findings from Chapter 3. High agreement was found between blackness preference in this chapter and Chapter 3, with the correlation coefficient of 0.89 to 0.97. Figure 57 shows blackness preference results for these two chapters, illustrating high correlation between data.

Table 20. Scale values for blackness preference (all observers).

Hue	V/C = 1/2	V/C = 1/4	V/C = 2/2
5B	0.23	0.35	0.33
5BG	-0.04	0.05	0.11
5G	-0.30	-0.12	0.05
5GY	-0.52	-0.40	-0.56
5Y	-0.65	-	-0.66
5YR	-0.57	-0.46	-0.47
5R	-0.09	0.12	-0.11
5RP	0.28	0.19	0.17
5P	0.30	0.35	0.37
5PB	0.85	0.66	0.74

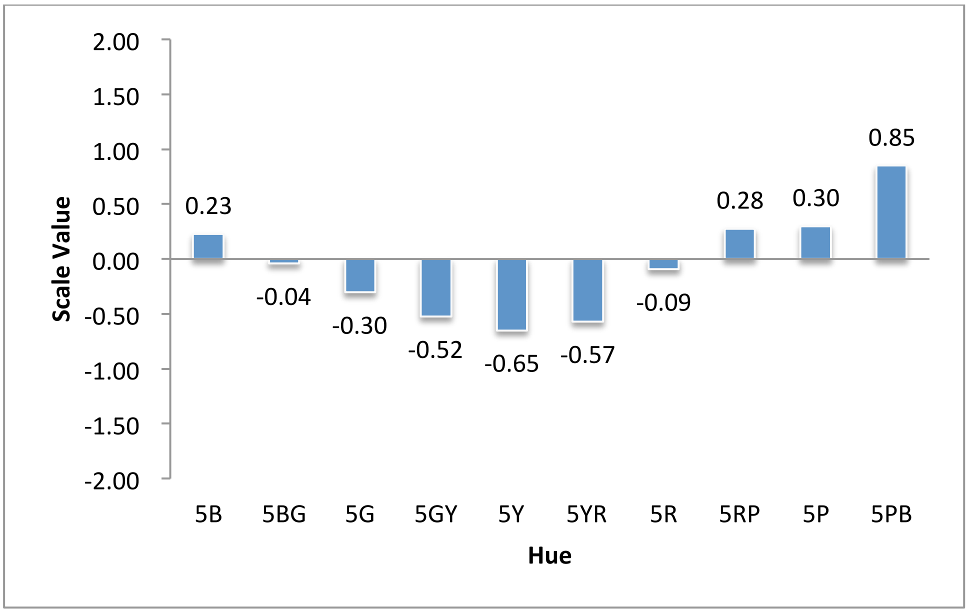


Figure 54. Scale values for blackness preference in V/C = 1/2 (all observers).

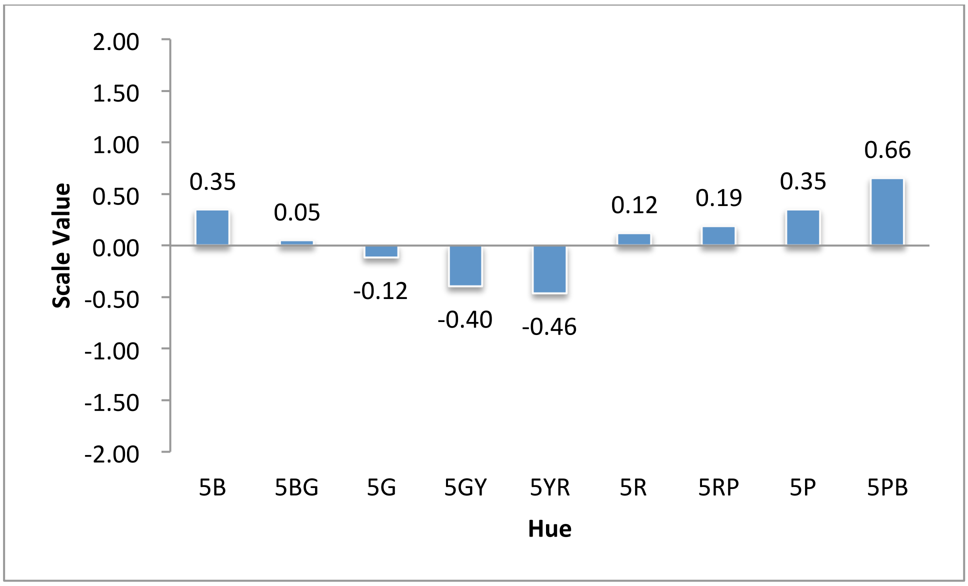


Figure 55. Scale values for blackness preference in V/C = 1/4 (all observers).

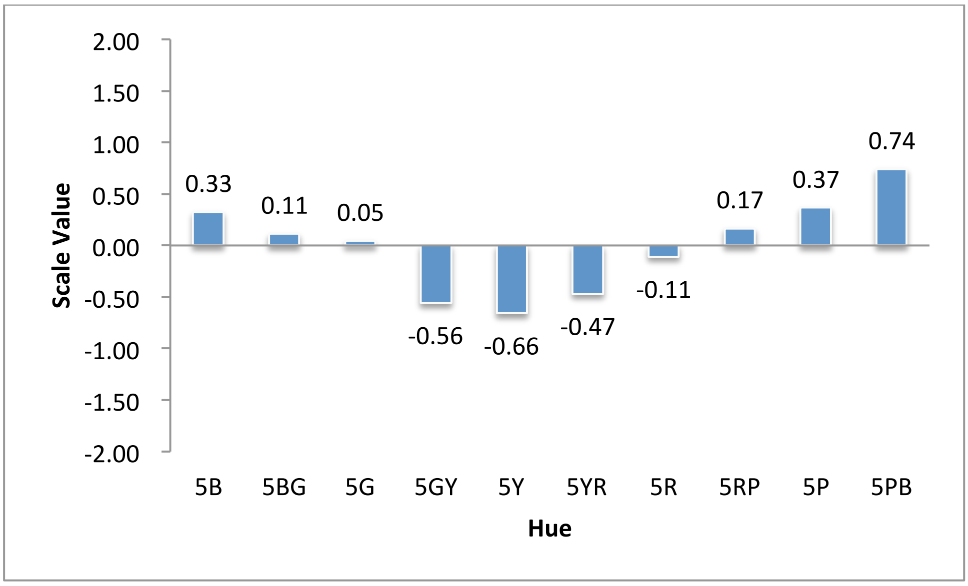


Figure 56. Scale values for blackness preference in V/C = 2/2 (all observers).

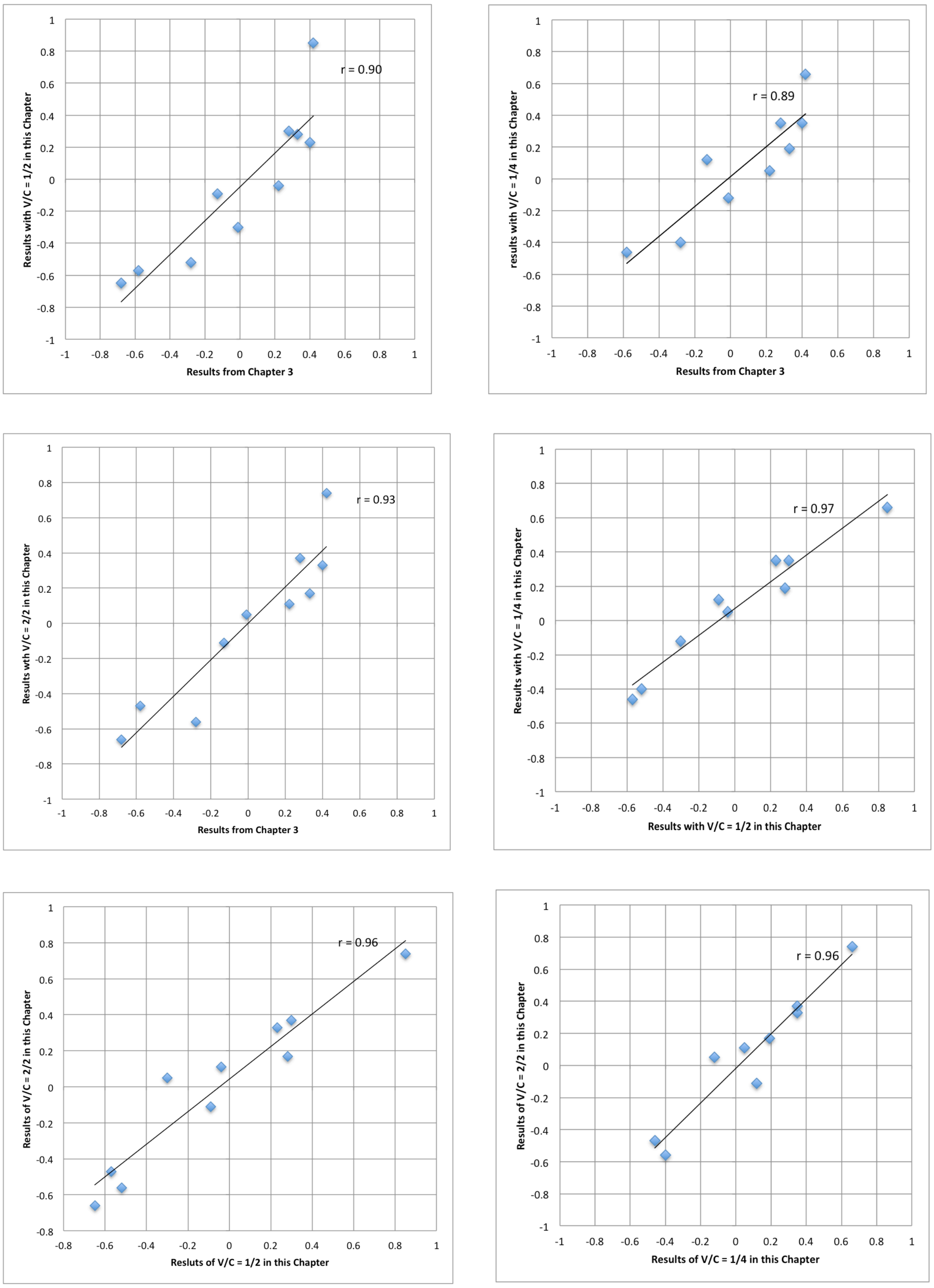


Figure 57. The correlation coefficient between the results in this chapter and Chapter 3.

In order to understand the difference between Chinese and UK observers, the preference scale values broken down by nationality are presented in Table 21. Figure 58 shows the scale values for V/C = 1/2. In Figure 58 it is evident that there is reasonable agreement between the UK and China groups with both showing a preference for bluish blacks and a dislike for yellowish blacks. However, the Chinese observers have a strong preference for bluish blacks that are redder (5PB, 5RP and 5P) and the UK observers seem to prefer bluish blacks that are greener (5PB, 5B and 5BG). This result is consistent with Section 3.3.1.

Table 21. Scale values of colour preference according to nationality (UK and Chinese).

Hue	V/C = 1/2		V/C = 1/4		V/C = 2/2	
	UK	Chinese	UK	Chinese	UK	Chinese
5B	0.27	0.20	0.53	0.27	0.43	0.26
5BG	-0.14	0.04	0.06	0.05	0.29	-0.02
5G	-0.37	-0.31	0.03	-0.24	0.24	-0.13
5GY	-0.45	-0.61	-0.48	-0.40	-0.42	-0.78
5Y	-0.52	-0.93	-	-	-0.66	-0.81
5YR	-1.04	-0.45	-0.64	-0.39	-0.73	-0.45
5R	-0.50	0.15	0.10	0.13	-0.41	0.04
5RP	-0.22	0.67	0.15	0.23	-0.02	0.33
5P	0.12	0.46	0.02	0.59	0.44	0.32
5PB	1.23	0.97	0.83	0.69	1.24	0.59

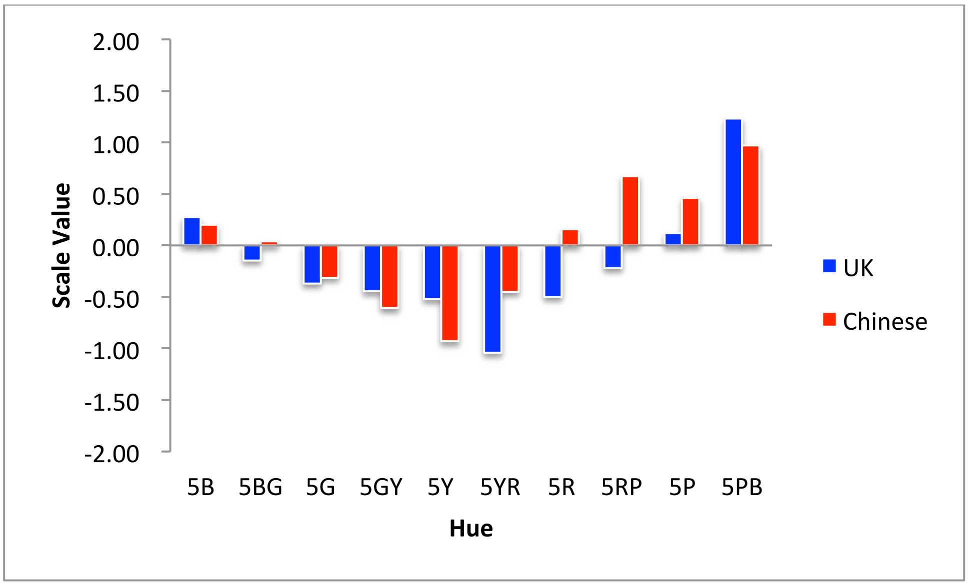


Figure 58. Scale values of colour preference according to hue in V/C = 1/2 section (UK vs. Chinese).

Figures 59 and Figure 60 illustrate the scale values for blackness preference according to nationality (UK and China) of colour samples which with V/C = 1/4 and V/C = 2/2. Again there is broad agreement between Chinese and UK observer responses. The ranking orders of colour samples for the two nationality groups are quite similar. The blacks with purple and blue tones always have higher scores for both nationality groups and the blacks with yellow tones less preferred. The observation that UK observers prefer greenish blue-blacks and Chinese observers prefer reddish blue-blacks that was noted in Chapter 3.3.1 and in this chapter for samples that were V/C = 1/2 is also evident in Figures 59 and 60 for samples that are lighter and more chromatic.

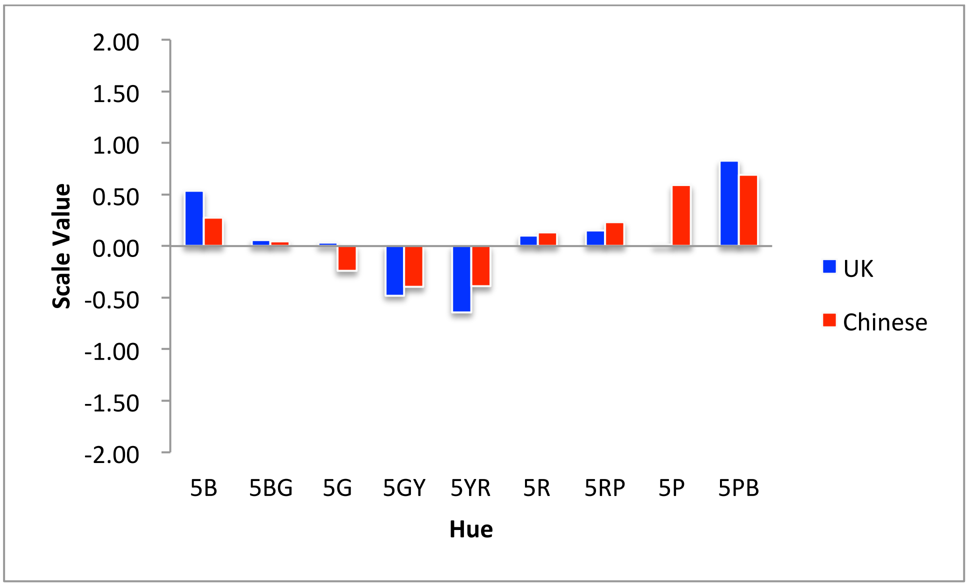


Figure 59. Scale values of colour preference according to hue in V/C = 1/4 section (UK vs. Chinese).

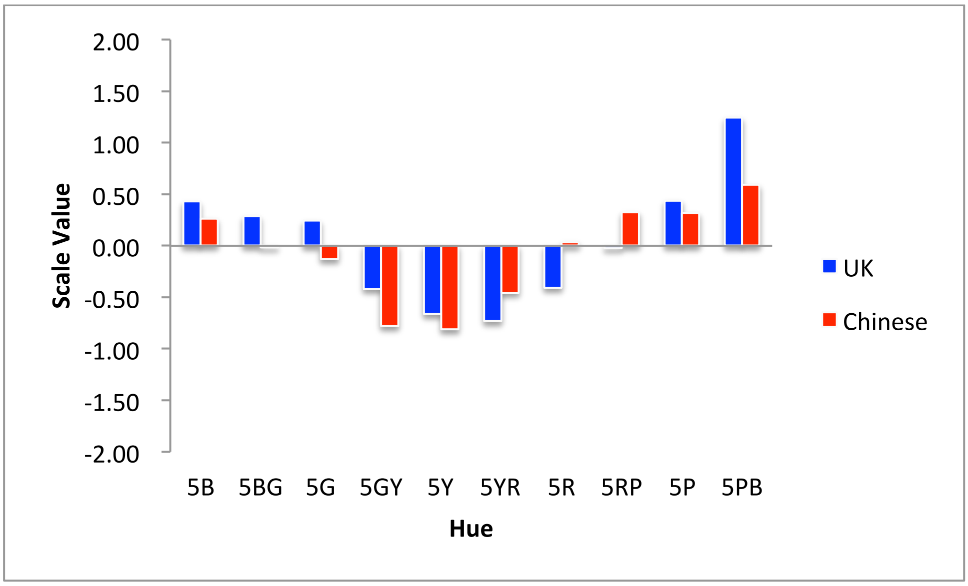


Figure 60. Scale values of colour preference according to hue in V/C = 2/2 section (UK vs. Chinese).

Table 22 shows the preference scale values for male and female observer groups. Figure 61 (V/C = 1/2) indicates that both male and female observers like purplish blacks and dislike yellowish blacks. However, female observers have a preference for reddish blue-blacks (5PB, 5RP and 5P) and male observers have a preference for greenish blue-blacks (5PB and 5GB). This, again, supports the results that were found in Section 3.3.1. Figures 62 and 63 show scale values for colour preference according to gender for colour samples with V/C = 1/4 and V/C = 2/2. These figures both show females have a strong preference for reddish blue-blacks (5P and 5RP) with males preferring greenish blue blacks (5R and 5BG).

Table 22. Scale values of colour preference according to gender (male and female).

	V/C = 1/2		**V/C = 1/4**		**V/C = 2/2**	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**
5B	0.77	0.01	0.56	0.23	0.08	0.51
5BG	0.38	-0.33	0.29	-0.10	0.23	0.04
5G	-0.05	-0.51	-0.16	-0.09	0.30	-0.13
5GY	-0.27	-0.85	-0.31	-0.46	-0.46	-0.71
5Y	-0.46	-0.82	-	-	-1.10	-0.60
5YR	-0.68	-0.62	-0.57	-0.47	-0.88	-0.33
5R	0.13	-0.26	-0.07	0.25	-0.48	0.09
5RP	-0.02	0.56	-0.27	0.49	-0.26	0.43
5P	0.25	0.38	0.10	0.53	0.07	0.68
5PB	1.47	0.94	0.99	0.71	0.92	0.86

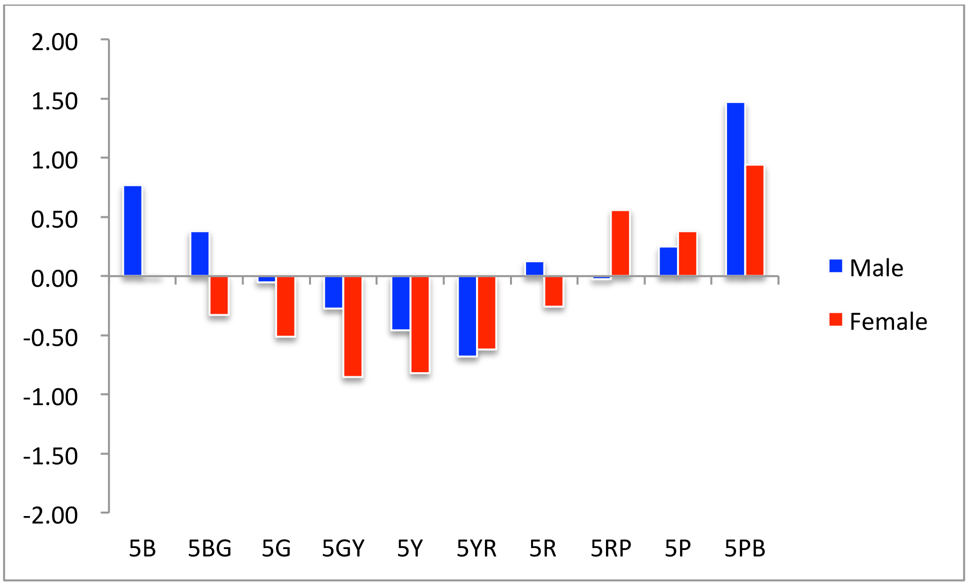


Figure 61. Scale values of colour preference according to hue in V/C = 1/2 section (male and female).

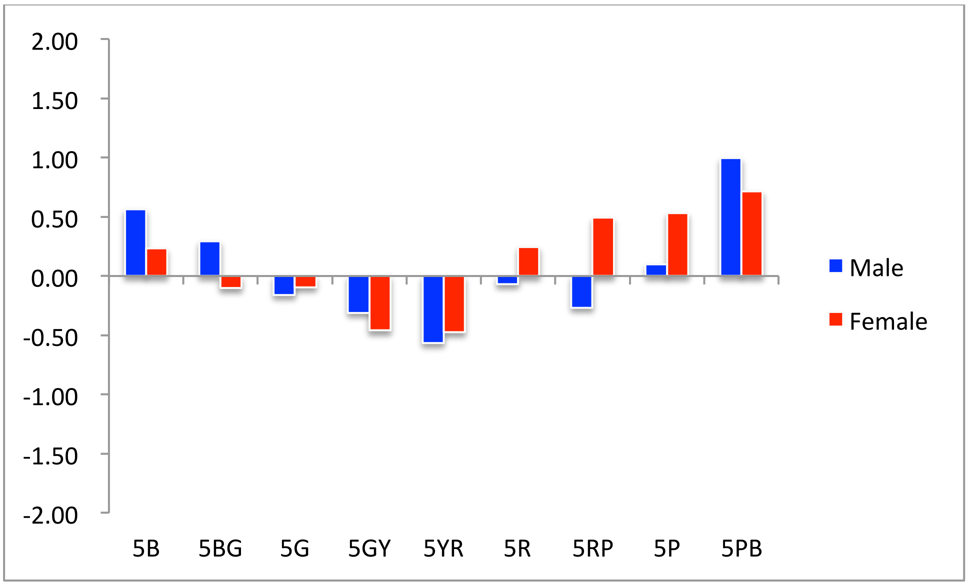


Figure 62. Scale values of colour preference according to hue in V/C = 1/4 section (male and female).

