The Impact of Colour on Impulsivity, Arousal and Emotion

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The candidate confirms that the work submitted is her own and that appropriate credit has been given where reference has been made to the work of others.

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Abstract

Colour has the potential to influence people’s emotions and behaviour. However, there is little empirical research exploring in depth how colour influences performance. This study focuses on exploring the impact of colour on two particular responses: impulsivity and arousal. Response time and error rate were used as two indicators to define the levels of impulsivity and arousal. The impact of colour on impulsivity, arousal, and emotions were investigated in detail. To achieve this goal, three psychophysical experiments were conducted to explore the impact of hue and chroma on impulsivity and arousal; and how colour influences impulsivity, arousal and colour emotions such as colour heat.

The hue and chroma experiments were designed to determine whether, in a particular colour environment, response time and error rate of the participants were different across different hues and chroma levels. Participants were required to complete a range of screen-based psychometric tests with different colour backgrounds. During the experiment, participants were asked to give their responses to each test as quickly and accurately as possible. The results showed that background hue and chroma differences significantly influence response time and error rate. This suggests that colour has a distinctive influence on impulsivity and arousal. Hue has a greater influence on arousal than impulsivity while chroma affect impulsivity more than arousal. The impact of colour on impulsivity and arousal were also considered with different psychometric test types, different genders and colour preference. To explore the impact of colour on impulsivity, arousal and emotions, the emotion experiment was designed to study ten emotion scales. Participants were asked to report their emotional responses to 20 colours both on cardboard and textile fabric based on ten emotion scales. The reliability of Ou’s (2004) colour emotion models for single colour have been verified using the experimental data in this study. This result suggested that colour influence on impulsivity and arousal can be linked with other emotions. The finding from this study can be applied in various affective design, such as product packaging, consumer purchasing, education efficiency and so forth.

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List of Abbreviations in the Thesis

MFFT: matching familiar figure test

LI: low impulsivity

HI: high impulsivity

HA: high arousal

LA: low arousal

ER: error rate

RT: response time

WC: warm-cool

HL: heavy-light

AP: active-passive

HS: hard-soft

CD: clean-dirty

FS: fresh-stale

LD: like-dislike

MF: masculine-feminine

MC: modern-classical

TR: tense-relaxed

Chapter 1 Introduction

1.1 Background

Colour is an important element not only in evoking design with aesthetics and different meanings, but also in supporting design with a scientific basis. Colour impact on people's emotion and physical expression can be found in many design disciplines, such as functional clothing design, environment design, and web page design (Karvonen, 2000; Barton & Hill, 2005; Kűller, 2008; Iwase *et al*. 2010). In functional clothing design area, colour of sportswear are reported to influence an athlete's performance (Rowe, Harris and Roberts, 2005; Barton and Hill, 2005; Iwase *et al.*, 2010). Some findings can be summarised as: black and red influence sports players to be more impulsive and aggressive (Frank & Gilovich, 1988; Tiryaki, 2005; Hagemann, Strauss and LeiBing, 2008; Feltman and Elliot, 2011). Sports players wearing red always have a better performance than those wearing blue. (Hagemann *et al*., 2008). In environment design, AL-Ayash *et al.* (2015) found that vivid colours used in learning environments lead to significantly high reading scores. Kwallek (1990) indicated that people in red office make the fewest errors, compared with those in green and white office. Wang and Russ (2008) found that cool colours are more preferred as wall colours for the computer classroom. Read *et al.* (1999) reported that differentiation in wall colour is related to higher levels of cooperative behaviour among preschool children. Mckean (2014) reported the blue lights on train platforms could reduce Tokyo's suicide rate. In web page design area, colour of website is shown to be a determination for both website trust and people's satisfaction (Karvonen, 2000; Cyr *et al*., 2010). The high contract of colour combinations for text and background in web design can improve the readability of text and reduce the reading time (Ling & Schaik, 2002; Chen *et al*., 2005). Bonnardel *et al*. (2011) found that orange is the best colour appreciated by most people for web page. People normally spend more time on warm colour background than cool colour background. Green and red combination is relatively slow