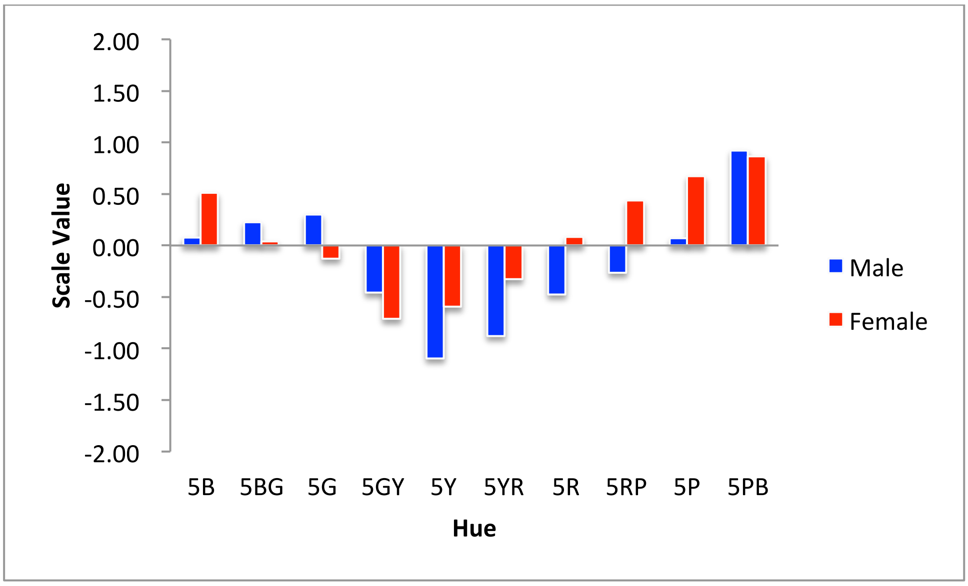


Figure 63. Scale values of colour preference according to hue in V/C = 2/2 section (male and female).

5.3.1.2. Blackness Preference According to Value/Chroma

In order to validate and extend the previous finding in Section 4.3.1, blackness preference according to value/chroma are explored in this section.

The scale values for colour preference scaling in different value/Chroma (V/C = 1/2, V/C = 1/4 and V/C =2/2) according to nationality and gender groups shown in Table 23. Figure 64 indicates the general order of preference for the colour samples viewed by different nationality groups (UK shown as blue bars and Chinese shown as red bars). UK observers preferred V/C = 2/2 (the lightest, least chromatic samples), but Chinese observers ranked V/C = 2/2 as the least prefer blacks. It indicated that V/C = 1/2 (the darkest, least chromatic samples) has a highest preference score for Chinese observers, but it has the lowest score in UK group respectively. So the positions of V/C = 1/2 and V/C = 2/2 are complete reversed. This result is consistent with the findings from Chapter 4.

Table 23. Scale values of colour preference according varied in value and chroma.

	UK	Chinese	Male	Female
V/C = 1/2	-0.13	0.07	0.18	-0.15
V/C = 1/4	-0.01	0.01	-0.08	0.05
V/C = 2/2	0.13	-0.07	-0.10	0.10

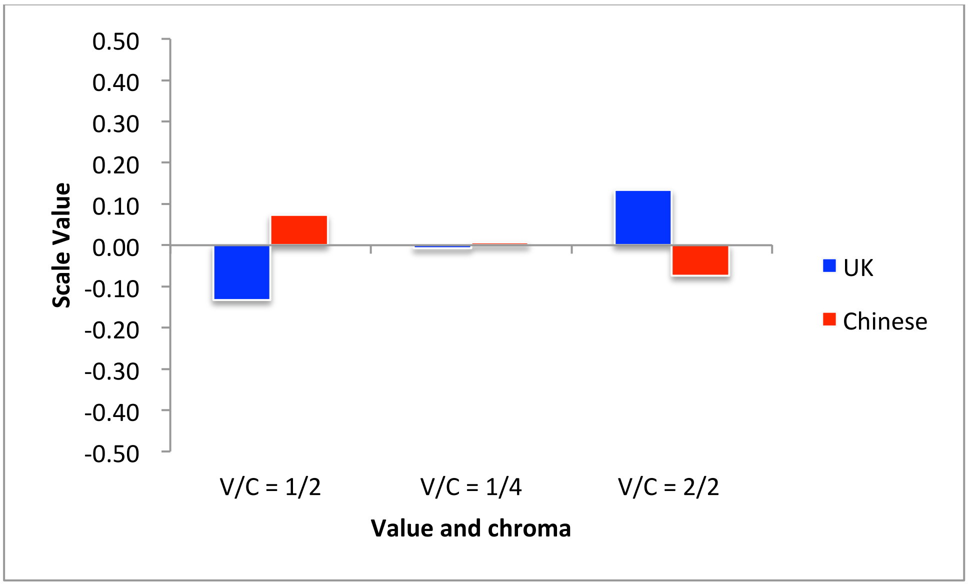


Figure 64. Scale values of colour preference according to UK (blue bars) and Chinese (red bars) observers in each hue.

Figure 65 shows scale values for blackness preference according to gender. For male observers there is a strong preference for V/C = 1/2 samples, irrespective of hue; the different trend is evident in the female data. This result is consistent with the findings of Section 4.3.1 which highlights differences between male and female responses; for example, females always gave the lowest scores to V/C = 1/2 (the darkest, least chromatic samples) whereas males dislike V/C = 2/2 (the lightest, least chromatic samples) in most hue groups.

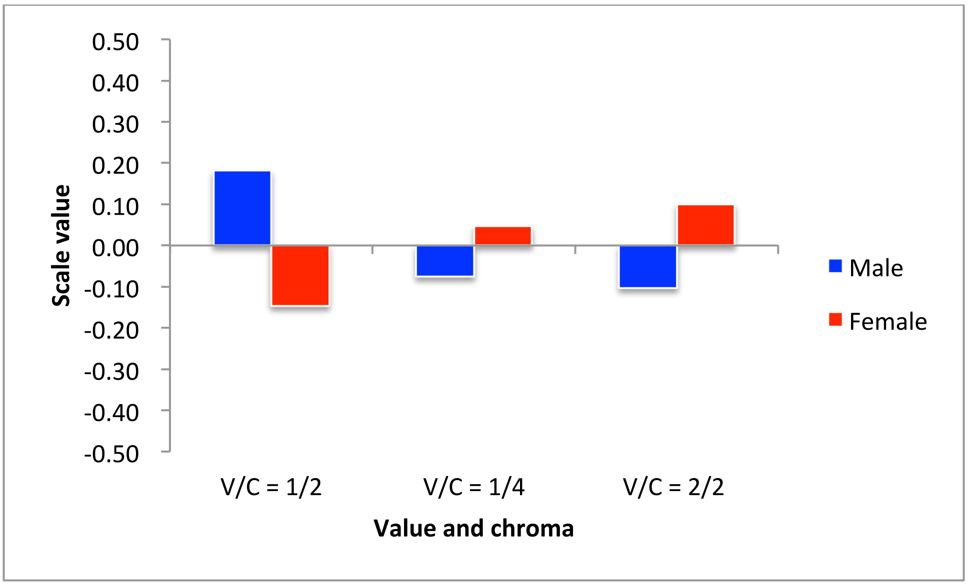


Figure 65. Scale values of colour preference according to male (blue bars) and female (red bars) observers in each hue.

5.3.1.3. Correlation Coefficients of Blackness Preference

Figure 66 and Figure 67 show correlation coefficients (r) for nationality and gender of blackness preference. The correlation coefficients are 0.75 for nationality and 0.65 for gender. This could indicate that colour preference is influenced by culture, and that gender has more influence on preference than nationality. The results are consistent with the findings of Section 3.3.1 and Section 4.3.1.

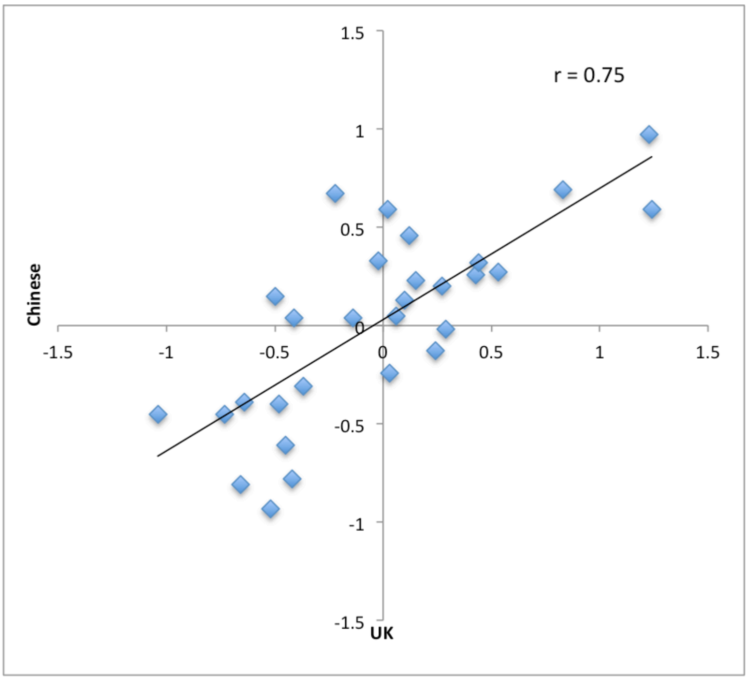


Figure 66. Correlation coefficient for colour preference scaling according to nationality (UK and Chinese).

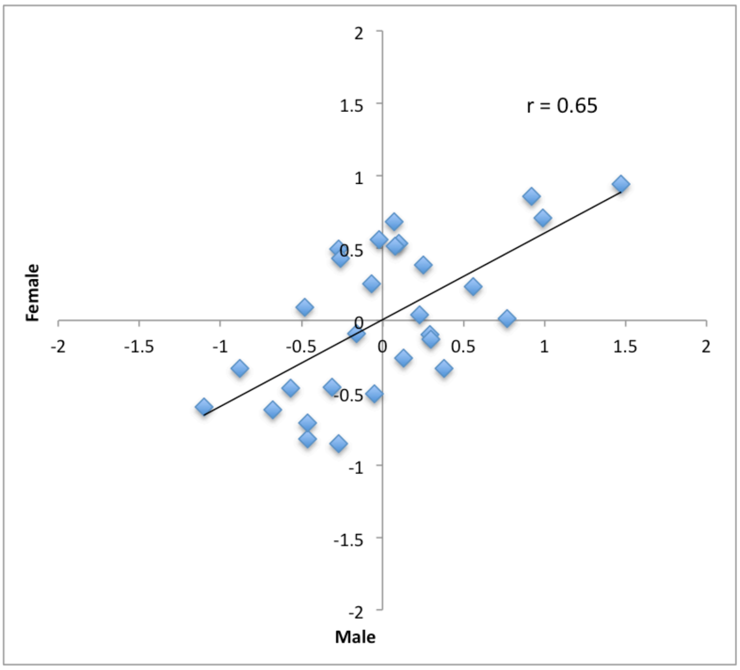


Figure 67. Correlation coefficient for colour preference according to gender (male and female).

5.3.2. Blackness Perception

Blackness perception (which colour sample is judged to be closest to a pure black) is discussed in this section. Firstly, the results of blackness perception according to hue are analysed; later, blackness perception according to values/chroma is explored.

5.3.2.1. Blackness Perception According to Hue

Table 24 shows the scale values of the colour sample of various hues according to blackness perception pooled over all observers. The colours are divided into ten hue groups, and there are then three samples (V/C = 1/2, V/C =1/4 and V/C =2/2) in each hue. Then Figures 68, 69 and 70 illustrate the scale values of colour samples which with V/C = 1/2, V/C = 1/4 and V/C = 2/2 respectively. All these three figures show that 5PB has the highest scale value (3.18 for V/C = 1/2, 0.21 for V/C = 1/4 and 0.22 for V/C = 2/2). This result indicates that people considered 5PB to be the nearest colour to pure black and samples 5R, 5Y and 5YR were considered to be the least black. Section 3.3.2 also indicated that 5PB was ranked in first place and samples 5R and 5Y were at the bottom in all chromatic colours when the effect of hue on blackness perception was explored.

Table 24. Scale values of blackness perception according to hue.

Hue	V/C = 1/2	V/C = 1/4	V/C = 2/2
5B	1.77	0.10	-0.48
5BG	2.02	-0.31	-0.16
5G	0.63	-0.49	-0.65
5GY	0.91	-0.92	-0.69
5Y	0.33	-	-0.88
5YR	0.04	-1.33	-0.90
5R	0.09	-0.91	-1.11
5RP	0.42	-0.52	-0.92
5P	0.80	-0.05	-0.40
5PB	3.18	0.21	0.22

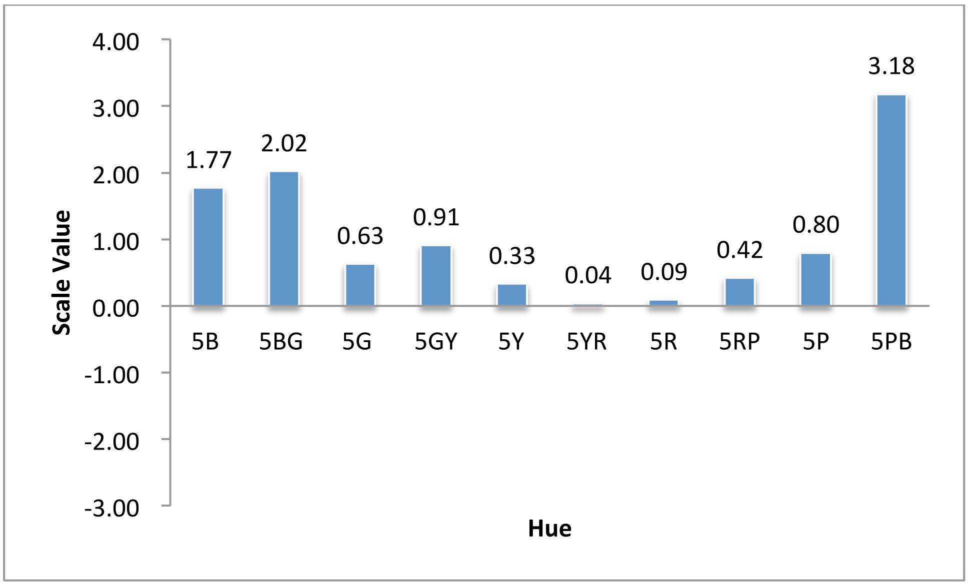


Figure 68. Scale values of blackness perception in V/C = 1/2 (all observers).

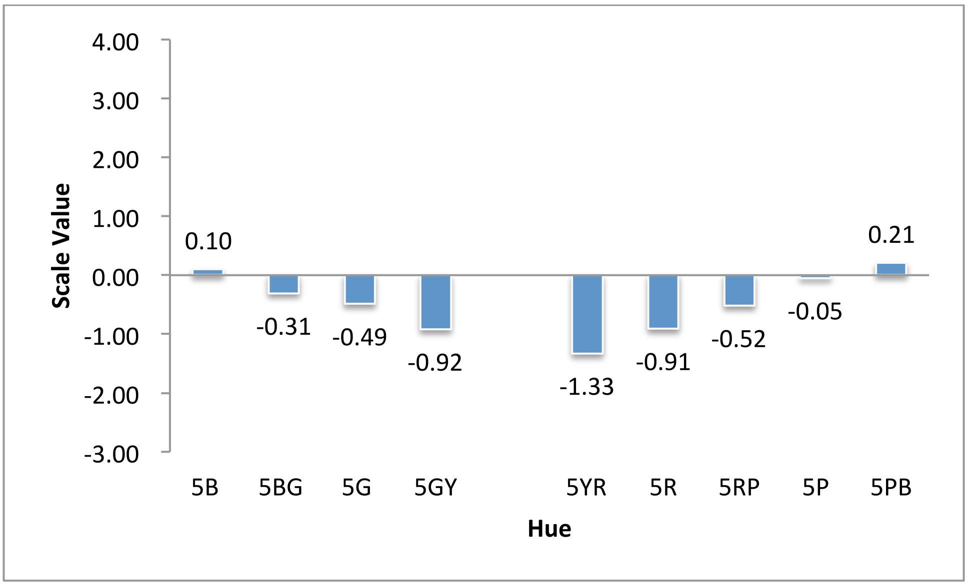


Figure 69. Scale values of blackness perception in V/C = 1/4 (all observers)

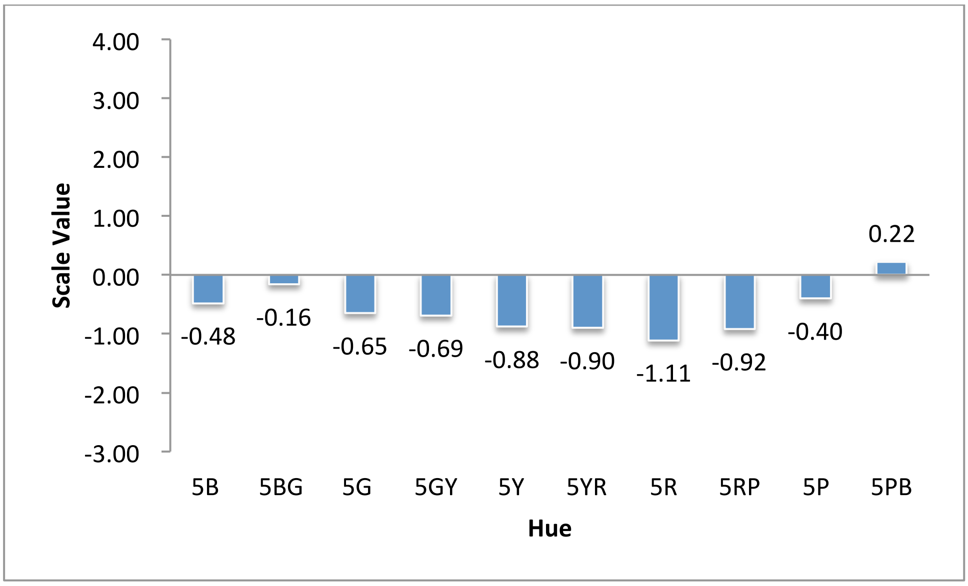


Figure 70. Scale values of blackness perception in V/C = 2/2 (all observers)

Table 25 shows the scale values of blackness perception according to different nationality of three samples (V/C = 1/2, V/C = 1/4 and V/C = 2/2) in each of the ten hues. Figure 71 illustrates the results of blackness perception of colour with value 1 and chroma 2 according to UK (blue bars) and Chinese (red bars). As Figure 71 indicates, the results of UK and Chinese observers are broadly correlated. Both UK and Chinese observers ranked 5PB first (consistent with Section 3.3.2). Figure 72 also shows 5PB ranked first place by both UK and Chinese observers in colour which with value 1 and chroma 4. However, for V/C = 1/4, though Chinese observers also thought that 5PB is closest to the pure black, UK observers gave 5P the highest score (Figure 72). 5Y, 5YR and 5R are consistently considered to the least black samples. Both Chinese and UK observers arranged these three colour samples at the bottom in all three value/chroma colour sets (V/C = 1/2, V/C = 1/4 and V/C = 2/2) (also consistent with Section 3.3.2).

Table 25. Scale values of blackness perception according to nationality (UK and Chinese).

Hue	V/C = 1/2		V/C = 1/4		V/C = 2/2	
	UK	Chinese	UK	Chinese	UK	Chinese
5B	1.94	2.08	0.05	0.17	-0.78	-0.35
5BG	2.05	2.28	-0.41	-0.29	-0.11	-0.19
5G	0.84	0.83	-0.21	-0.69	-0.83	-0.61
5GY	1.31	0.90	-1.05	-0.94	-1.11	-0.57
5Y	0.37	0.33	-	-	-1.55	-0.74
5YR	0.18	0.03	-2.18	-1.25	-1.70	-0.66
5R	0.13	0.06	-0.68	-1.43	-1.68	-1.08
5RP	1.09	0.38	-0.32	-0.88	-1.37	-0.83
5P	1.69	0.64	0.29	-0.33	-0.20	-0.54
5PB	3.32	3.16	0.70	0.04	0.23	0.45

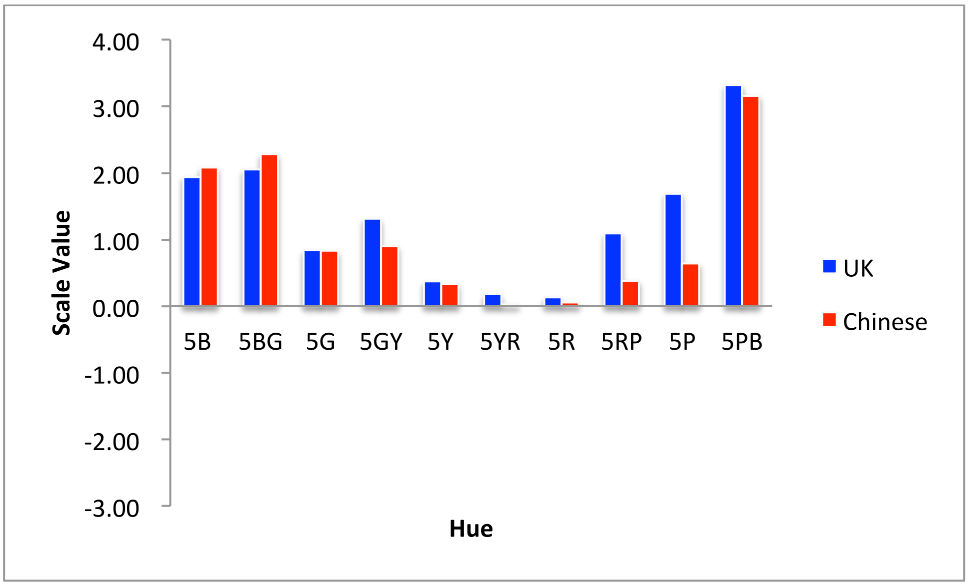


Figure 71. Scale values of blackness perception according to hue in V/C = 1/2 section (UK and Chinese).

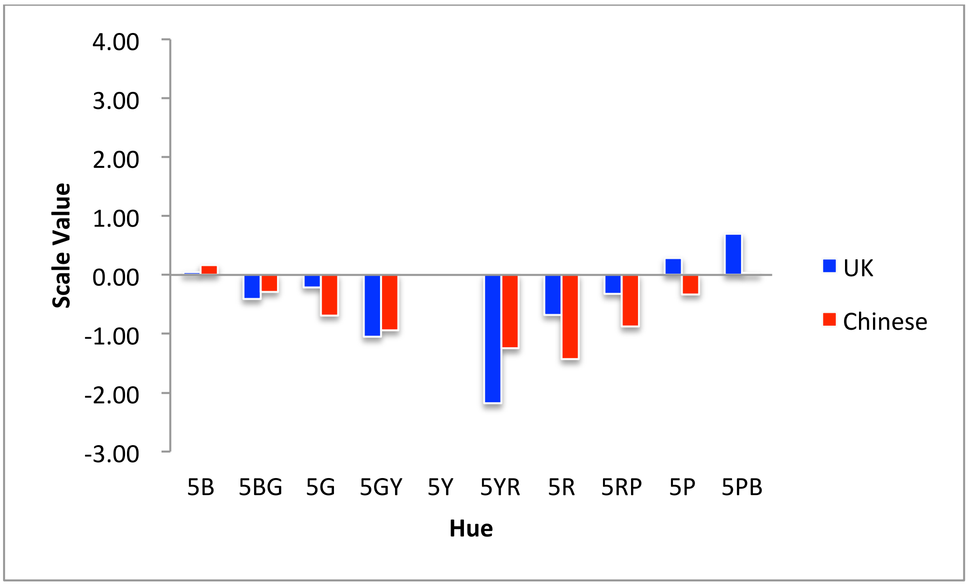


Figure 72. Scale values of blackness perception according to hue in V/C = 1/4 section (UK and Chinese).

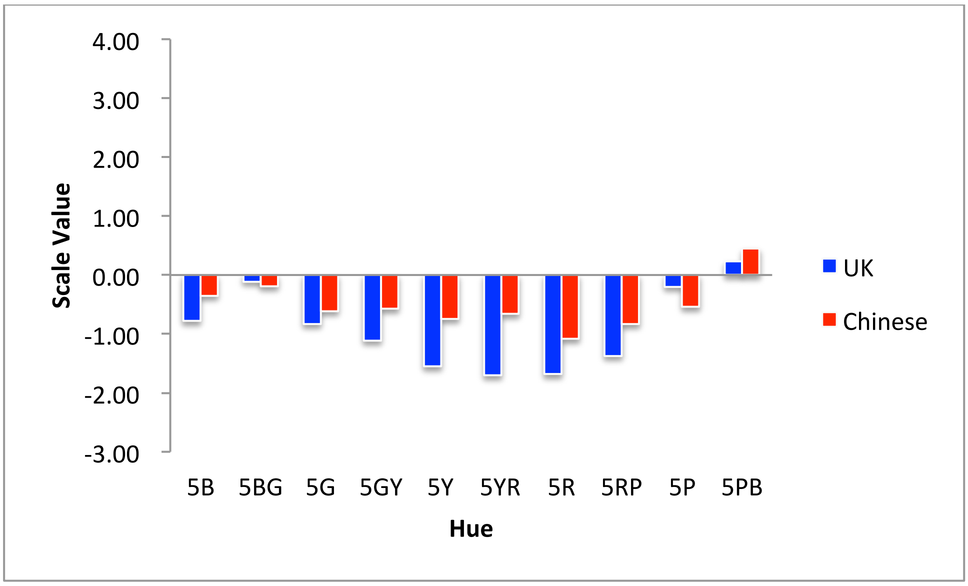


Figure 73. Scale values of blackness perception according to hue in V/C = 2/2 section (UK and Chinese).

Table 26 shows the scale values according to gender; Figure 74, Figure 75 and Figure 76 allow a direct comparison between male and female observers. These three figures indicate that there are little differences in blackness perception between male and female. The ranking orders of all colour samples in these three value/chroma sections are nearly same. Both male and female considered that the blacks contain purple and blue hues are close to the pure black and the yellowish blacks always are considered to be the least blacks. So in general, gender does not have a significant influence on blackness perception

Table 26. Scale values of blackness perception according to gender (male and female).

Hue	V/C = 1/2		V/C = 1/4		V/C = 2/2	
	Male	Female	Male	Female	Male	Female
5B	1.79	2.14	0.09	0.18	-0.48	-0.57
5BG	1.97	2.32	-0.38	-0.35	0.10	-0.34
5G	0.28	1.32	-0.43	-0.65	-0.97	-0.59
5GY	0.59	1.53	-0.95	-1.21	-0.87	-0.69
5Y	-0.09	0.55	-	-	-1.50	-0.80
5YR	0.21	0.02	-1.79	-1.46	-1.93	-0.68
5R	0.20	0.13	-0.69	-1.30	-1.50	-1.19
5RP	0.90	0.45	-0.38	-0.81	-1.01	-1.08
5P	1.74	0.64	0.58	-0.51	-0.08	-0.62
5PB	3.41	3.16	0.63	0.24	0.55	0.18

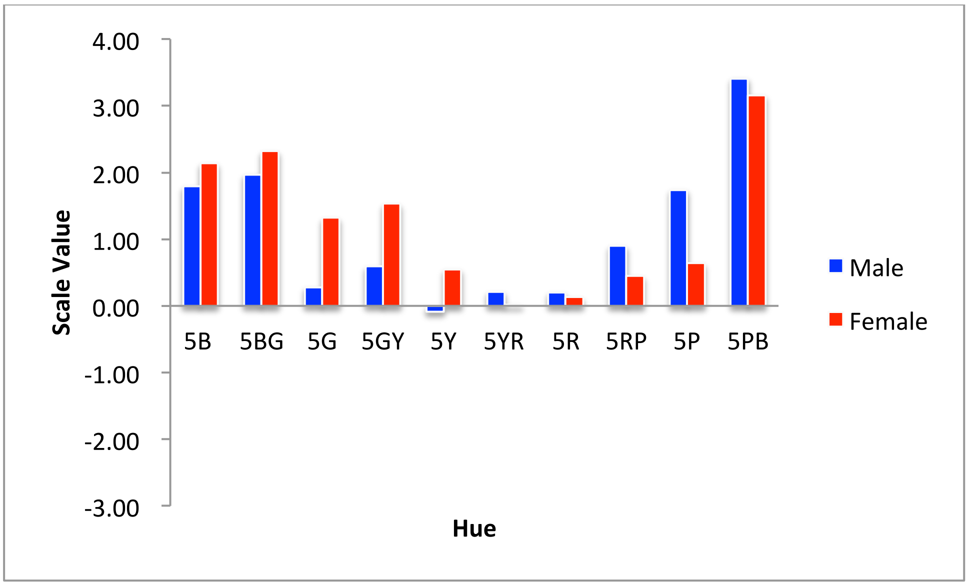


Figure 74. Scale values of blackness perception according to hue in V/C = 1/2 section (male and female).

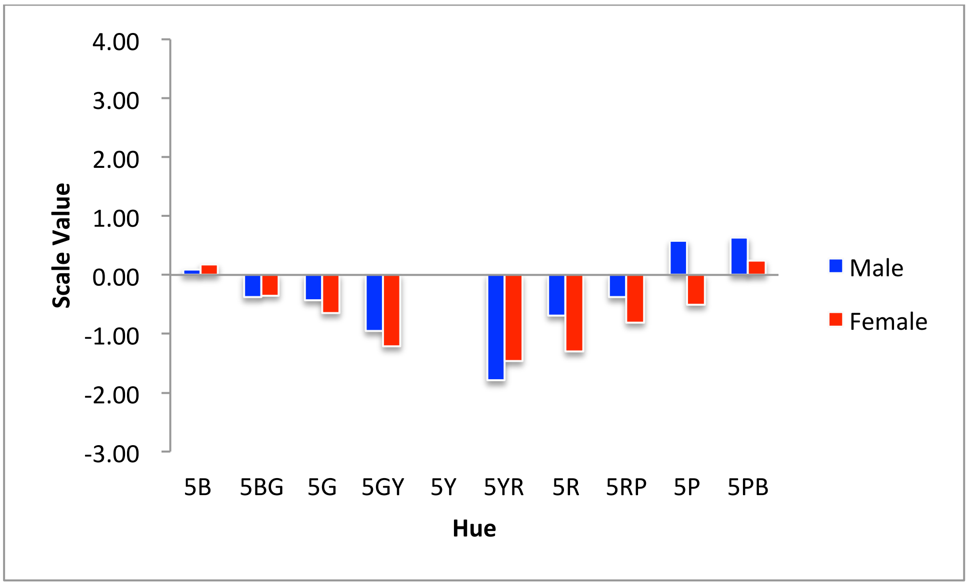


Figure 75. Scale values of blackness perception according to hue in V/C = 1/4 section (male and female).

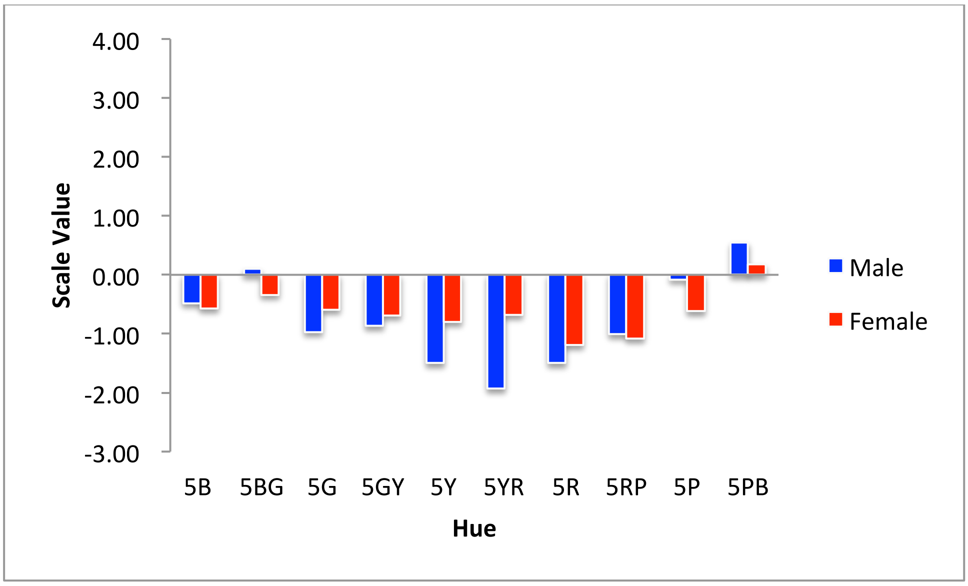


Figure 76. Scale values of blackness perception according to hue in V/C = 2/2 section (male and female).

5.3.2.2. Blackness Perception According to Value/Chroma

In this section the results of the blackness perception according to value/chroma are analysed. The scale values of each colour sample with different value and chroma in different nationality and gender groups are found in Table 27. It indicates that the colours with value 1 and chroma 2(darkest and least chromatic) are considered to be closest to the pure black in both nationality and gender groups. However the scale value of samples with value 1 and chroma 4 is similar to samples with value 2 and chroma 2. Chinese and female observers considered that V/C = 2/2 is blacker than V/C = 1/4. That means more colourful then less black. However UK and male observers considered that V/C = 1/4 is blacker than V/C = 2/2. That means that if the sample is lighter then, it is considered as less black.

Table 27. Blackness perception varied in value and chroma.

	UK	Chinese	Male	Female
V/C = 1/2	0.60	0.94	0.53	0.57
V/C = 1/4	-0.44	-0.49	-0.34	-0.56
V/C = 2/2	-0.62	-0.45	-0.63	-0.53

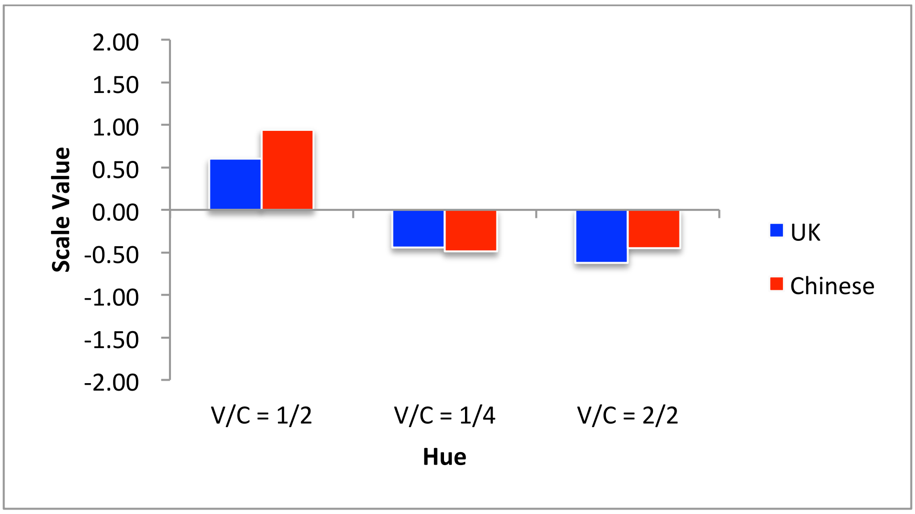


Figure 77. Blackness perception varied in value and chroma according to nationality.

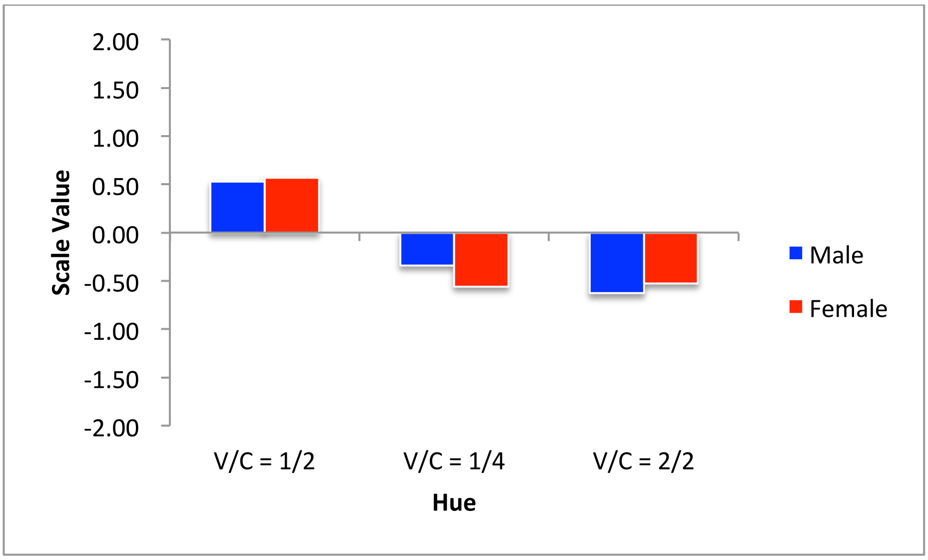
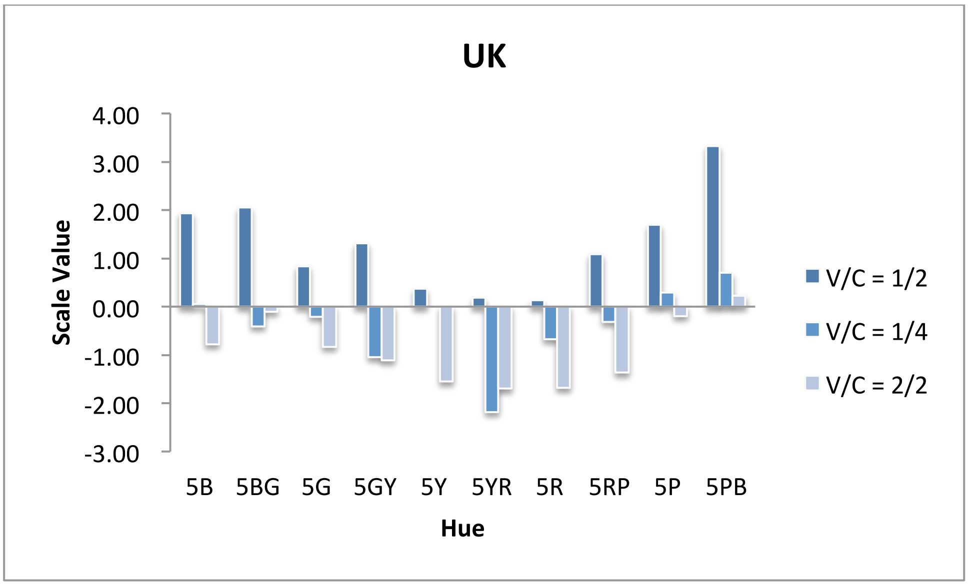


Figure 78. Blackness perception varied in value and chroma according to gender.

Figure 79 illustrates scale values for blackness perception in different nationality groups (blue bars for UK observers and red bars for Chinese observers) intuitively. As Figure 7 indicates that V/C = 1/2 is considered to be nearest to the pure black in both UK and Chinese groups of each ten hues. This result is expected and consistent with findings from Section 4.3.2. Then Chinese observers gave V/C = 2/2 the more positive the scale values in most hue groups except 5B and 5P. Chinese observers considered that V/C = 1/4 is blacker than V/C = 2/2 in 5B and 5P. That means the more colourful, the more blackness in 5P and 5B. This result was also indicated in Section 4.3.2.



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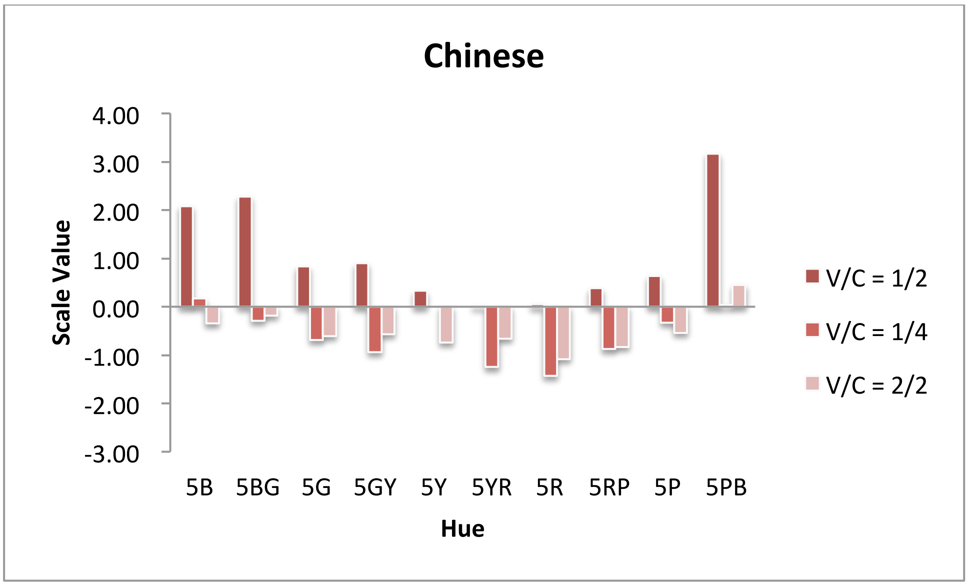
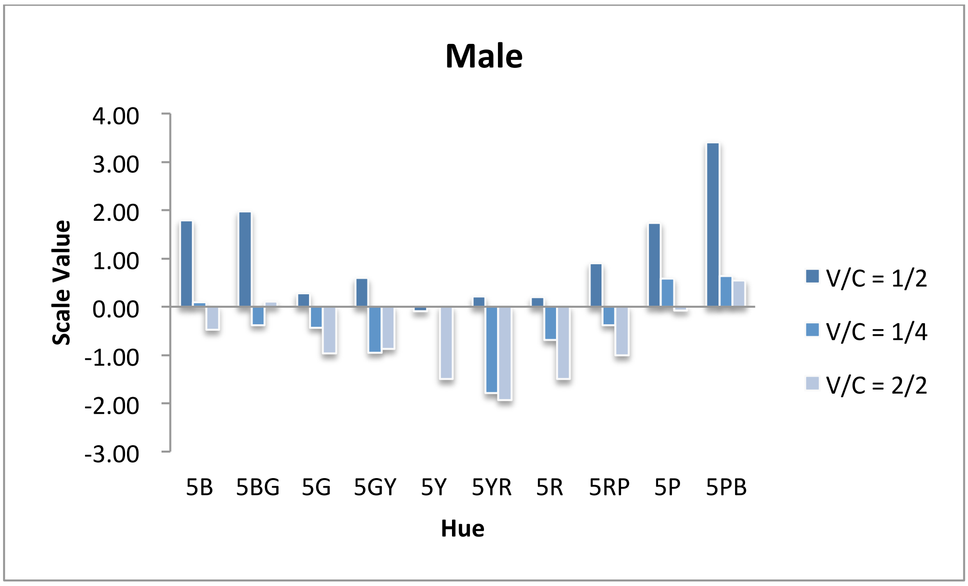


Figure 79. Scale values of colour perception according to UK (blue bars) and Chinese (red bars) observers in each hue.

Figure 80 indicated the scale values for colour perception according to gender in each hue, and there are no differences compared to when we considered the effect of nationality. The sequence of three Value/Chroma sections of different hues is nearly the same in both male and female group. V/C = 1/2 has the highest score in all hues. Then V/C = 1/4 ranked as second places in 5P, 5PB and 5B for both male and female groups. As the result also indicated in Section 4.3.4, V/C = 1/4 is blacker than V/C = 2/2 in 5B and 5P. It means more colourful, then more blackness when colours contain purple and blue tone. In other hue groups, the colours with value 2 and chroma 2 are considered blacker than colours with value 1 and chroma 4. It could suggest more colourful, then less black in these hue groups. This results display a satisfied consistence with section 4.3.4.



VS.

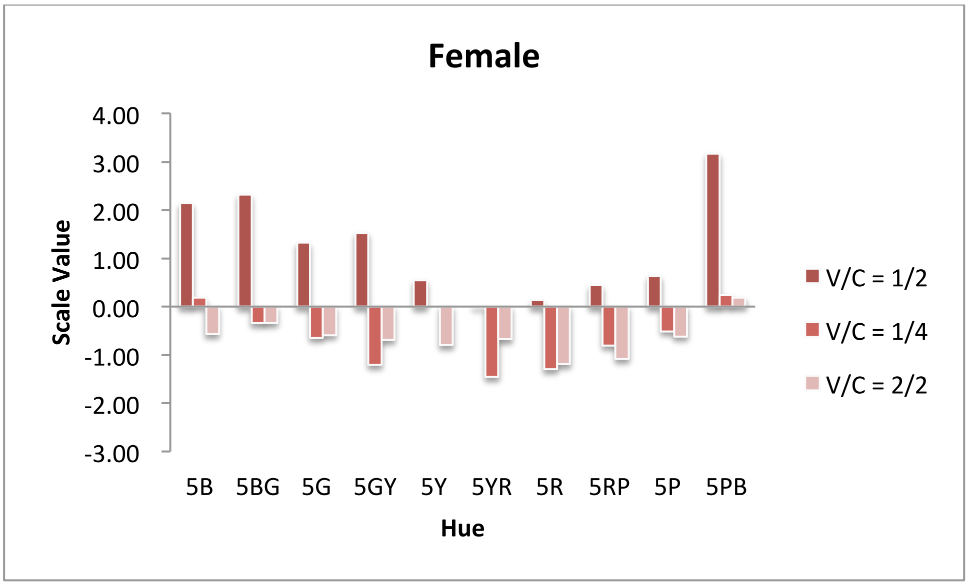


Figure 80. Scale values of colour perception according to male (blue bars) and female (red bars) observers in each hue.

5.3.2.3. Correlation Coefficients of Blackness Perception

Figure 81 and 82 indicate the correlation coefficient of perception for nationality is 0.91 and for gender is 0.88. These results could suggest that neither nationality nor gender have a significant influence on blackness perception. This result is consistent with the findings of Chapter 3 and Chapter 4.

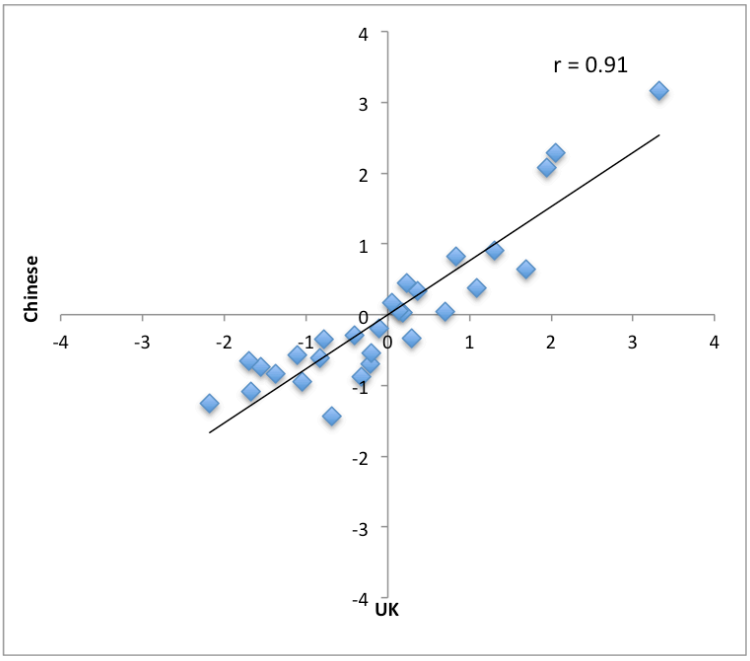


Figure 81. Correlation coefficient of analysis of colour samples closed to pure black by scaling according to nationality (UK and Chinese).

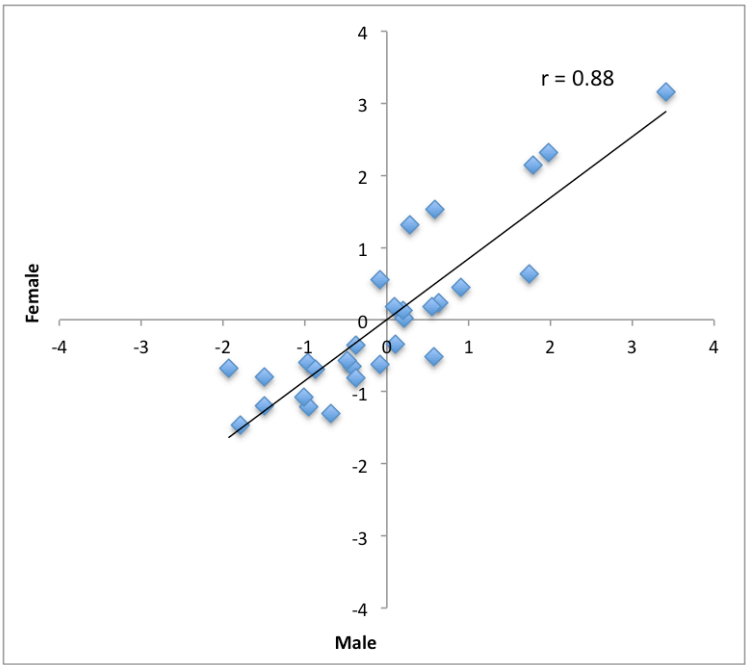


Figure 82. Correlation coefficient for colour samples closed to pure black by scaling according to gender (male and female).

5.4. Conclusion

The main purpose of this chapter was to validate and extend the previous investigation of blackness preference and perception with respect to differences in gender and nationality. The results indicate that neither nationality nor gender significantly influence blackness perception. When observers were asked about blackness perception, the correlation coefficients (r) for the nationality and gender comparisons were 0.91 and 0.88. However, there is some evidence that cultural factors (nationality and gender) could affect blackness preference. The correlation coefficient of blackness preference for the nationality comparison is 0.75 and for the gender comparison is 0.60. The results are broadly consistent with those from the two previous chapters.

According to hue, the results of blackness preference and blackness perception in this chapter are identical with the results of Chapter 3. For blackness preference, both these two experiments indicated that observers preferred bluish and purplish blacks and dislike yellowish blacks. For blackness perception, 5PB is considered to be closest to the pure black in chromatic colour samples in this chapter and Chapter 3.

According to Value/Chroma, the results of blackness perception in this chapter are close to results of Chapter 4. Chinese and female considered that more colourful less black, but the results for UK and male groups were contrary to it. However, the agreement was found in nationality and gender groups which is samples with value 1 and chroma 2 (the darkest, least chromatic samples) are considered to be closest to the pure blacks; then V/C = 1/4 is blacker than V/C = 2/2 in purplish and bluish blacks. That means more colourful, more blackness when colours contain purple and blue tone. When observers are asked about blackness preference, the results are also identified with Chapter 4, Observers from UK and female groups preferred V/C = 2/2 (lightness, less chromatic), but observers from Chinese and male groups preferred V/C = 1/2 (darkest, less chromatic).

For the results from these three chapters, in general, observers have common understanding what black it is. The darker and less chromatic colour samples are considered to be closet to pure black. However although blackness perception experiment revealed the blackest samples, these samples were not always ranked as the most preferred in blackness preference experiment. Furthermore, there are some differences between nationality and gender groups of blackness preference. These three experiments used the colour samples without particular context. In order to understand the relationship between blackness preference and perception findings, which were obtained in the absence of any particular context, and corresponding findings when there is a strong product context, a particular product will be chosen and presented with different blacks in the next chapter.

6. Application to Design

6.1. Introduction

The design of new products is important for many companies; the design process is a combination of art, science and technology and usually needs to consider the product's appearance, usability, physical ergonomics, marketing, brand development and sales (Morris, 2009). Therefore product design is a series of actions rather than engineering.

Forms, colour and their arrangement are the basic essentials of product design and colours play an important role (Wong, 1997). Indeed, colour is an important factor in our life, design and art and is arguably the primary factor of human vision. In reality, human emotions such as happiness, sadness, inspiration, relaxation, anger and forcing can all be produced by colour. Usually, combinations of different colours can create phenomenal results in meaning and request. So colour is deemed to have psychological and symbolic characteristics (Allegos, 1999) and designers can use colour to arouse positive emotions. Moreover, the use of black is particularly important in product design and this is why the impact of blackness preference and blackness perception on product design is explored in this research.

In the previous three chapters, blackness preference and blackness perception were explored for colour samples that were considered in an abstract sense; that is, without reference to a particular product. The effect of hue on blackness preference and perception has been considered and in this chapter the question of whether the findings can be applied to a more practical aspect of product design is investigated. A particular product is chosen and represented with blacks in different hues.

6.2. Experimental Methods

6.2.1. Definition of Stimuli

In order to understand the applicability of the results from this thesis to a practical example of product design the iPhone is used as a product model to represent colours. The iPhone is a smartphone designed and marketed by Apple Inc, The first-generation iPhone was released in 2007; in this research, the iPhone 4 (fourth-generation iPhone) is used as a particular product to present colours. The greatest difference between the iPhone 4 and its predecessors is the new design. The iPhone 4 is smaller (115 mm high, 59 mm wide, and 9.4 mm deep). Apple Inc always produces the iPhone in two colours: black and white. In this research, the black iPhone is used.

According to the previous three chapters, the colour which with value 1 and chroma 2 are considered to be closet to pure black. Therefore a series of iPhone images were constructed using 3-D software (3D Max) with colours which chosen from ten Munsell hues (R YR Y GY G BG B PB P RP) with value 1 and chroma 2 and two neutral samples with value 1 and chroma 2 and value 0 and chroma 0. So there are 12 stimuli in this experiment (Figure 83). RGB values were obtained for each of the 12 samples and these were used to display the colours in iPhone model on a CRT computer display. The RGB values were shown in Table 28.

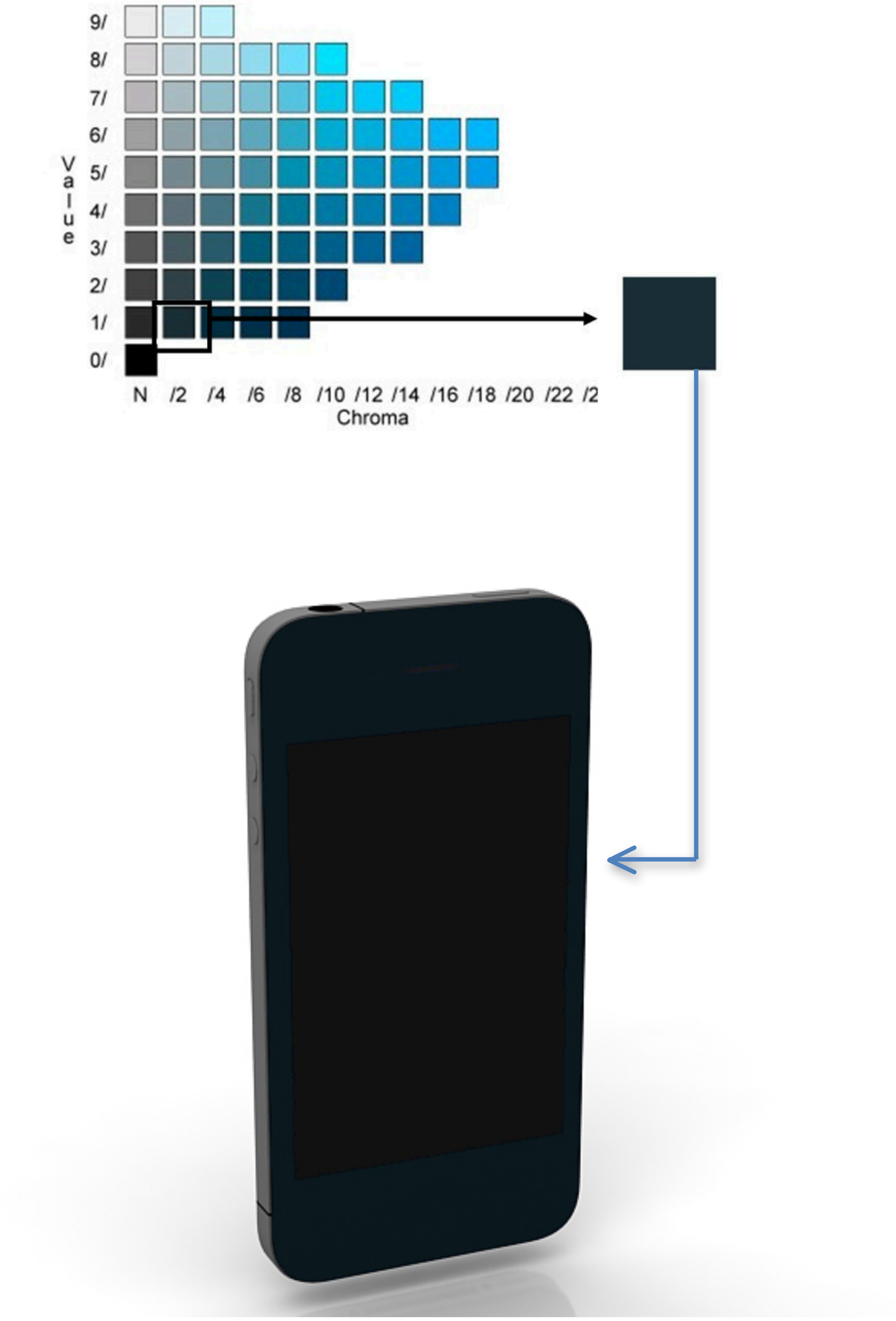


Figure 83. An example of the iPhone image showing the position of the Munsell colour system used in the experiment.

Table 28. RGB values of samples used in the experiment.

Hue	Stimuli	RGB		Hue	Stimuli	RGB
N0		[R = 0 G = 0 B = 0]		**N1**		[R = 34 G = 34 B = 34]
5B		[R = 19 G = 36 B = 43]		**5BG**		[R = 20 G = 36 B = 37]
5G		[R = 24 G = 36 B = 31]		**5GY**		[R = 31 G = 35 B = 24]
5Y		[R = 40 G = 33 B = 16]		**5YR**		[R = 47 G = 30 B = 23]
5R		[R = 48 G = 28 B = 32]		**5RP**		[R = 45 G = 28 B = 40]
5P		[R = 41 G = 30 B = 45]		**5PB**		[R = 28 G = 34 B = 46]

6.2.2. Observers

In this study 20 observers took part; 10 Chinese people and 10 UK people of whom 12 were female (6 Chinese and 6 UK) and 8 were male (4 Chinese and 4 UK). All of these observers passed the Ishihara Test for colour blindness before participating in the experiment and were therefore assumed to have normal colour vision.

6.2.3. Experimental Procedure

As in Chapter 3, a complete pair-wise comparison procedure was used in this experiment. That is, the samples were presented in pairs and the observer was asked to choose one of a pair over the other according to the criterion – phase 1 (blackness preference) and phase 2 (blackness perception). Therefore for the 12 samples there were 66 paired comparisons meaning that there were 1320 (66 pairs × 20 observers) total observations for each of the two phases.

The samples were presented to the observers on a computer screen GUI (written in MATLAB) on a neutral grey (R= 133, G= 133, B=133) background in pairs (see Figure 84). The experiment was carried out in two phases. First, the observers were asked to choose which one (of a pair) they prefer (refer to this as blackness preference); second, they were asked to choose which one was the closest to a pure black (denote this as blackness perception). All observers were tested in the same environment (CRT monitor at a distance of 90 cm, a visual field size of 15°, and using the same computer in a dark room). Observers were asked to indicate their choice by pressing the button below the colour samples (see Figure 84) after which the next pair of colour samples would be displayed.

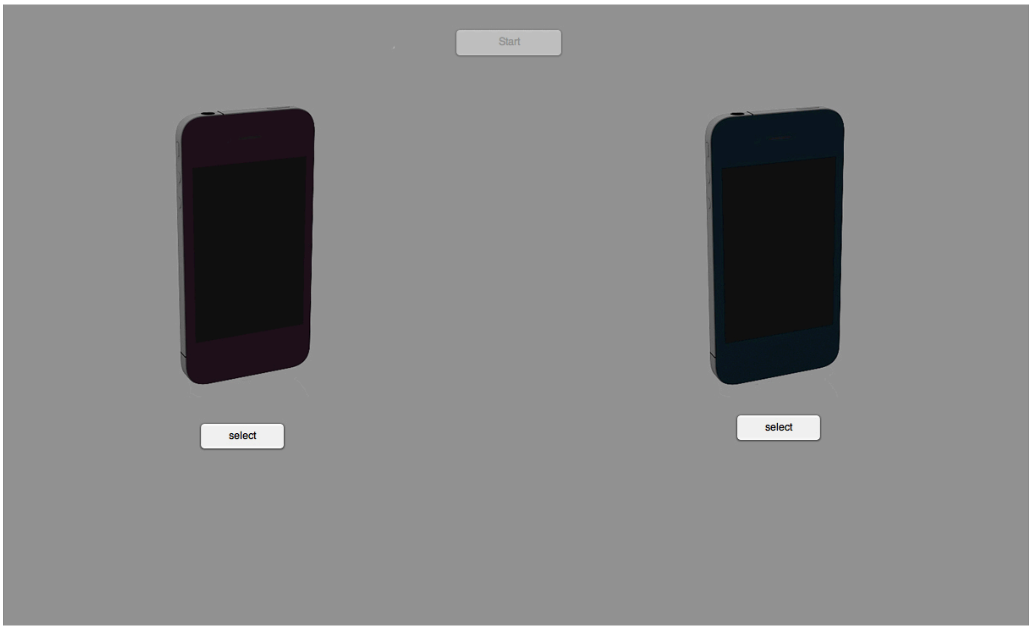


Figure 84. The GUI used in the experiment.

6.3. Data and Results

6.3.1. Blackness Preference

The experiment was conducted in two phases which are blackness preference and blackness perception. In this section the results of the blackness preference phase are analysed.

Table 29 displays the scale values of samples according to the blackness preference. The positive scale values are most preferred and negative values being least preferred. Figure 85 shows the scale values of colour samples more intuitively. As Figure 85 shows the iPhone images with 5PB, 5B and 5RP have the highest scores in all samples and Y, GY and YR are ranked as the least preferred. This result suggests that, on average, observers are preferred the iPhone image with purplish and bluish black and dislike the iPhone image with yellowish blacks. However, the iPhone images with two neutral samples are not ranked very higher. These results could suggest observers have strong preference with bluish and purplish black iPhone image.

Table 29. Scale values for colour preference pooled over all observers.

Sample	Scale Value
N0	0.04
N1	-0.03
5B	0.31
5BG	0.15
5G	0.04
5GY	-0.47
5Y	-1.08
5YR	-0.35
5R	0.11
5RP	0.36
5P	0.35
5PB	0.61

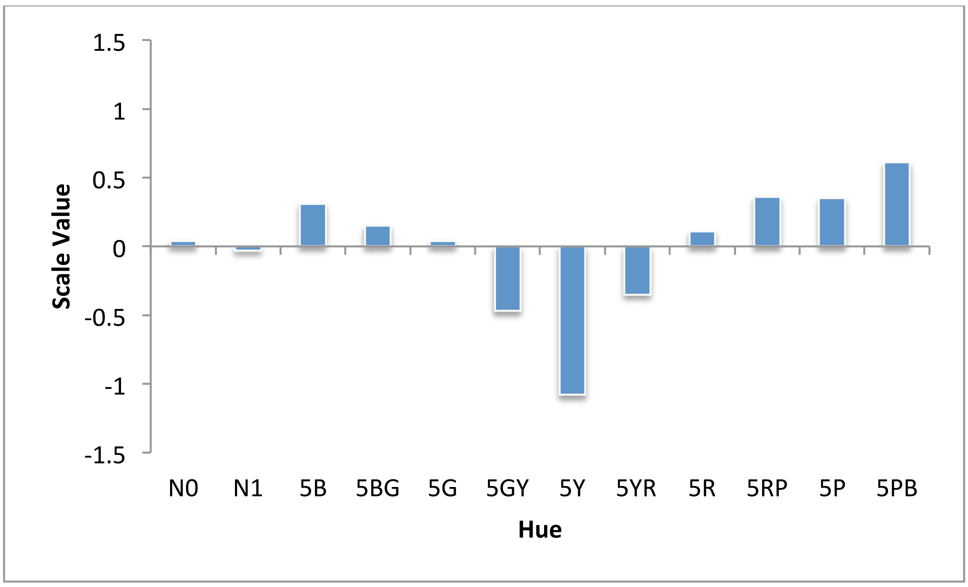


Figure 85. Scale values for colour preference pooled over all observers.

Compared with the experiment that only used the colour sample without a particular product, the results of these two experiments have the strong agreement. Figure 86 shows the scale values for blackness preference of colour samples (Chapter 3) and colour image of the iPhone (this chapter). As Figure 86 shows, the new results are very similar to those obtained in Chapter 3 using the colours in an abstract sense (the correlation coefficient r = 0.92). Either samples with a particular product or not, the purplish and bluish blacks are most preferred and yellowish blacks are least preferred pooled over all observers.

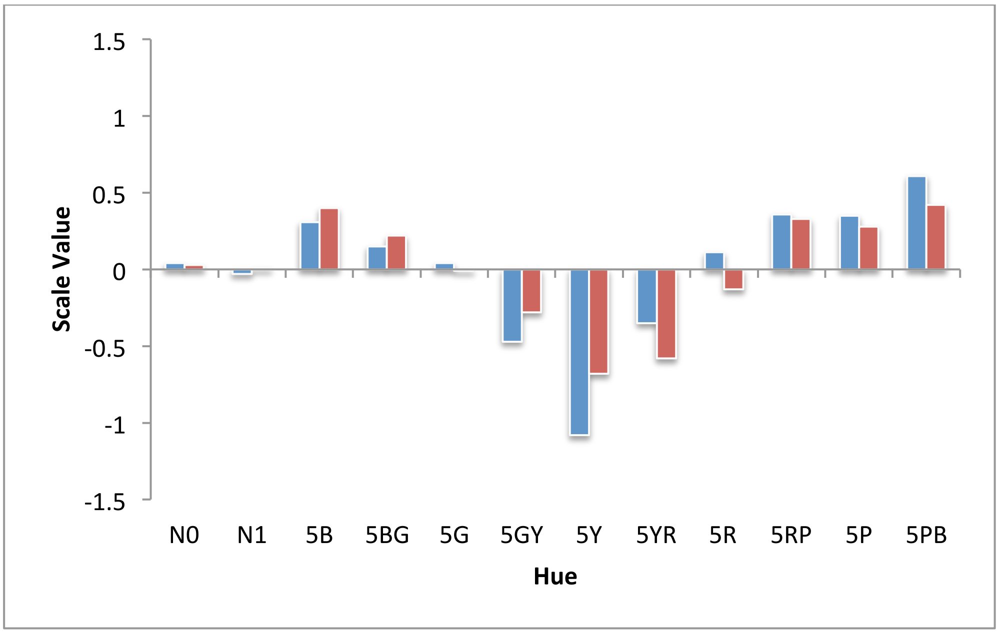


Figure 86. Colour preference scale values for colour samples viewed abstractly (blue bars) and for the iPhone image (red bars) pooled over all observers (note that r = 0.92).

Table 30 and Figure 87 show the scale values for colour preference according to nationality. The greater and more positive the scale values means that sample was judged more preferred. It shows that the iPhone image with 5PB has high score (5PB = 0.98 for UK; 5PB = 0.44 for Chinese) and 5Y, 5YR and 5GY are least preferred (5Y = -1.41, 5YR = -0.27 and 5GY = -0.53 for UK; 5Y = -1.48, 5YR = -0.58 and 5GY = -0.48 for Chinese) in both nationality groups. This result indicates that both Chinese and UK observers dislike yellowish blacks and like purplish and bluish blacks.

Though there is general agreement between UK and Chinese observers there are also some differences. Compared with UK observers, the iPhone image of 5P, 5RP, 5PB and 5R are ranked at first four places in Chinese groups (5P = 0.98, 5RP = 0.93, 5PB = 0.44 and 5R = 0.42). But UK observers ranked the iPhone image of 5PB, 5B, 5G and 5BG as the most preferred (5PB = 0.98, 5B = 0.59, 5G = 0.47 and 5BG = 0.36). These results could suggest that both UK and Chinese groups like the iPhone image of bluish black, but there is a tendency for Chinese observers to slightly prefer the iPhone image of reddish blue-blacks and UK observers prefer the iPhone image of greenish blue-blacks. This is the same tendency that was noted in Chapter 3 which used the abstract colour samples.

Table 30. Scale values for colour preference scaling according to nationality (UK vs. Chinese).

Sample	UK	Chinese
N0	-0.09	0.05
N1	0.04	-0.05
5B	0.59	0.05
5BG	0.36	-0.05
5G	0.47	-0.23
5GY	-0.53	-0.48
5Y	-1.41	-1.48
5YR	-0.27	-0.58
5R	-0.22	0.42
5RP	-0.03	0.93
5P	0.13	0.98
5PB	0.98	0.44

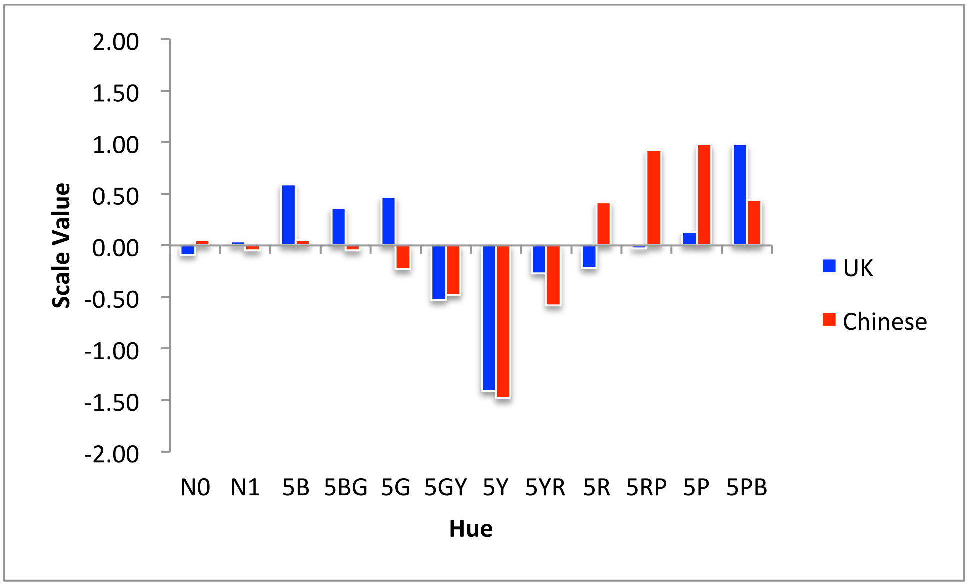
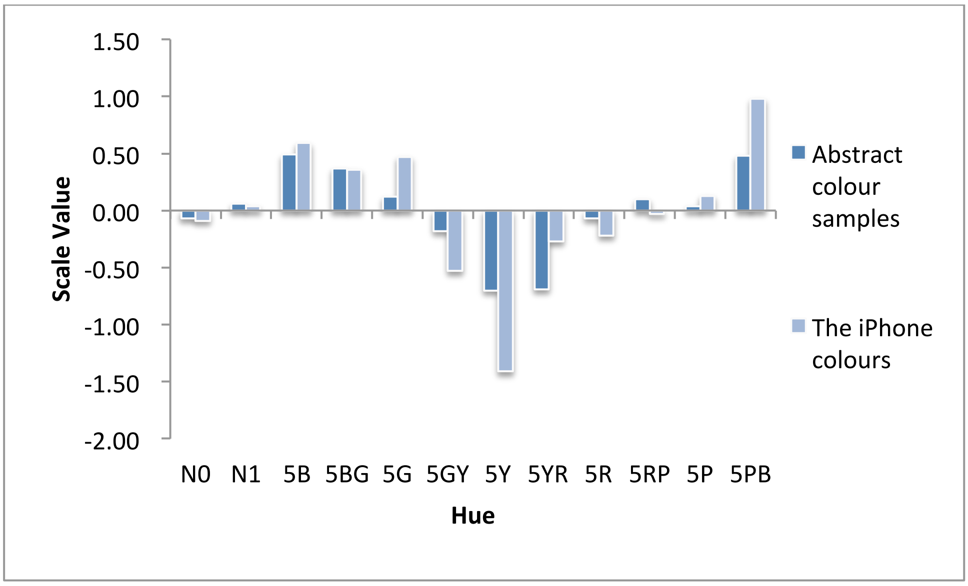
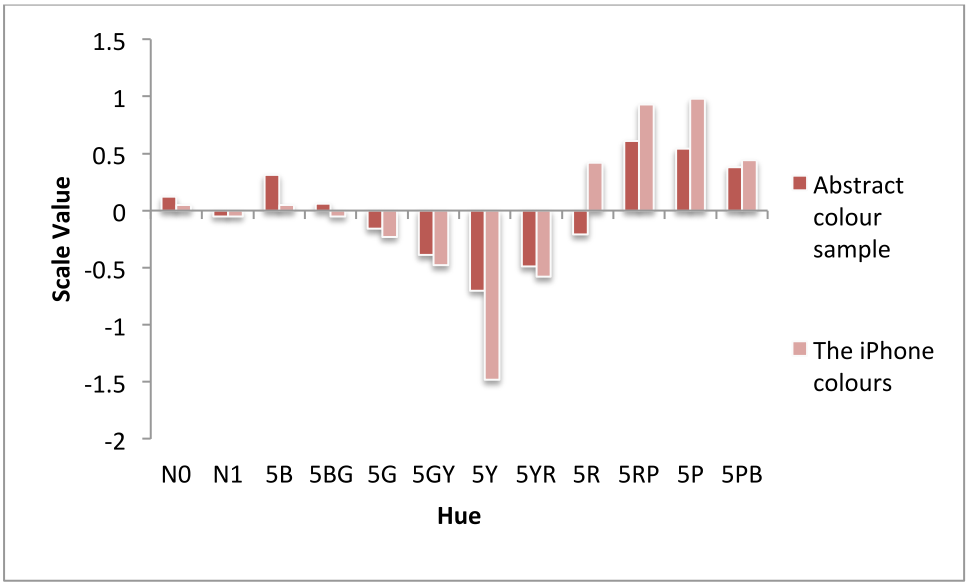


Figure 87. Scale values for colour preference scaling according to nationality (UK vs. Chinese).

Figure 88 shows the direct comparison of colour preference according to nationality between the abstract colour samples and the iPhone image. UK observers always ranked greenish blue-blacks in the top places and Chinese observers always gave the reddish blue-blacks high scores in both this experiment and in Chapter 3. The black samples which contain yellow tone always are considered are least preferred by both groups. The correlation coefficient between abstract and iPhone scale values was 0.87 and 0.89 for UK and Chinese observers respectively.



(a)



(b)

Figure 88. Colour preference scale values for(a) UK observers (dark blue for abstract colours and light blue for iPhone colours) and (b) Chinese observers (dark red for abstract colours and light red for iPhone colours).

Table 31 and Figure 89 indicate the general order of preference of samples in different gender groups. As indicated in Figure 89, almost all people in these two groups preferred the iPhone image of purplish and bluish black and disliked the iPhone image of yellowish black. The iPhone image that with 5PB has high scale values (5PB = 0.98 for male; 5PB = 0.48 for female); then the iPhone image of 5GY, 5YR and 5Y are at the bottom of all samples (5GY = -0.41, 5YR = -0.47, 5Y = -1.88 for male, 5GY = -0.76, 5YR = -0.65, 5Y = -1.46 for female) in both male and female groups.

Despite the common agreement between male and female, they also have some differences of opinions. Male group seems prefer the iPhone image of greenish blue-blacks and female group has clear preference for reddish blue-blacks. Female ranked 5P, 5RP and 5PB in the first three places (5P = 1.35, 5RP = 0.90 and 5PB = 0.48), but 5B, 5BG and 5G are the favourite colours of male (5B = 1.09, 5BG = 0.40 and 5G = 0.47).

Table 31. Scale values for colour preference scaling according to gender (male vs. female).

Sample	Male	Female
N0	0.01	0.08
N1	-0.03	0.06
5B	1.09	0.10
5BG	0.40	0.01
5G	0.47	-0.15
5GY	-0.41	-0.76
5Y	-1.88	-1.46
5YR	-0.47	-0.65
5R	-0.07	0.24
5RP	-0.12	0.90
5P	0.01	1.35
5PB	0.98	0.48

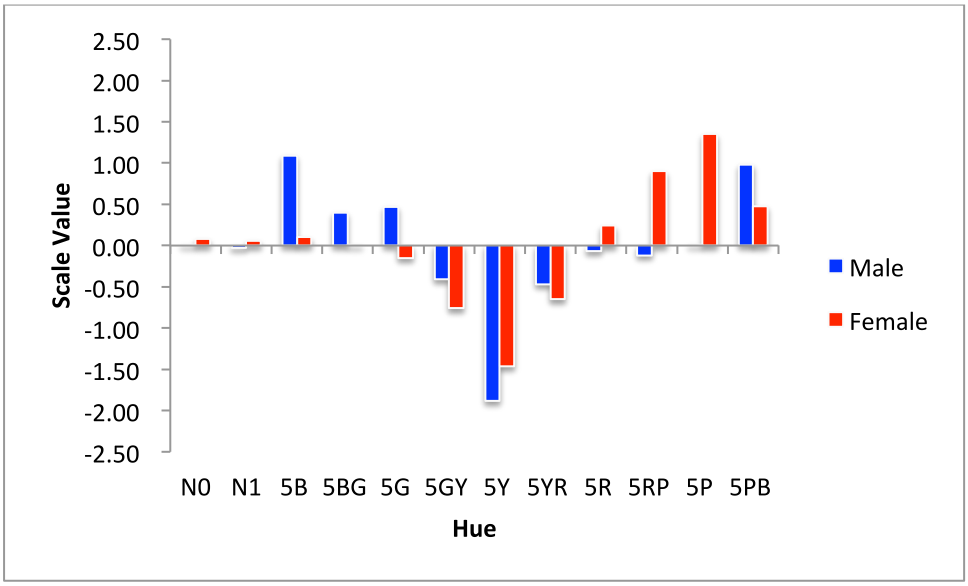
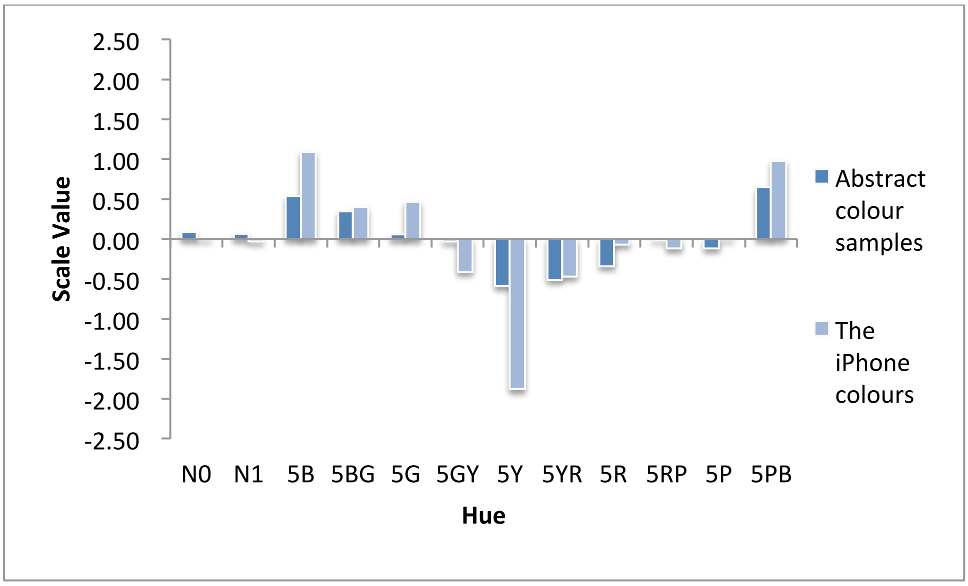
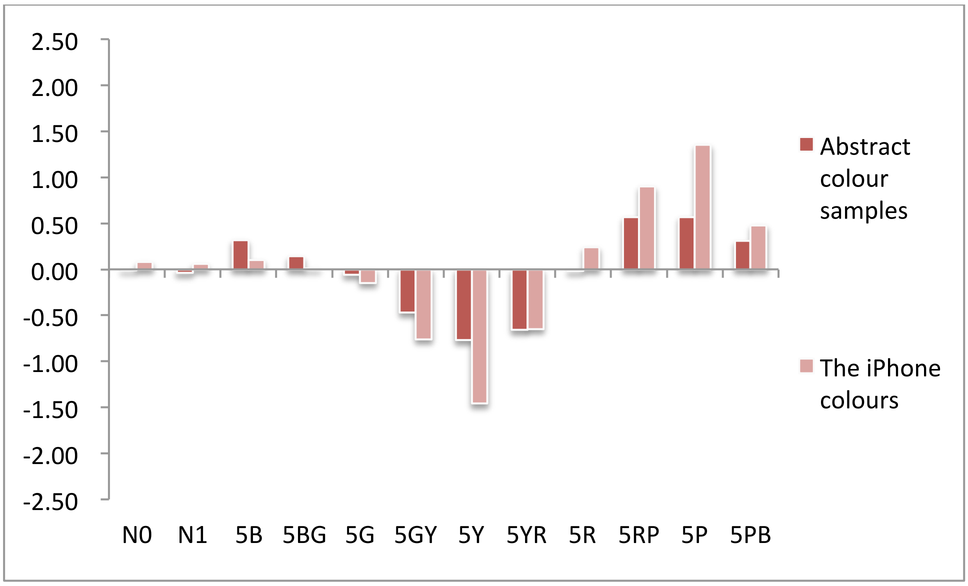


Figure 89. Scale values for colour preference scaling according to gender (male vs. female).

As the Figure 90 indicated, the results of colour preference according to gender in this experiment are consistent with previous experiment which only used colour samples without particular product. The results in these two experiments both indicated that male preferred the greenish blue blacks and female preferred the reddish blue blacks. The correlation coefficient between abstract and iPhone scale values was 0.87 and 0.94 for male and female observers respectively.



(a)



(b)

Figure 90. Colour preference scale values for (a) male observers (dark blue for abstract colours and light blue for iPhone colours) and (b) female observers (dark red for abstract colours and light red for iPhone colours).

Figures 91 and 92 indicate the correlation coefficient for nationality and gender. The correlation coefficient for the nationality comparison is 0.63 and for gender is 0.59. It could suggest that there are differences between nationality and gender.

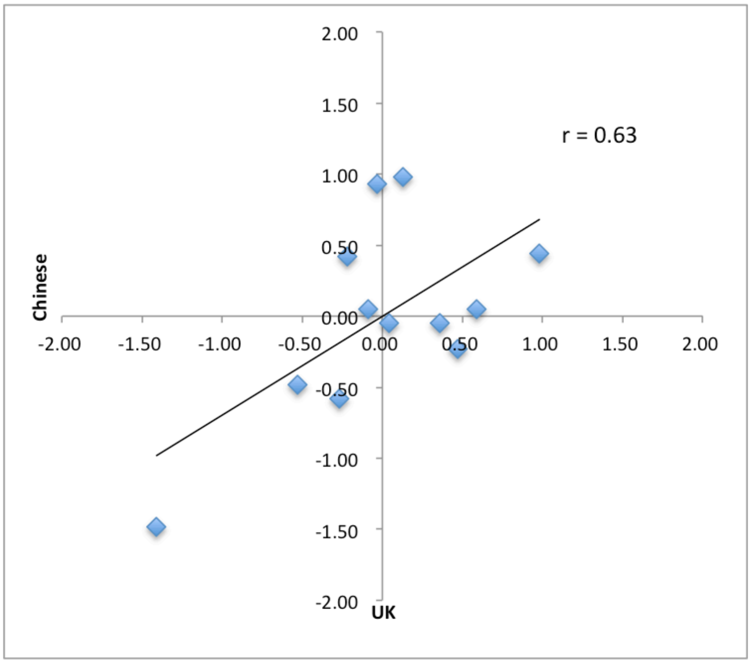


Figure 91. Colour preference scale values according to nationality (UK vs. Chinese).

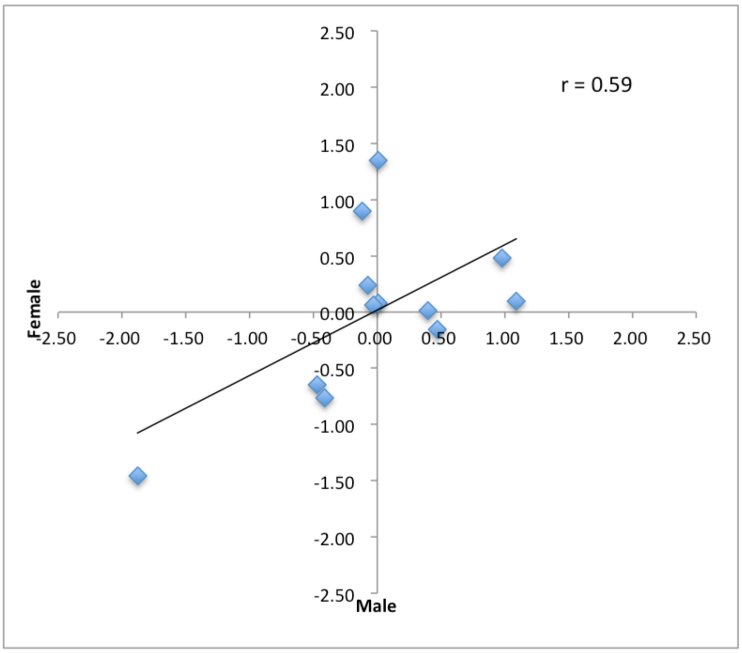


Figure 92. Colour preference scale values according to gender (male vs. female).

6.3.2. Blackness Perception

In this section, the blackness perception is discussed which referred to which colours used for the iPhone image is close to the pure black.

Table 32 displays the scale value of samples according to colour perception and more positive the scale values the more the sample was judged against the pure black. The general order of perception of colour samples is illustrated in Figure 93. It indicates that the iPhone image of N0 was considered to be nearest to the pure black. This result is excepted that N0 is the darkest neutral colour; then the iPhone image of 5PB are the highest in the chromatic colour set and iPhone image of 5Y and 5R were least.

Table 32. Scale values for blackness perception scaling pooled over all observers.

Samples	Scale Value
N0	3.41
N1	2.79
5B	-0.43
5BG	-0.51
5G	-0.47
5GY	-0.51
5Y	-1.09
5YR	-0.93
5R	-1.10
5RP	-0.94
5P	-0.64
5PB	0.38

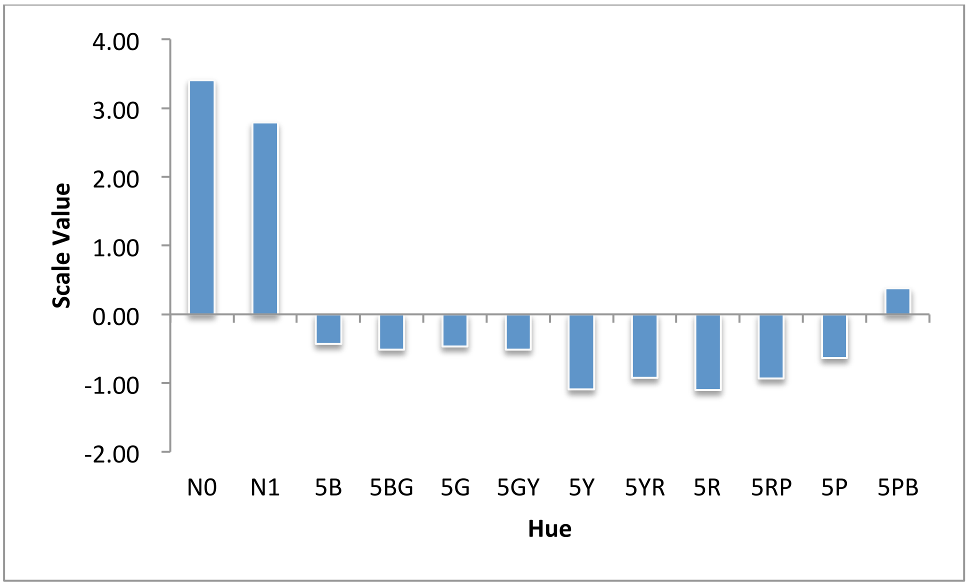


Figure 93. Scale values for blackness perception scaling pooled over all observers.

Figure 94 shows the direct comparison with result of colour perception in Chapter 3 and this experiment. It shows clearly that the ranking orders of these two experiments are nearly the same. N0 and N1 are considered to closest to the pure black. 5PB ranked in the first place in chromatic colour set then 5Y and 5R are at the bottom in both two experiments. The correlation coefficient between abstract and iPhone scale values was 0.96.

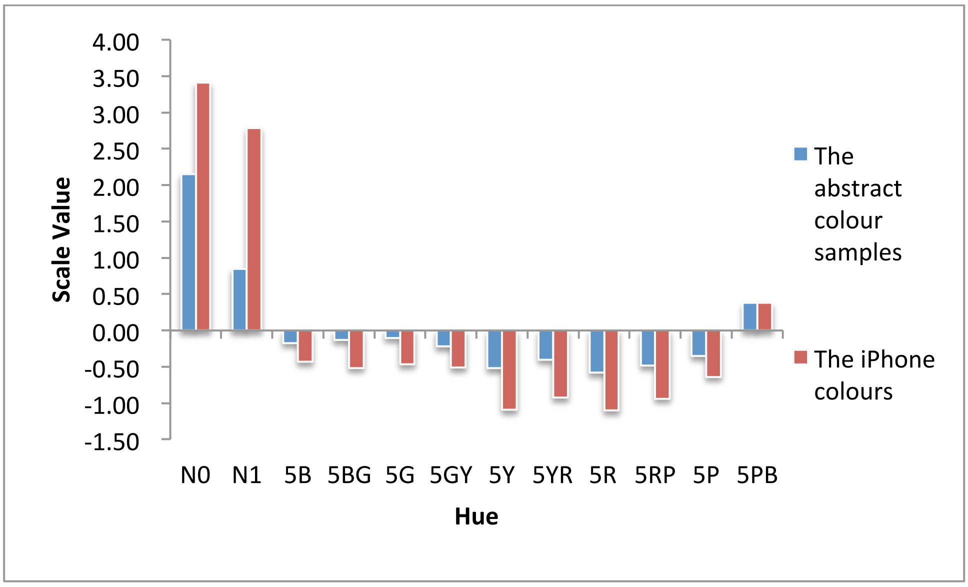


Figure 94. Colour perception scale values for colour samples viewed abstractly (blue bars) and for the iPhone image (red bars) pooled over all observers (note that r = 0.96).

Table 33 and Figure 95 show the scale values of colour perception according to the nationality. The greater and more positive the scale values the more the sample was judged against to the pure black. There are no differences between UK and Chinese observers. It shows that the iPhone image of N0 has the highest scale value of all the samples and 5PB has the highest scale value in chromatic colour set. That means people considered the image of the iPhone with 5PB to be the nearest to pure black in chromatic colour samples (5PB = 0.50 for UK; 5PB = 0.75 for Chinese). The iPhone image with 5R, 5YR and 5Y were considered to be the least black of all the samples in both nationality groups (5R = -1.11, 5YR = -0.95 and 5Y = -1.10 for UK; 5R = -1.26, 5YR = -0.92 and 5Y = -1.13 for Chinese). This result is expected; all previous experiments that used colour samples without particular product have a strong agreement with it.

Table 33. Scale values for colour perception scaling according to nationality (UK vs. Chinese).

Samples	UK	Chinese
N0	3.41	3.41
N1	2.79	2.79
5B	-0.41	-0.37
5BG	-0.49	-0.53
5G	-0.49	-0.44
5GY	-0.44	-0.60
5Y	-1.10	-1.13
5YR	-0.95	-0.92
5R	-1.11	-1.26
5RP	-1.10	-0.93
5P	-0.65	-0.80
5PB	0.50	0.75

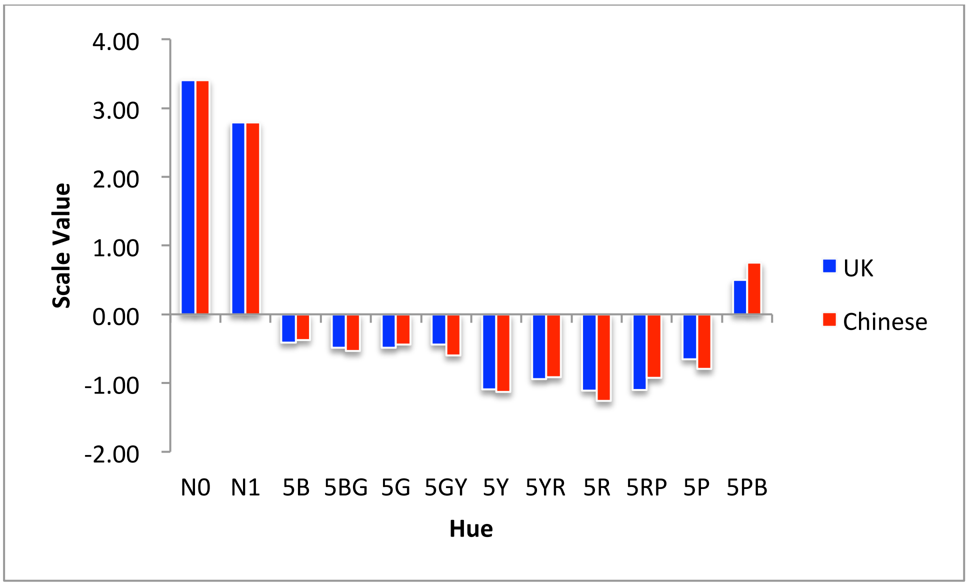


Figure 95. Scale values for colour perception scaling according to nationality (UK vs. Chinese).

Table 34 displays the scale values of colour perception according to gender then Figure 96 allows a direct comparison between male and female observers. According to the gender, the iPhone image with N0, N1 and 5PB are considered to the blackest samples and both male and female observers did not rate 5R and 5Y as being very black. In general, gender does not have a significant influence on blackness perception. The closer results also could find in the previous experiments.

Table 34. Scaled values for colour perception scaling according to gender (male vs. female).

Samples	Male	Female
N0	3.41	3.41
N1	2.79	2.79
5B	-0.33	-0.46
5BG	-0.59	-0.57
5G	-0.69	-0.42
5GY	-0.73	-0.35
5Y	-1.20	-1.06
5YR	-1.11	-0.94
5R	-0.97	-1.19
5RP	-0.93	-1.10
5P	-0.61	-0.66
5PB	0.95	0.48

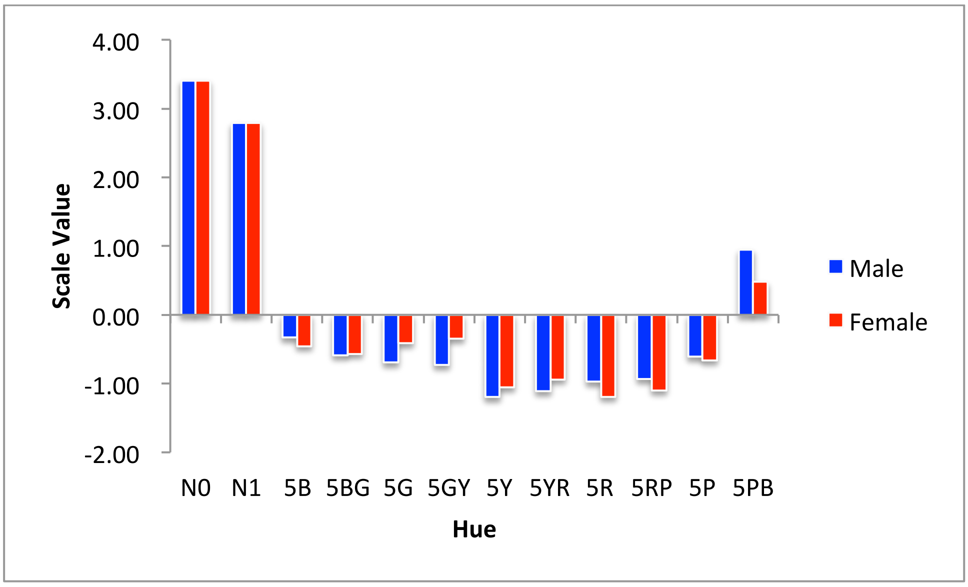


Figure 96. Scaled values for colour perception scaling according to gender (male vs. female).

According to the results in this phase, Figures 97 and 98 (the correlation coefficient is 0.99 for either the nationality or the gender) indicate that neither culture nor gender has a significant influence.

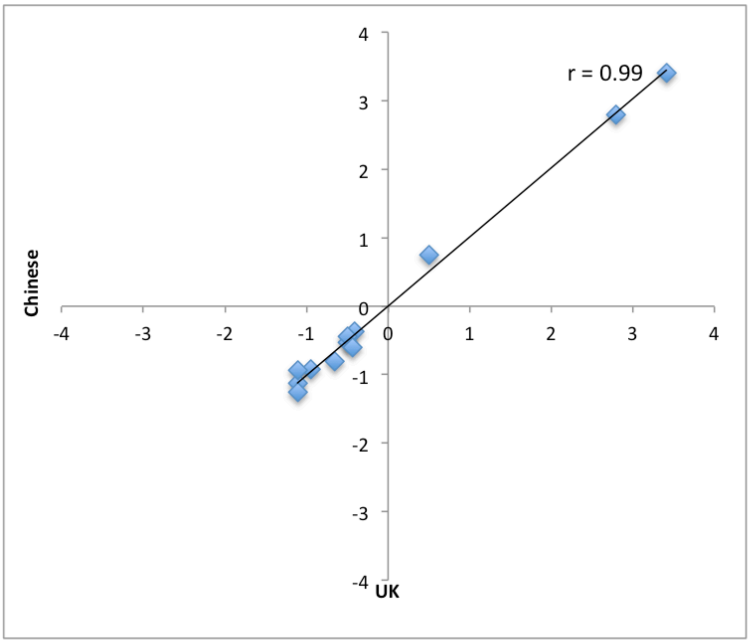


Figure 97. Correlation coefficient of analysis of colour samples closest to pure black by scaling according to nationality (UK vs. Chinese).

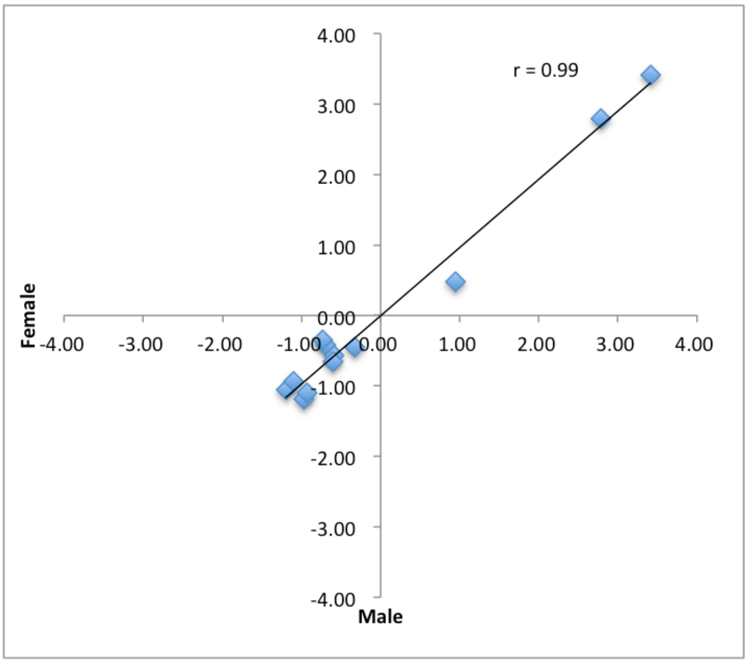


Figure 98. Correlation coefficient of analysis of colour samples closest to pure black by scaling according to nationality (male vs. female).

6.4. Conclusions

The main aim of this chapter was to investigate blackness preference and perception on product design and to explore the nationality and gender effects. Therefore, the particular product (the iPhone) was presented with different blacks.

When observers were asked about which iPhone image they preferred. The correlation coefficient for the nationality comparison is 0.63 and for the gender comparison is 0.59. This could suggest that there are some differences between nationality and gender groups in this regard. As the results indicated that male and UK observers preferred the iPhone image with greenish blue-blacks, however female and Chinese observers preferred the iPhone image with reddish blue-blacks.

When observers were asked about which colour image is close to a pure black neither nationality nor gender differences had a significant impact on results. For example, the scale values derived from observers from Chinese and UK observers were strongly correlated. Both the correlation coefficients (r) for the nationality and gender comparisons were 0.99.

It is interested to note that though the iPhone image with N0 and N1 was considered as the most black, samples with bluish blacks were most preferred compared to samples N0 and N1. Therefore it would seem that observers have strong preference for the iPhone image with bluish blacks. This finding is also consistent with earlier studies which only used abstract colour samples; for example, Chapter 3 also indicated that bluish and purplish is the most preferred blackness and the yellowish is the least preferred. Then the N0 and N1 are considered to be closest to the pure black then reddish and yellowish black is least close to the pure black. It seems neither used a particular product or the abstract colour samples, the findings always same.

7. Testing Blackness Equations

7.1. Introduction

A great number of equations have been published that predict whiteness. However, relatively few blackness equations have been published. In 2006 Westland *et al*. (2006) performed a psychophysical experiment whereby 25 observers ranked 100 black samples (produced using an ink-jet printer using slightly different ink formulations) and consider several potential equations to model the results. The performance of the equations was quantified using root-mean-squared error and the wrong-decision criterion (whereby samples are considered in pairs and a wrong decision is where the equation predicts a different result – in terms of which of the pair is black – compared with the consensus of the visual assessments). Equation 10 gave the best results although the average number of wrong decisions was about 39% (note that even random chance would perform at 50% on average). Thus,

$B_W = 8.6542 - 0.2583L^* - 0.0052a^{*2} + 0.0045b^{*2}$ Equation 10

where B_W is Westland blackness and L*, a* and b* are the CIELAB coordinates. Later Cho *et al*. (2012) carried out a psychophysical experiment where 77 colour samples were assessed by 39 observers. She tested the Westland equation and found that it did not predict the blackness of her sample set at all well. She also tested the NCS blackness model. However, she found that an optimised equation (Equation 11) gave best performance with the data set. Thus,

$B_C = 3.02 - 0.05 \{(L^*)^2 + 0.89(a^*+2)^2 + 0.36 (b^* -33)^2\}^{1/2}$ Equation 11

where B_C is Cho blackness and L*, a* and b* are the CIELAB coordinates.

In this Chapter the Westland and Cho equations are tested with the data generated in this thesis. A blackness equation based on the CIE Whiteness equation (Equation 12) was also tested. Thus,

$W_{CIE} = Y + a\ (xn - x) + b\ (yn - y)$ Equation 12 where W_{CIE} is CIE whiteness, Y, x and y are tristimulus values and chromaticity coordinates and the parameters *a* and *b* are equal to 800 and 1700 respectively in the CIE whiteness equation. A blackness index B_{CIE} based W_{CIE} was tested where

$$B_{CIE} = cY + d\,(xn - x) + e\,(yn - y) \qquad \text{Equation 13}$$

and the coefficients c-e were determined by optimisation.

7.2. Method

Two sets of psychophysical data were used to optimise and test the equations. The data from 13 samples in Chapter 3 and the data from 29 samples from Chapter 5. In each case, Yxy and blackness scale values are available. Three blackness equations were tested, B_W, B_C and B_{CIE}. In each case an error metric was calculated as 1 – r (where r is the correlation coefficient between the psychophysical and predicted blackness values). The values of the weighting parameters in Equation 13 were optimised to minimise the error metric. Optimisation was performed using MATLAB's *fminsearch* function which performs a multidimensional unconstrained nonlinear minimisation (Nelder-Mead). The Nelder-Mead method is a simplex method for finding a local minimum of a function of several variables.

7.3. Stimuli

The X, Y, Z values and scale values according to blackness perception of 13 and 29 colour samples are shown in Tables 35 and 36.

Table 35. The XYZ, L*a*b* and scale values for 13 stimuli.

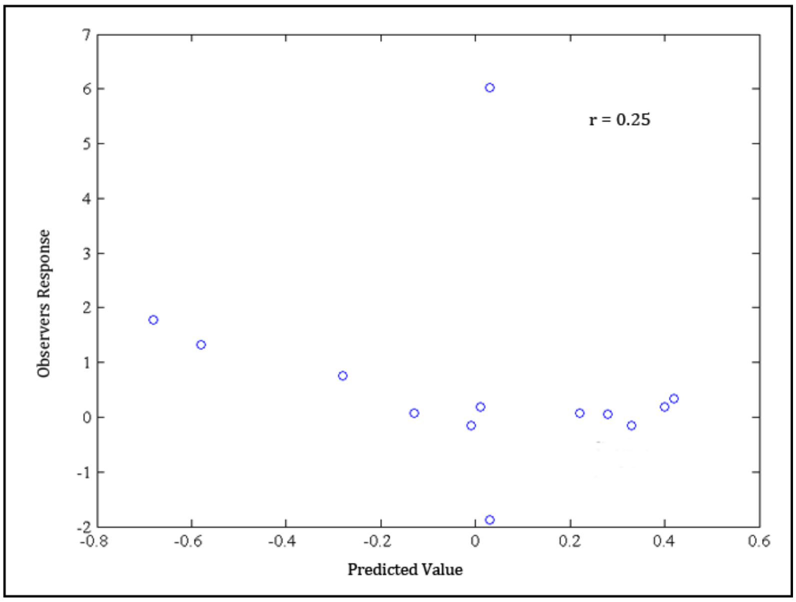
L*	a*	b*	X	Y	Z	Scale Value
10.23	1.37	1.71	0.89	0.95	1.11	2.15
32.89	0.68	2.62	5.62	6.16	7.35	0.85
40.89	-1.34	2.69	8.63	9.71	11.72	-0.48
32.73	-4.43	-4.66	5.17	6.10	9.41	-0.17
31.92	-7.93	0.00	4.66	5.80	7.61	-0.13
32.51	-10.36	5.62	4.67	6.02	6.41	-0.10
31.92	-6.65	11.42	4.82	5.88	4.94	-0.22
32.24	-4.62	18.69	5.00	5.92	3.62	-0.52
30.70	3.64	12.22	5.12	5.37	4.30	-0.40
31.83	8.92	3.56	5.92	5.77	6.63	-0.58
32.02	10.61	-2.98	6.13	5.84	8.52	-0.48
32.65	8.04	-6.22	6.14	6.07	9.87	-0.35
32.83	-0.99	-6.32	5.47	6.14	10.01	0.38

Table 36. The XYZ, L*a*b* and scale values for 29 stimuli.

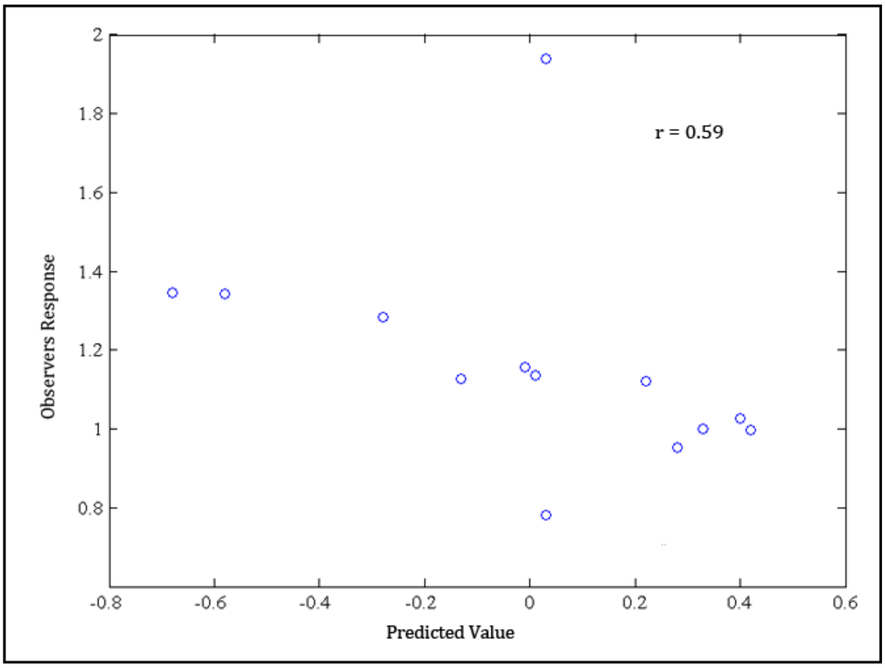
L*	a*	b*	X	Y	Z	Scale Value
32.73	-4.43	-4.66	5.17	6.10	9.41	1.77
31.91	-7.93	0.00	4.66	5.80	7.61	2.02
32.51	-10.36	5.62	4.67	6.02	6.41	0.63
32.13	-6.62	11.46	4.82	5.88	4.94	0.91
32.24	-4.62	18.69	5.00	5.92	3.62	0.33
30.70	3.64	12.22	5.12	5.37	4.30	0.04
31.83	8.92	3.56	5.92	5.77	6.63	0.09
32.02	10.61	-2.98	6.13	5.84	8.52	0.42
32.65	8.04	-6.22	6.14	6.07	9.87	0.80
32.83	-0.99	-6.32	5.47	6.14	10.01	3.18
30.23	-10.84	-10.90	3.98	5.21	10.04	0.10
30.64	-17.14	-2.99	3.70	5.35	7.83	-0.31
30.08	-20.72	7.11	3.35	5.16	5.11	-0.49
30.41	-18.65	31.83	3.55	5.27	1.51	-0.92
29.48	9.30	30.23	5.15	4.96	1.51	-1.33
30.05	19.10	2.08	6.13	5.15	6.24	-0.91
29.93	19.50	-8.30	6.12	5.11	9.04	-0.52
30.84	14.50	-12.76	6.03	5.42	11.04	-0.05
31.53	1.14	-14.11	5.20	5.66	11.96	0.21
40.80	-6.61	-3.50	8.04	9.66	14.08	-0.48
40.00	-7.71	0.64	7.59	9.26	11.91	-0.16
40.54	-9.83	6.28	7.61	9.53	10.24	-0.65
40.14	-6.39	10.05	7.78	9.33	8.81	-0.69
41.24	-2.38	13.66	8.68	9.89	8.30	-0.88
40.99	2.95	10.44	9.14	9.76	9.14	-0.90
40.78	5.23	5.19	9.29	9.65	10.75	-1.11
40.89	7.30	-0.87	9.58	9.71	13.08	-0.92
40.58	5.09	-5.80	9.18	9.55	14.90	-0.40
41.20	-1.37	-4.54	8.77	9.87	14.82	0.22

7.4. Results

As Figure 99 indicated, the results of the predictive performance are 0.25 for Westland's blackness model (Equation 10), 0.59 for Cho's blackness model (Equation 11) and 0.99 for blackness equation (Equation 13) based on the CIE whiteness equation, respectively. The results show that the blackness equation based on CIE whiteness equation fit the experiment data quite well; however, Cho and Westland equations seem to not perform well.

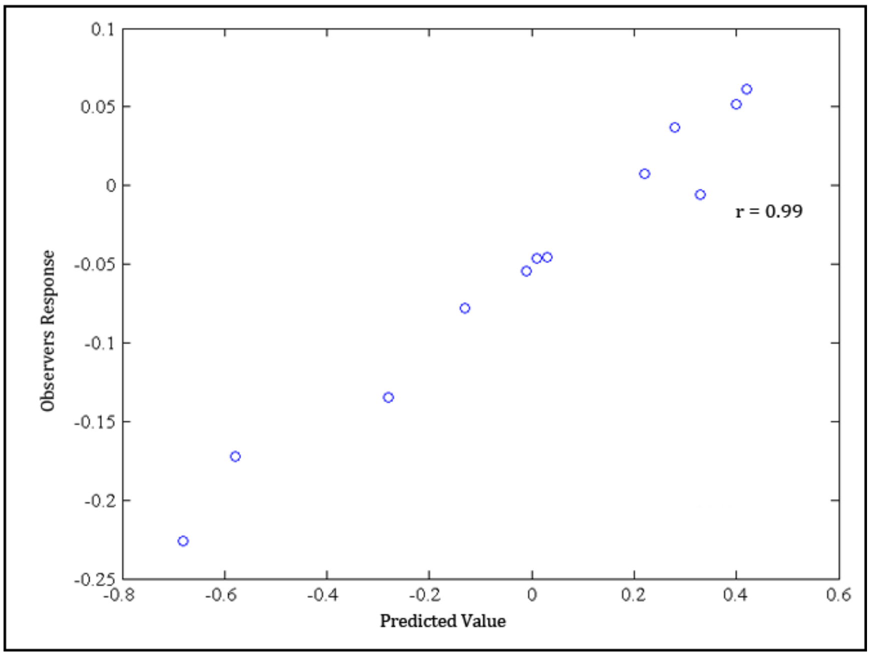


(a)



(b)

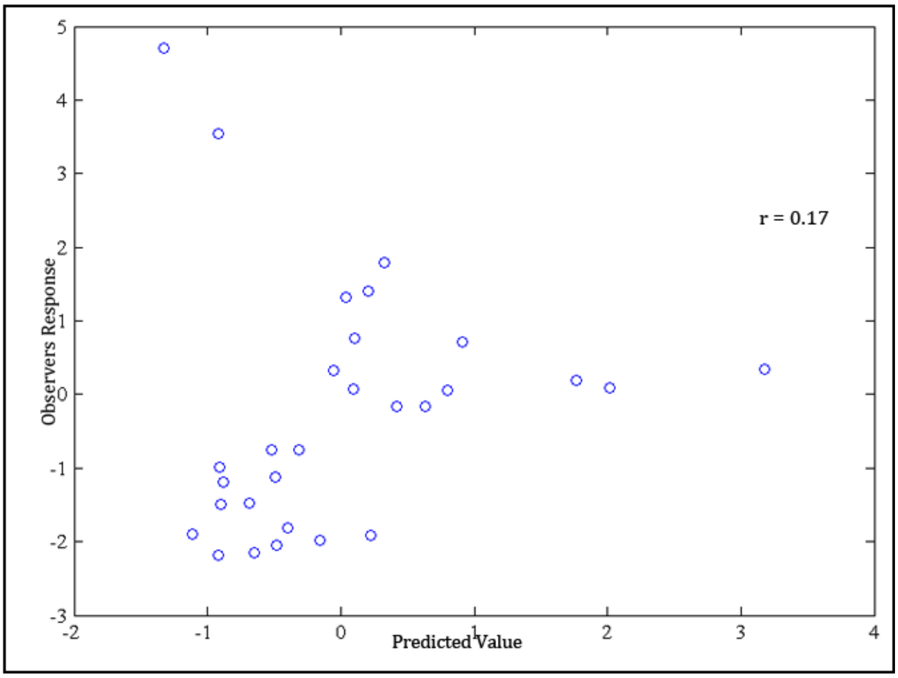
Figure 99. Correlation between observer response and (a) Westland's blackness model, (b) Cho's blackness model and (c) blackness equation based on CIE whiteness equation for Stimuli in Chapter 3.



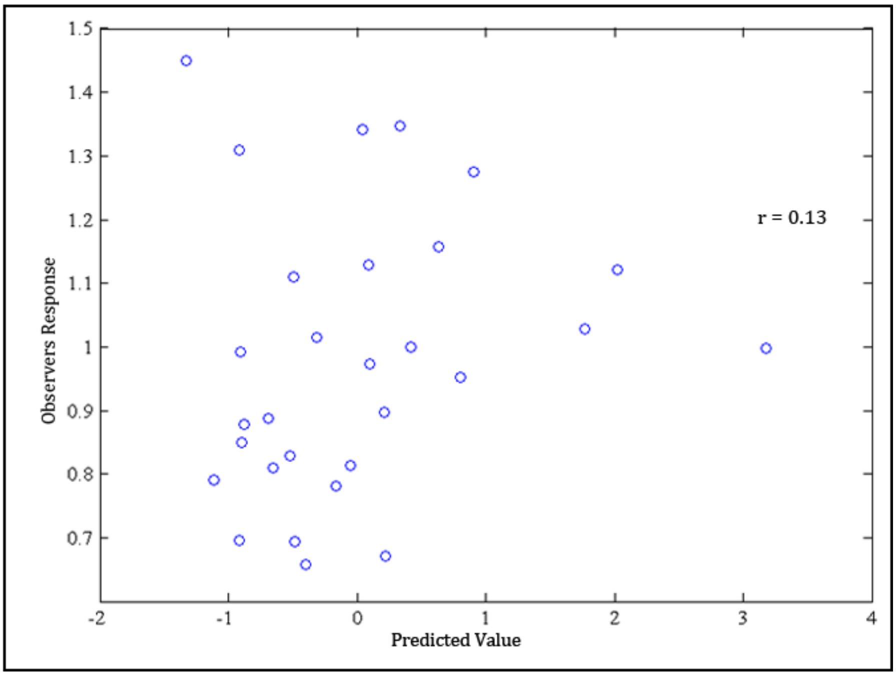
(c)

Figure 99. Correlation between observer response and (a) Westland's blackness model, (b) Cho's blackness model and (c) blackness equation based on CIE whiteness equation for Stimuli in Chapter 3 (continued).

Figure 100 shows the correlation between observer response and three equations. The predictive performance are 0.17 for B_W (Equation 10), 0.13 for B_C (Equation 11) and 0.60 (Equation 13) for B_{CIE}. The results indicate that the blackness equation based on CIE whiteness equation fit the experimental data better, but these two models do not seem to fit well here.

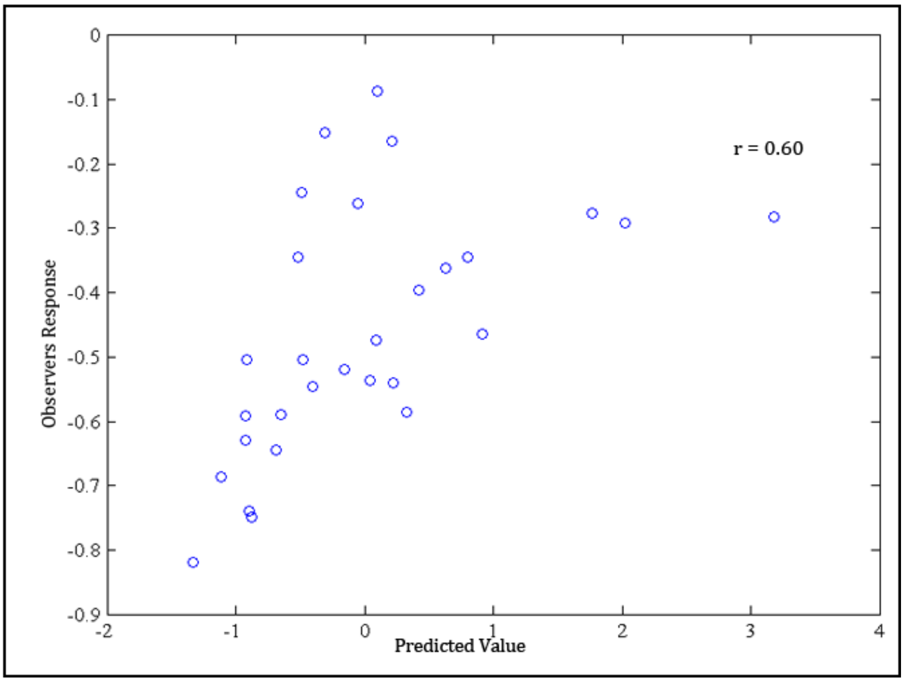


(a)



(b)

Figure 100. Correlations between observer response and (a) Westland's blackness model, (b) Cho's blackness model and (c) blackness equation based on CIE whiteness equation for stimuli in Chapter 5.



(c)

Figure 100. Correlations between observer response and (a) Westland's blackness model, (b) Cho's blackness model and (c) blackness equation based on CIE whiteness equation for stimuli in Chapter 5 (continued).

7.5. Discussion

The equations developed by Cho and Westland did not seem to make good predictions for the data in this thesis. The CIE whiteness equation, adopted as a blackness equation, performed much better. The CIE equation gave excellent performance on the 13 samples from Chapter 3 and slightly less well on the 29 samples from Chapter 5. It can be concluded that much more work needs to be done to be able to reliably predict blackness but that the CIE whiteness equation has potential as a blackness equation.

According to the results reported in Chapter 5, the coefficients c-e of equation 13 were determined by optimisation. The Equation 13 is:

$$B_{CIE} = -0.0609Y + 2.8722(x_n - x) + 0.4506(y_n - y) \qquad \text{Equation 13}$$

Figure 101(a) shows the chromaticity diagram and two lines of iso-whiteness for the CIE whiteness equation. The lower of the two lines is the CIE whiter; however, within each line all points have the same CIE whiteness. Movement towards the bottom length of the diagram (in the blue direction) orthogonal to the orientation of the lines increases the CIE whiteness. Figure 101(b) shows a similar plot but for the optimised Blackness equation (based on Equation 13); this time two lines of iso-blackness are shown. The left-most line is the B_W blacker so movement in the blue-green direction increases the B_W blackness. This would seem to suggest some hue differences between whiteness and blackness perception.

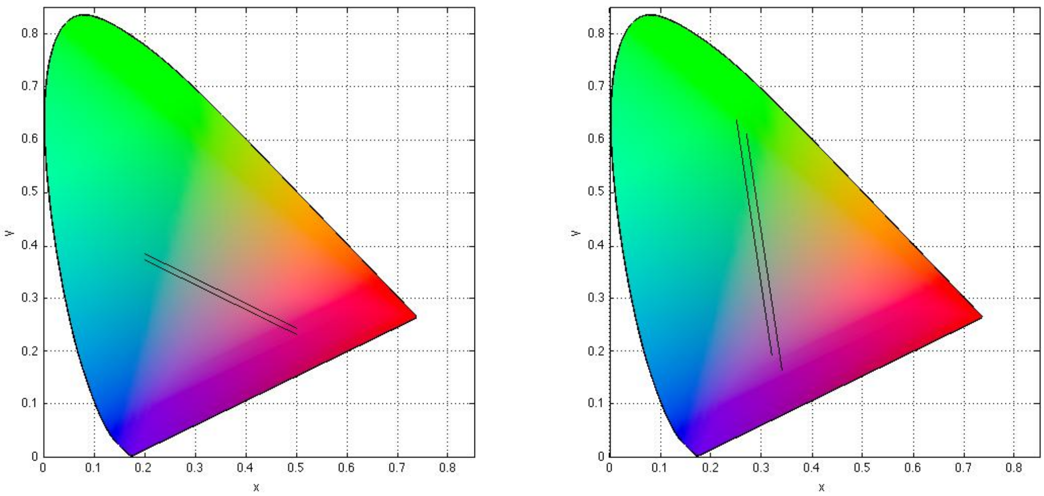


Figure 101. (a) iso-whiteness lines predicted by equation 12 and (b) iso-blackness lines predicted by equation 13.

When looking at the equation which was developed by Westland, the paper published by Westland *et al*. (2006) contains a typographical error and Equation 14 is correct even though it differs slightly from the equation published in that paper (Westland, 2013)

$B_W = 8.6542 – 0.2583L^* - 0.0052a^{*2} - 0.0045b^{*2}$ Equation 14

Figure 102 shows the correlation between observer response and Bw (Equation 14). The predictive performance is 0.69 for Bw (Equation 14). Now the equation of Westland gave best performance for the data in this thesis.

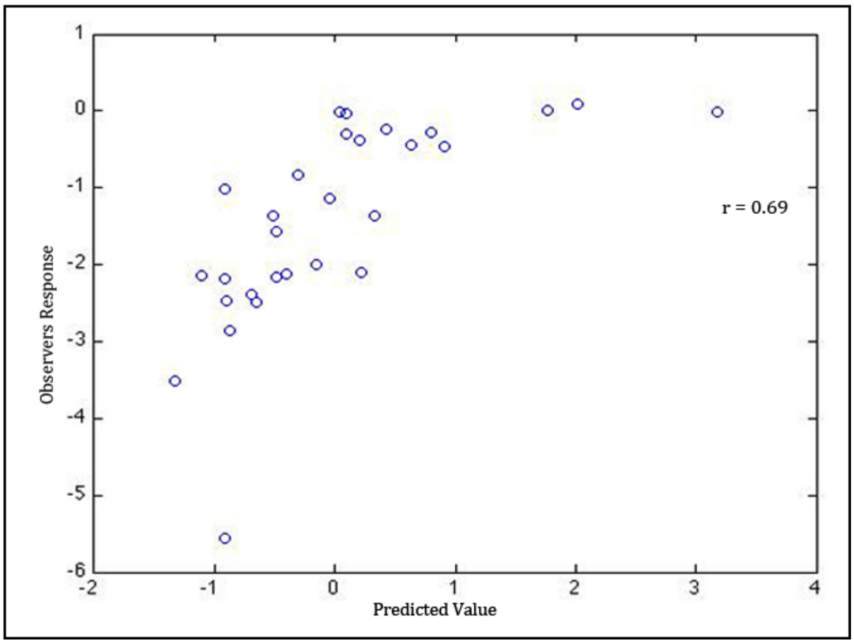


Figure 102. Correlation between observer response and Westland's blackness model for stimuli in Chapter 5.

8. Discussions

8.1. Overview

This study investigates the impact of blackness on product design and specifically explores the influence of different cultural backgrounds. Black is a colour, albeit one that in its purest form lacks chroma and it is important in different industries; for example, textiles, prints, and product manufacturing. A great number of equations have been published over the last 100 years that attempt to predict perception of whiteness; however, by contrast blackness perception has received relatively little attention. Understanding blackness perception could help towards the development of a suitable model of blackness for use in industry and commercial applications. For example, Bode *et al.* (1970) discussed the quantification of blackness using black print pastes based on the assumption that bluish blacks were the ''best'' and commercial printers also empirically found that adding a small amount of blue ink improves the appearance of dark black patches. But these assumptions were not supported or verified with robust studies. Despite the importance of black there have been relatively few studies into blackness preference. Some work has been carried out to determine observers' preferences for colour, especially those of different hue. Understanding blackness preference in product design could help manufacturers to avoid unfavourable hues of blacks and reduce issues (and hence costs).

Therefore, the aims of this research are to explore blackness preference and blackness perception for blacks of abstract colours and colours with a particular product and for observers from different cultures. Two questions were considered: blackness preference relates to whether observers prefer one black rather than another; blackness perception relates to whether observers consider one black sample to be more black than another. Whether these two terms are distinct were also explored by the work. Thus, psychophysical experiments were carried out. Three experimental chapters (Chapters 3-5) described psychophysical experiments to explore blackness preference and perception. The first two experiments used a paired-comparison methodology and the third experiment replicated the second experiment but using a different psychophysical paradigm, namely ranking. The findings from these experiments are discussed in some detail below; however, in summary it was found that blackness preference and blackness perception are not the same. Furthermore, blackness perception was invariant to the cultural background of the observer whereas a gender, and to a lesser extent nationality, factor was found for the blackness preference results. In Chapter 6 a study was carried out to explore whether the findings from Chapters 3-5 would be applicable in a design context. Broadly speaking, participants' judgments on blackness preference and perception in the design context could have been predicted from the results obtained from the study of colours judged in an abstract context.

8.1.1. Blackness Preference

This section describes the blackness preference results. In the blackness perception results (see later) sample N0 was considered to be the blackest sample. This is not surprising given that it is the darkest and least chromatic sample used. However, it was not the most preferred black sample; several chromatic samples such 5PB and 5B were preferred to N0. Therefore it seems that observers have a strong preference for bluish and purplish blacks. Observers also consistently indicated that they had low preference for blacks with yellow tone. This result can be related to he studies of Jacobsen and Ketterling (1989) about the role of background colour on consumer acceptability of self luminous and light-modulating displays which indicated that observers preferred backgrounds with a hue in the range from greenish blue to purplish blue with low value and chroma. The preference for blackness found in this work is also consistent with general studies on colour preference (Hogg, 1969; Ou *et al*., 2004; Palmer and Schloss, 2010); according to their studies, blue and purple are the most preferred hues and yellow is the least preferred.

When hue was the main variable correlation coefficients for scale values were 0.75 (nationality comparison) and 0.61 (gender comparison); when value and chroma were the main variables, the correlation coefficients were 0.30 (nationality comparison) and 0.61 (gender comparison); when the experiment was replicated using ranking the correlation coefficients were 0.75 (nationality comparison) and 0.65 (gender comparison). In all three experiments the correlation coefficient for gender was only 0.6 which suggest that males and females do not have the same blackness preferences. The lower correlation coefficients of gender were found in almost experiments over Chapters 3-5, that could suggest it is more important to consider that qualitative differences between male and female responses (on average). These differences are discussed below.

This work showed differences between male and female responses; female observers preferred reddish blue-blacks (purples) whereas male observers preferred greenish blue-blacks. This difference between the genders is also consistent with studies (Jastrow, 1897; Xin *et al.*, 2004b; Hurlbert *et al.*, 2007) of colour preference (rather than blackness preference). Jastrow (1897) indicated that contrary to women's preferences, men preferred blue to red; then Hurlbert *et al.* (2007) also pointed out the scale value for female preference was higher from the red to purple region, and lower in the green to yellow region, but the scale values for male preference is highest in the blue to green region. Aside from hue, there were some differences between the male and female response; for example, the sample V/C = 1/2 was most preferred by males where sample V/C = 2/2 was most preferred by females. This suggests that males prefer darker blacks than do females.

The correlation coefficients between nationalities were generally higher than for between genders which suggest greater agreement between nationalities than between genders (the results from Chapter 2 were somewhat anomalous). Averaged over all hues, Chinese observers preferred V/C = 1/2 but UK observers ranked V/C = 2/2 as the most preferred place. This could suggest that Chinese observers like the darkest samples and UK observers like the lightest ones. In general Chinese responses were somewhat similar to female responses and UK responses were somewhat similar to male responses. Thus, it was found that Chinese observers preferred red-blue blacks and UK observers preferred green-blue blacks. Hurlbert *et al.* (2007) also indicated that Chinese observers gave a stronger preference for reddish colours than did UK observers.

8.1.2. Blackness Perception

In terms of blackness perception there was strong agreement between both genders and both nationalities. When hue was the main variable (Chapter 3) the correlation coefficients for the nationality and gender comparisons were 0.99 and 0.98 respectively; when value and chroma were the main variables (Chapter 4) the correlation coefficients for the nationality and gender comparisons were 0.96 and 0.95 respectively; when the ranking method was used to explore the effect of value and chroma (Chapter 5) the correlation coefficients for the nationality and gender comparisons were 0.91 and 0.88 respectively. None of these experiments indicate that nationality or gender has any impact on how we see blacks or on how we evaluate samples in terms of blackness, Observer demonstrated a common understanding about what is black. Sample N0 was consistently ranked as the blackest sample and this result is not surprising since it was the darkest and least chromatic of the samples used in the study. However, the results for the stimuli of chromatic colour set which varied in hue but had same chroma and value revealed that samples 5PB and 5B were considered to be blacker than other hues (in particular, yellow). These results are consistent with other studies on blackness perception. For example, Hering (1920/1964) and Hillebrand (1889) indicated that black samples with the same purity but different hue can appear lighter or darker. They also indicated that the colour samples with red and yellow tone were considered as the lightness blacks and the colour samples which contained blue and green tone were closest to pure blacks. Later Haslup (2012) pointed out that observers considered that colour samples with green and blue tone are perceived as ‘‘blacker’’ than colour samples with red and yellow tone. Cho (2012) also agreed with this finding that bluish blacks tended to appear blacker than the other.

8.1.3. Application to Design

The key results of this thesis relate to blackness preference and perception for samples viewed in an abstract context. The findings suggest that neither gender nor nationality have an impact on blackness perception but that there are differences between the preferences of male and female observers and, to a lesser extent, between British and Chinese observers. These results are potentially very valuable to designers who may wish to select a black for a product that will be most preferred. This work suggests that different blacks may be optimal for products intended for a mainly male or female audience. However, to what extent can the results from a psychophysical study carried out using abstract coloured squares displayed on a computer be extended to the very practical problem of product design where context may be powerful? This is the question that was addressed by the work in Chapter 6.

In Chapter 6 the correlation coefficient for blackness preference scale values for the nationality comparison is 0.63 and for the gender comparison is 0.59. Male and UK observers preferred greenish blue-blacks; however, female and Chinese observers preferred reddish blue-blacks. This finding is consistent with the findings from the earlier chapters. Interestingly, however, the scale values obtained from the experiment using the simulation of the iPhone were greater than for corresponding abstract experiments which could suggest that observers' preference for the colour was enhanced by the context in which the colour was displayed; however, as noted above the trends found in this work were very similar to those from the work in Chapter 3-5. For blackness perception the correlation coefficients for the nationality and gender comparisons were 0.99; again, consistent with the findings from Chapters 3-5.

The iPhone image with N0 considered the most black. It is no surprise since the colour N0 was the darkest and least chromatic of all samples. However when observers were asked which image they preferred. It did not rank higher. The iPhone images of several chromatic blacks were preferred to N1 and even N0. Therefore it would seem that that observers have a strong preference for chromatic blacks.

9. Future Work

There are several limitations of this research. Firstly, in the psychophysical experiments carried out to explore the blackness preference and perception that varied on value and chroma. Only colour stimuli in some hue were judged in pairs. So for all colour stimuli this is the incomplete paired comparison. Therefore, the scale values only could present the colour stimuli in each hue but could not across hues. Even the ranking experiment is used to check the results, more scaling method needs to be carried out. Secondly, only the 29 colour stimuli were considered in the psychophysical experiment of abstract colours. Work to test blackness preference and perception, then develop a blackness index, more colour stimuli should be considered. Thirdly, only the iPhone product model was chosen to present different blacks. To further investigate the effect of blackness preference and perception on product, more product categories need to be considered. Therefore more experiments with different stimuli should be conducted.

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Appendices

Appendix I: MATLAB Code for the Experiment in Chapter 3

```
function varargout = exp1(varargin)
% EXP1 M-file for exp1.fig
%      EXP1, by itself, creates a new EXP1 or raises the
existing
%      singleton*.
%
%      H = EXP1 returns the handle to a new EXP1 or the
handle to
%      the existing singleton*.
%
%      EXP1('CALLBACK',hObject,eventData,handles,...) calls
the local
%      function named CALLBACK in EXP1.M with the given
input arguments.
%
%      EXP1('Property','Value',...) creates a new EXP1 or
raises the
%      existing singleton*.  Starting from the left,
property value pairs are
%      applied to the GUI before exp1_OpeningFunction gets
called.  An
%      unrecognized property name or invalid value makes
property application
%      stop.  All inputs are passed to exp1_OpeningFcn via
varargin.
%
%      *See GUI Options on GUIDE's Tools menu.  Choose "GUI
allows only one
%      instance to run (singleton)".
```

```
%
% See also: GUIDE, GUIDATA, GUIHANDLES

% Edit the above text to modify the response to help exp1

% Last Modified by GUIDE v2.5 02-Feb-2010 11:05:33

% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @exp1_OpeningFcn, ...
                   'gui_OutputFcn',  @exp1_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State,
varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT


% --- Executes just before exp1 is made visible.
function exp1_OpeningFcn(hObject, eventdata, handles,
varargin)
% This function has no output args, see OutputFcn.
```

```
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version
of MATLAB
% handles    structure with handles and user data (see
GUIDATA)
% varargin   command line arguments to exp1 (see VARARGIN)

% Choose default command line output for exp1
handles.output = hObject;

% Update handles structure
guidata(hObject, handles);

% UIWAIT makes exp1 wait for user response (see UIRESUME)
% uiwait(handles.figure1);

% reset the software
resetall(hObject, handles)

function resetall(hObject, handles)
defaultim(1,1,:) = uint8([150 200 200]);
axes(handles.axes1);
image(defaultim);
axes(handles.axes2);
image(defaultim);
set(handles.axes1, 'Visible', 'off', 'Units', 'pixels');
set(handles.axes2, 'Visible', 'off', 'Units', 'pixels');
set(handles.left,'Enable','off');
set(handles.right,'Enable','off');

handles.blacks = [0 0 0; 34 34 34; 52 52 52; 19 36 43; 20
36 37; 24 36 31; 31 35 24; 41 30 45; 28 34 46; 48 28 32; 45
28 40; 40 33 16; 47 30 23];
```

```
handles.num = 13;


guidata(hObject,handles);


% --- Outputs from this function are returned to the
command line.

function varargout = exp1_OutputFcn(hObject, eventdata,
handles)

% varargout  cell array for returning output args (see
VARARGOUT);

% hObject    handle to figure

% eventdata  reserved - to be defined in a future version
of MATLAB

% handles    structure with handles and user data (see
GUIDATA)


% Get default command line output from handles structure

varargout{1} = handles.output;




% --- Executes on button press in left.

function left_Callback(hObject, eventdata, handles)

% hObject    handle to left (see GCBO)

% eventdata  reserved - to be defined in a future version
of MATLAB

% handles    structure with handles and user data (see
GUIDATA)


% record which button

if (handles.flip(handles.index))

    handles.record(handles.index,:) =
[handles.store(handles.index,1)
handles.store(handles.index,2) 2];

else
```

```
    handles.record(handles.index,:) =
[handles.store(handles.index,1)
handles.store(handles.index,2) 1];

end



% display next if there is another one

if (handles.index<handles.maxiters)

    handles.index = handles.index + 1;

    if (handles.flip(handles.index))

        rightnum =
handles.store(handles.order(handles.index),1);

        leftnum =
handles.store(handles.order(handles.index),2);

    else

        leftnum =
handles.store(handles.order(handles.index),1);

        rightnum =
handles.store(handles.order(handles.index),2);

    end

    im1(1,1,:) = uint8(handles.blacks(leftnum,:));

    axes(handles.axes1);

    image(im1);

    im2(1,1,:) = uint8(handles.blacks(rightnum,:));

    axes(handles.axes2);

    image(im2);

    set(handles.axes1, 'Visible', 'off', 'Units', 'pixels');

    set(handles.axes2, 'Visible', 'off', 'Units', 'pixels');

else

    stopexp(hObject, handles);

end


guidata(hObject,handles);
```

```
% --- Executes on button press in right.
function right_Callback(hObject, eventdata, handles)
% hObject    handle to right (see GCBO)
% eventdata  reserved - to be defined in a future version
of MATLAB
% handles    structure with handles and user data (see
GUIDATA)


% record which button
if (handles.flip(handles.index))
    handles.record(handles.index,:) =
[handles.store(handles.order(handles.index),1)
handles.store(handles.order(handles.index),2)  1];
else
    handles.record(handles.index,:) =
[handles.store(handles.order(handles.index),1)
handles.store(handles.order(handles.index),2)  2];
end




% display next if there is another one
if (handles.index<handles.maxiters)
    handles.index = handles.index + 1;
    if (handles.flip(handles.index))
        rightnum =
handles.store(handles.order(handles.index),1);
        leftnum =
handles.store(handles.order(handles.index),2);
    else
        leftnum =
handles.store(handles.order(handles.index),1);
        rightnum =
handles.store(handles.order(handles.index),2);
    end
```

```
    im1(1,1,:) = uint8(handles.blacks(leftnum,:));
    axes(handles.axes1);
    image(im1);
    im2(1,1,:) = uint8(handles.blacks(rightnum,:));
    axes(handles.axes2);
    image(im2);
    set(handles.axes1, 'Visible', 'off', 'Units', 'pixels');
    set(handles.axes2, 'Visible', 'off', 'Units', 'pixels');
else
    stopexp(hObject, handles);
end

guidata(hObject,handles);





% --- Executes on button press in start.
function start_Callback(hObject, eventdata, handles)
% hObject    handle to start (see GCBO)
% eventdata  reserved - to be defined in a future version
of MATLAB
% handles    structure with handles and user data (see
GUIDATA)

set(handles.left,'Enable','on');
set(handles.right,'Enable','on');
set(handles.start,'Enable','off');

for i=1:handles.num-1
    for j = i+1:handles.num;
```

```
        if (i== 1 & j==2)
            handles.store = [i j];
        else
            handles.store = [handles.store; i j];
        end
    end
end

dims = size(handles.store);
handles.maxiters = dims(1);
handles.record = zeros(handles.maxiters,3);
handles.order = randperm(handles.maxiters)
handles.flip = floor(rand(handles.maxiters,1)+0.5);
handles.index = 1;
if handles.flip(handles.index)
    rightnum = handles.store(handles.order(1),1);
    leftnum = handles.store(handles.order(1),2);
else
    leftnum = handles.store(handles.order(1),1);
    rightnum = handles.store(handles.order(1),2);
end

im1(1,1,:) = uint8(handles.blacks(leftnum,:));
axes(handles.axes1);
image(im1);
im2(1,1,:) = uint8(handles.blacks(rightnum,:));
axes(handles.axes2);
image(im2);
set(handles.axes1, 'Visible', 'off', 'Units', 'pixels');
set(handles.axes2, 'Visible', 'off', 'Units', 'pixels');
```

```
guidata(hObject,handles);
```

```
function stopexp(hObject, handles)
set(handles.left,'Enable','off');
set(handles.right,'Enable','off');
beep
disp(handles.record)
guidata(hObject,handles);
```

Appendix II: MATLAB Code for the Experiment in Chapter 5

```
function varargout = ranking(varargin)

% RANKING MATLAB code for ranking.fig

%       RANKING, by itself, creates a new RANKING or raises the existing

%       singleton*.

%

%       H = RANKING returns the handle to a new RANKING or the handle to

%       the existing singleton*.

%

%       RANKING('CALLBACK',hObject,eventData,handles,...) calls the local

%       function named CALLBACK in RANKING.M with the given input arguments.

%

%       RANKING('Property','Value',...) creates a new RANKING or raises the

%       existing singleton*.  Starting from the left, property value pairs are

%       applied to the GUI before ranking_OpeningFcn gets called.  An

%       unrecognized property name or invalid value makes property application

%       stop.  All inputs are passed to ranking_OpeningFcn via varargin.

%

%       *See GUI Options on GUIDE's Tools menu.  Choose "GUI allows only one

%       instance to run (singleton)".

%

% See also: GUIDE, GUIDATA, GUIHANDLES
```

```
% Edit the above text to modify the response to help
ranking


% Last Modified by GUIDE v2.5 19-Oct-2011 21:42:13


% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn',
@ranking_OpeningFcn, ...
                   'gui_OutputFcn',  @ranking_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end


if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State,
varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT


 % --- Executes just before ranking is made visible.
function ranking_OpeningFcn(hObject, eventdata, handles,
varargin)
% This function has no output args, see OutputFcn.
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version
of MATLAB
```

```
% handles    structure with handles and user data (see
GUIDATA)
% varargin   command line arguments to ranking (see
VARARGIN)


% Choose default command line output for ranking
handles.output = hObject;


handles.rgb=[19 36 43; 0 38 52; 39 55 61; 20 36 37; 0 39 41;
39 55 55; 24 36 31; 0 39 27; 42 55 49; 31 35 24; 23 38 0;
49 54 42; 41 30 45; 45 26 52; 58 49 63; 28 34 46; 21 34 56;
47 52 65; 48 28 32; 57 22 32; 67 47 49; 45 28 40; 52 23 44;
65 47 56; 40 33 16; 58 52 37; 47 30 23; 57 24 5; 65 49
41]/400;
% for i=1:29
%     handles.rgb(i,:) = [(i*8/255) (i*8/255) (i*8/255)];
% end
% disp(handles.rgb)
handles.order = randperm(29);


set(handles.axes1, 'Color',
handles.rgb(handles.order(1),:));
set(handles.axes2, 'Color',
handles.rgb(handles.order(2),:));
set(handles.axes3, 'Color',
handles.rgb(handles.order(3),:));
set(handles.axes4, 'Color',
handles.rgb(handles.order(4),:));
set(handles.axes5, 'Color',
handles.rgb(handles.order(5),:));
set(handles.axes6, 'Color',
handles.rgb(handles.order(6),:));
set(handles.axes7, 'Color',
handles.rgb(handles.order(7),:));
set(handles.axes8, 'Color',
handles.rgb(handles.order(8),:));
set(handles.axes9, 'Color',
handles.rgb(handles.order(9),:));
```

```
set(handles.axes10, 'Color',
handles.rgb(handles.order(10),:));

set(handles.axes11, 'Color',
handles.rgb(handles.order(11),:));

set(handles.axes12, 'Color',
handles.rgb(handles.order(12),:));

set(handles.axes13, 'Color',
handles.rgb(handles.order(13),:));

set(handles.axes14, 'Color',
handles.rgb(handles.order(14),:));

set(handles.axes15, 'Color',
handles.rgb(handles.order(15),:));

set(handles.axes16, 'Color',
handles.rgb(handles.order(16),:));

set(handles.axes17, 'Color',
handles.rgb(handles.order(17),:));

set(handles.axes18, 'Color',
handles.rgb(handles.order(18),:));

set(handles.axes19, 'Color',
handles.rgb(handles.order(19),:));

set(handles.axes20, 'Color',
handles.rgb(handles.order(20),:));

set(handles.axes21, 'Color',
handles.rgb(handles.order(21),:));

set(handles.axes22, 'Color',
handles.rgb(handles.order(22),:));

set(handles.axes23, 'Color',
handles.rgb(handles.order(23),:));

set(handles.axes24, 'Color',
handles.rgb(handles.order(24),:));

set(handles.axes25, 'Color',
handles.rgb(handles.order(25),:));

set(handles.axes26, 'Color',
handles.rgb(handles.order(26),:));

set(handles.axes27, 'Color',
handles.rgb(handles.order(27),:));

set(handles.axes28, 'Color',
handles.rgb(handles.order(28),:));

set(handles.axes29, 'Color',
handles.rgb(handles.order(29),:));
```

```
handles.stat=0;

set(gcf, 'WindowButtonDownFcn',{@mClick,handles});

% Update handles structure
guidata(hObject, handles);

% UIWAIT makes ranking wait for user response (see UIRESUME)
% uiwait(handles.figure1);



% --- Outputs from this function are returned to the
command line.
function varargout = ranking_OutputFcn(hObject, eventdata,
handles)
% varargout  cell array for returning output args (see
VARARGOUT);
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version
of MATLAB
% handles    structure with handles and user data (see
GUIDATA)

% Get default command line output from handles structure
varargout{1} = handles.output;



% --- Executes on button press in pushbutton3.
function pushbutton3_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton3 (see GCBO)
% eventdata  reserved - to be defined in a future version
of MATLAB
```

```
% handles    structure with handles and user data (see
GUIDATA)


disp('in start button')
handles.stat = 1;
disp(handles.stat)
guidata(hObject, handles);
set(gcf, 'WindowButtonDownFcn',{@mClick,handles});


% --- Executes on button press in pushbutton4.
function pushbutton4_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton4 (see GCBO)
% eventdata  reserved - to be defined in a future version
of MATLAB
% handles    structure with handles and user data (see
GUIDATA)
disp(handles.stat)
%handles.stat = 0; % do nothing until we click start
guidata(hObject, handles);


function mClick(hObject, eventdata, handles)
pos=get(hObject,'CurrentPoint');
x = pos(1);
y = pos(2);
if (handles.stat==0)
   axpos = get(handles.axes1,'Position');
   x1 = axpos(1);
   y1 = axpos(2);
   disp([x1 y1])
   axpos = get(handles.axes2,'Position');
   x1 = axpos(1);
   y1 = axpos(2);
```

```
disp([x1 y1])
axpos = get(handles.axes3,'Position');
x1 = axpos(1);
y1 = axpos(2);
disp([x1 y1])
axpos = get(handles.axes4,'Position');
x1 = axpos(1);
y1 = axpos(2);
disp([x1 y1])
axpos = get(handles.axes5,'Position');
x1 = axpos(1);
y1 = axpos(2);
disp([x1 y1])
axpos = get(handles.axes6,'Position');
x1 = axpos(1);
y1 = axpos(2);
disp([x1 y1])
axpos = get(handles.axes7,'Position');
x1 = axpos(1);
y1 = axpos(2);
disp([x1 y1])
axpos = get(handles.axes8,'Position');
x1 = axpos(1);
y1 = axpos(2);
disp([x1 y1])
axpos = get(handles.axes9,'Position');
x1 = axpos(1);
y1 = axpos(2);
disp([x1 y1])
axpos = get(handles.axes10,'Position');
x1 = axpos(1);
```

```
y1 = axpos(2);
disp([x1 y1])
axpos = get(handles.axes11,'Position');
x1 = axpos(1);
y1 = axpos(2);
disp([x1 y1])
axpos = get(handles.axes12,'Position');
x1 = axpos(1);
y1 = axpos(2);
disp([x1 y1])
axpos = get(handles.axes13,'Position');
x1 = axpos(1);
y1 = axpos(2);
disp([x1 y1])
axpos = get(handles.axes14,'Position');
x1 = axpos(1);
y1 = axpos(2);
disp([x1 y1])
axpos = get(handles.axes15,'Position');
x1 = axpos(1);
y1 = axpos(2);
disp([x1 y1])
axpos = get(handles.axes16,'Position');
x1 = axpos(1);
y1 = axpos(2);
disp([x1 y1])
axpos = get(handles.axes17,'Position');
x1 = axpos(1);
y1 = axpos(2);
disp([x1 y1])
axpos = get(handles.axes18,'Position');
```

```
x1 = axpos(1);
y1 = axpos(2);
disp([x1 y1])
axpos = get(handles.axes19,'Position');
x1 = axpos(1);
y1 = axpos(2);
disp([x1 y1])
axpos = get(handles.axes20,'Position');
x1 = axpos(1);
y1 = axpos(2);
disp([x1 y1])
axpos = get(handles.axes21,'Position');
x1 = axpos(1);
y1 = axpos(2);
disp([x1 y1])
axpos = get(handles.axes22,'Position');
x1 = axpos(1);
y1 = axpos(2);
disp([x1 y1])
axpos = get(handles.axes23,'Position');
x1 = axpos(1);
y1 = axpos(2);
disp([x1 y1])
axpos = get(handles.axes24,'Position');
x1 = axpos(1);
y1 = axpos(2);
disp([x1 y1])
axpos = get(handles.axes25,'Position');
x1 = axpos(1);
y1 = axpos(2);
disp([x1 y1])
```

```
        axpos = get(handles.axes26,'Position');
        x1 = axpos(1);
        y1 = axpos(2);
        disp([x1 y1])
        axpos = get(handles.axes27,'Position');
        x1 = axpos(1);
        y1 = axpos(2);
        disp([x1 y1])
        axpos = get(handles.axes28,'Position');
        x1 = axpos(1);
        y1 = axpos(2);
        disp([x1 y1])
        axpos = get(handles.axes29,'Position');
        x1 = axpos(1);
        y1 = axpos(2);
        disp([x1 y1])
    elseif (handles.stat==1)
        disp('in stat==1')
        [handles]=getclosest(handles,x,y);
        handles.aselected = handles.firstclosest;
        disp(handles.aselected)
        handles.stat=2;
    elseif (handles.stat==2)
        disp('in stat==2')
        [handles]=getclosest(handles,x,y);
        disp(handles.order)
        order = handles.order;
        asel = handles.aselected;
        index1 = handles.firstclosest
        index2 = handles.secondclosest
        if (index2<index1)
```

```
        swapval = index1;
        index1=index2;
        index2=swapval;
    end
    disp([asel index1 index2])
    if (asel<index1 | asel>index2)
       if (asel>index2)
          disp('a')
          % insert the selected one
          neworder=[order(1:index1) order(asel)
order(index2:29)];
          disp([asel index1 index2])
          % remove it from its previous position
          neworder(asel+1)=[];
       end
       if (asel<index1)
          disp('b')
          % insert the selected one
          neworder=[order(1:index1) order(asel)
order(index2:29)];
          disp([asel index1 index2])
          % remove it from its previous position
          neworder(asel)=[];
       end
       disp(neworder)
       set(handles.axes1, 'Color',
handles.rgb(neworder(1),:));
       set(handles.axes2, 'Color',
handles.rgb(neworder(2),:));
       set(handles.axes3, 'Color',
handles.rgb(neworder(3),:));
       set(handles.axes4, 'Color',
handles.rgb(neworder(4),:));
```

```
        set(handles.axes5, 'Color',
handles.rgb(neworder(5),:));

        set(handles.axes6, 'Color',
handles.rgb(neworder(6),:));

        set(handles.axes7, 'Color',
handles.rgb(neworder(7),:));

        set(handles.axes8, 'Color',
handles.rgb(neworder(8),:));

        set(handles.axes9, 'Color',
handles.rgb(neworder(9),:));

        set(handles.axes10, 'Color',
handles.rgb(neworder(10),:));

        set(handles.axes11, 'Color',
handles.rgb(neworder(11),:));

        set(handles.axes12, 'Color',
handles.rgb(neworder(12),:));

        set(handles.axes13, 'Color',
handles.rgb(neworder(13),:));

        set(handles.axes14, 'Color',
handles.rgb(neworder(14),:));

        set(handles.axes15, 'Color',
handles.rgb(neworder(15),:));

        set(handles.axes16, 'Color',
handles.rgb(neworder(16),:));

        set(handles.axes17, 'Color',
handles.rgb(neworder(17),:));

        set(handles.axes18, 'Color',
handles.rgb(neworder(18),:));

        set(handles.axes19, 'Color',
handles.rgb(neworder(19),:));

        set(handles.axes20, 'Color',
handles.rgb(neworder(20),:));

        set(handles.axes21, 'Color',
handles.rgb(neworder(21),:));

        set(handles.axes22, 'Color',
handles.rgb(neworder(22),:));

        set(handles.axes23, 'Color',
handles.rgb(neworder(23),:));

        set(handles.axes24, 'Color',
handles.rgb(neworder(24),:));
```

```
      set(handles.axes25, 'Color',
handles.rgb(neworder(25),:));

      set(handles.axes26, 'Color',
handles.rgb(neworder(26),:));

      set(handles.axes27, 'Color',
handles.rgb(neworder(27),:));

      set(handles.axes28, 'Color',
handles.rgb(neworder(28),:));

      set(handles.axes29, 'Color',
handles.rgb(neworder(29),:));

      handles.order = neworder;

      handles.stat=1;

    end

end

   %[handles]=getclosest(handles,pos);

guidata(hObject, handles);

set(gcf, 'WindowButtonDownFcn',{@mClick,handles});


function [handles] = getclosest(handles, x,y)

% first square

disp('in getclosest')

disp([x y])


% work out which row we are on

axpos = get(handles.axes1,'Position');

data(1,:) = [1 (axpos(2)-y)^2];

axpos = get(handles.axes11,'Position');

data(2,:) = [2 (axpos(2)-y)^2];

axpos = get(handles.axes21,'Position');

data(3,:) = [3 (axpos(2)-y)^2];

data = sortrows(data,2);

row = data(1,1)
```

```
if (row==1)

axpos = get(handles.axes1,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(1,:) = [1 sqrt((x1-x)^2 + (y1-y)^2)];

% second square
axpos = get(handles.axes2,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(2,:) = [2 sqrt((x1-x)^2 + (y1-y)^2)];

% third square
axpos = get(handles.axes3,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(3,:) = [3 sqrt((x1-x)^2 + (y1-y)^2)];

% fourth square
axpos = get(handles.axes4,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(4,:) = [4 sqrt((x1-x)^2 + (y1-y)^2)];

% fifth square
axpos = get(handles.axes5,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(5,:) = [5 sqrt((x1-x)^2 + (y1-y)^2)];
```

```
% sixth square
axpos = get(handles.axes6,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(6,:) = [6 sqrt((x1-x)^2 + (y1-y)^2)];

% seventh square
axpos = get(handles.axes7,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(7,:) = [7 sqrt((x1-x)^2 + (y1-y)^2)];

% eighth square
axpos = get(handles.axes8,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(8,:) = [8 sqrt((x1-x)^2 + (y1-y)^2)];

% ninth square
axpos = get(handles.axes9,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(9,:) = [9 sqrt((x1-x)^2 + (y1-y)^2)];

% tenth square
axpos = get(handles.axes10,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(10,:) = [10 sqrt((x1-x)^2 + (y1-y)^2)];

elseif (row==2)
```

```
% 11th square
axpos = get(handles.axes11,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(1,:) = [11 sqrt((x1-x)^2 + (y1-y)^2)];

% 12th square
axpos = get(handles.axes12,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(2,:) = [12 sqrt((x1-x)^2 + (y1-y)^2)];

% 13th square
axpos = get(handles.axes13,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(3,:) = [13 sqrt((x1-x)^2 + (y1-y)^2)];

% 14th square
axpos = get(handles.axes14,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(4,:) = [14 sqrt((x1-x)^2 + (y1-y)^2)];

% 15th square
axpos = get(handles.axes15,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(5,:) = [15 sqrt((x1-x)^2 + (y1-y)^2)];
```

```
% 16th square
axpos = get(handles.axes16,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(6,:) = [16 sqrt((x1-x)^2 + (y1-y)^2)];

% 17th square
axpos = get(handles.axes17,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(7,:) = [17 sqrt((x1-x)^2 + (y1-y)^2)];

% 18th square
axpos = get(handles.axes18,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(8,:) = [18 sqrt((x1-x)^2 + (y1-y)^2)];

% 19th square
axpos = get(handles.axes19,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(9,:) = [19 sqrt((x1-x)^2 + (y1-y)^2)];

% 20th square
axpos = get(handles.axes20,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(10,:) = [20 sqrt((x1-x)^2 + (y1-y)^2)];

else
```

```
% 21th square
axpos = get(handles.axes21,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(1,:) = [21 sqrt((x1-x)^2 + (y1-y)^2)];

% 22th square
axpos = get(handles.axes22,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(2,:) = [22 sqrt((x1-x)^2 + (y1-y)^2)];

% 23th square
axpos = get(handles.axes23,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(3,:) = [23 sqrt((x1-x)^2 + (y1-y)^2)];

% 24th square
axpos = get(handles.axes24,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(4,:) = [24 sqrt((x1-x)^2 + (y1-y)^2)];

% 25th square
axpos = get(handles.axes25,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(5,:) = [25 sqrt((x1-x)^2 + (y1-y)^2)];
```

```
% 26th square
axpos = get(handles.axes26,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(6,:) = [26 sqrt((x1-x)^2 + (y1-y)^2)];

% 27th square
axpos = get(handles.axes27,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(7,:) = [27 sqrt((x1-x)^2 + (y1-y)^2)];

% 28th square
axpos = get(handles.axes28,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(8,:) = [28 sqrt((x1-x)^2 + (y1-y)^2)];

% 29th square
axpos = get(handles.axes29,'Position');
x1 = axpos(1);
y1 = axpos(2);
data(9,:) = [29 sqrt((x1-x)^2 + (y1-y)^2)];

end

data = sortrows(data,2);
handles.firstclosest = data(1,1);
handles.secondclosest = data(2,1);

set(gcf, 'WindowButtonDownFcn',{@mClick,handles});
```

Appendix III: MATLAB Code for the Experiment in Chapter 6

```
function varargout = iphone_model(varargin)

% iphone_model M-file for iphone_model.fig

%      iphone_model, by itself, creates a new iphone_model
or raises the existing

%      singleton*.

%

%      H = iphone_model returns the handle to a new
iphone_model or the handle to

%      the existing singleton*.

%

%
iphone_model('CALLBACK',hObject,eventData,handles,...)
calls the local

%      function named CALLBACK in iphone_model.M with the
given input arguments.

%

%      iphone_model('Property','Value',...) creates a new
iphone_model or raises the

%      existing singleton*.  Starting from the left,
property value pairs are

%      applied to the GUI before
iphone_model_OpeningFunction gets called.  An

%      unrecognized property name or invalid value makes
property application

%      stop.  All inputs are passed to
iphone_model_OpeningFcn via varargin.

%

%      *See GUI Options on GUIDE's Tools menu.  Choose "GUI
allows only one

%      instance to run (singleton)".

%

% See also: GUIDE, GUIDATA, GUIHANDLES
```

```
% Edit the above text to modify the response to help
iphone_model

% Last Modified by GUIDE v2.5 02-Feb-2010 11:05:33

% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn',
@iphone_model_OpeningFcn, ...
                   'gui_OutputFcn',
@iphone_model_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State,
varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT


% --- Executes just before iphone_model is made visible.
function iphone_model_OpeningFcn(hObject, eventdata,
handles, varargin)
% This function has no output args, see OutputFcn.
% hObject    handle to figure
```

```
% eventdata  reserved - to be defined in a future version
of MATLAB

% handles    structure with handles and user data (see
GUIDATA)

% varargin   command line arguments to iphone_model (see
VARARGIN)


% Choose default command line output for iphone_model

handles.output = hObject;


% Update handles structure

guidata(hObject, handles);



% UIWAIT makes iphone_model wait for user response (see
UIRESUME)

% uiwait(handles.figure1);



% --- Outputs from this function are returned to the
command line.

function varargout = iphone_model_OutputFcn(hObject,
eventdata, handles)

% varargout  cell array for returning output args (see
VARARGOUT);

% hObject    handle to figure

% eventdata  reserved - to be defined in a future version
of MATLAB

% handles    structure with handles and user data (see
GUIDATA)


% Get default command line output from handles structure

varargout{1} = handles.output;
```

```
% --- Executes on button press in left.
function left_Callback(hObject, eventdata, handles)
% hObject    handle to left (see GCBO)
% eventdata  reserved - to be defined in a future version
of MATLAB
% handles    structure with handles and user data (see
GUIDATA)


% record result
handles.record(handles.index,:) = [handles.leftimage
handles.rightimage 1];


% display next if there is another one
if (handles.index<handles.trials)
    handles.index = handles.index + 1;


    if (handles.flip(handles.index)==0)
        i=handles.data(handles.order(handles.index),1);
        j=handles.data(handles.order(handles.index),2);
    else
        i=handles.data(handles.order(handles.index),2);
        j=handles.data(handles.order(handles.index),1);
    end
    handles.leftimage=i;
    handles.rightimage=j;
    filename = sprintf('iphone%d.jpg',i);
    [handles.imagei] = imread(filename,'jpg');
    filename = sprintf('iphone%d.jpg',j);
    [handles.imagej] = imread(filename,'jpg');
    axes(handles.axes1);
    image(handles.imagei);
    set(handles.axes1, 'Visible', 'off', 'Units', 'pixels');
```

```
    axes(handles.axes2);
    image(handles.imagej);
    set(handles.axes2, 'Visible', 'off', 'Units', 'pixels');
else
    stopexp(hObject, handles);
end

guidata(hObject,handles);

% --- Executes on button press in right.
function right_Callback(hObject, eventdata, handles)
% hObject    handle to right (see GCBO)
% eventdata  reserved - to be defined in a future version
of MATLAB
% handles    structure with handles and user data (see
GUIDATA)

% record result
handles.record(handles.index,:) = [handles.leftimage
handles.rightimage 2];

% display next if there is another one
if (handles.index<handles.trials)
    handles.index = handles.index + 1;

    if (handles.flip(handles.index)==0)
        i=handles.data(handles.order(handles.index),1);
        j=handles.data(handles.order(handles.index),2);
    else
        i=handles.data(handles.order(handles.index),2);
        j=handles.data(handles.order(handles.index),1);
    end
```

```
    handles.leftimage=i;
    handles.rightimage=j;
    filename = sprintf('iphone%d.jpg',i);
    [handles.imagei] = imread(filename,'jpg');
    filename = sprintf('iphone%d.jpg',j);
    [handles.imagej] = imread(filename,'jpg');
    axes(handles.axes1);
    image(handles.imagei);
    set(handles.axes1, 'Visible', 'off', 'Units', 'pixels');
    axes(handles.axes2);
    image(handles.imagej);
    set(handles.axes2, 'Visible', 'off', 'Units', 'pixels');
else
    stopexp(hObject, handles);
end

guidata(hObject,handles);



% --- Executes on button press in start.
function start_Callback(hObject, eventdata, handles)
% hObject    handle to start (see GCBO)
% eventdata  reserved - to be defined in a future version
of MATLAB
% handles    structure with handles and user data (see
GUIDATA)



set(handles.left,'Enable','on');
set(handles.right,'Enable','on');
set(handles.start,'Enable','off');
```

```
num_images = 12;


index = 0;
for i=1:num_images-1
    for j=i+1:num_images
        index=index+1;
        handles.data(index,:)=[i j];
    end
end

dims = size(handles.data);
handles.trials = dims(1);
handles.order = randperm(handles.trials);



handles.record = zeros(handles.trials,3);
handles.flip = floor(rand(handles.trials,1)+0.5);

handles.index = 1;

if (handles.flip(handles.index)==0)
    i=handles.data(handles.order(handles.index),1);
    j=handles.data(handles.order(handles.index),2);
else
    i=handles.data(handles.order(handles.index),2);
    j=handles.data(handles.order(handles.index),1);
end

handles.leftimage=i;
handles.rightimage=j;
```

```
filename = sprintf('iphone%d.jpg',i);
[handles.imagei] = imread(filename,'jpg');
filename = sprintf('iphone%d.jpg',j);
[handles.imagej] = imread(filename,'jpg');
axes(handles.axes1);
image(handles.imagei);
set(handles.axes1, 'Visible', 'off', 'Units', 'pixels');
axes(handles.axes2);
image(handles.imagej);
set(handles.axes2, 'Visible', 'off', 'Units', 'pixels');

guidata(hObject,handles);



function stopexp(hObject, handles)
set(handles.left,'Enable','off');
set(handles.right,'Enable','off');
beep
disp(handles.record)
guidata(hObject,handles);


guidata(hObject,handles);
```

Appendix IV: MATLAB Code for the Experiment in Chapter 7

Code 1 Testblackmodels

```
clear
close all
load lan29blacks.mat

x = [1,1,1];
options = optimset;
x = fminsearch('fitdata',x,options,Yxy,blackness,xn,yn);

[err, b] = fitdata(x, Yxy, blackness, xn, yn);
disp(x)
disp(err)
figure
plot(blackness,b,'bo')

[err1, b] = westlandfitdata(lab, blackness);
disp(err1)

figure
plot(blackness,b,'bo')

[err2, b] = chofitdata(lab, blackness);
disp(err2)

figure
plot(blackness,b,'bo')
```

Code 2 Westlandfitdata

```
function [err,b] = westlandfitdata(lab, blackness)
```

```
b = 8.6542 - 0.2583*lab(:,1) -0.0052*lab(:,2).^2 +
0.0045*lab(:,3).^2;


err = 1-rsqroot(b,blackness);
```

Code 3 Chofitdata

```
function [err,b] = chofitdata(lab, blackness)


b = 3.02 - 0.05*(lab(:,1).^2 + 0.89*(lab(:,2)+2).^2 +
0.36*(lab(:,3)-33).^2).^0.5;


err = 1-rsqroot(b,blackness);
```

Code 4 B_{CIE}fitdata

```
function [err,b] = fitdata(x, Yxy, blackness, xn, yn)


b = x(1)*Yxy(:,1) + x(2)*(xn-Yxy(:,2)) + x(3)*(yn-Yxy(:,3));


err = 1-rsqroot(b,blackness);
```

Appendix V: Significant Differences for the Experiment in Chapter 6

The significant differences between Chinese and UK groups

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	14.0	50	0.280	3.920	0.032
Within Groups	0.500	7	0.071		
Total	14.5	57			

$P = 0.032 < 0.05$. This means that the difference between Chinese and UK group is significant.

The significant differences between male and female groups

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	14.5	54	0.269	.	.
Within Groups	0.000	3	0.000		
Total	14.5	57			

The significant differences within UK groups

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2810	28	100.4	1.486	0.058
Within Groups	21550	319	67.6		
Total	24360	347			

$P = 0.058 > 0.05$. This means that the difference between different observers in UK group is not significant.

The significant differences within Chinese groups

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1924	28	68.7	0.978	0.500
Within Groups	26496	377	70.3		
Total	28420	405			

$P = 0.500 > 0.05$. This means that the difference between different observers in Chinese group is not significant.

The significant differences within female groups

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2010	28	71.8	1.025	0.433
Within Groups	30470	435	70.0		
Total	32480	463			

$P = 0.433 > 0.05$. This means that the difference between different observers in female group is not significant.

The significant differences within male groups

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2570	28	91.8	1.363	0.115
Within Groups	13669	203	67.3		
Total	16240	231			

$P = 0.115 > 0.05$. This means that the difference between different observers in male group is not significant.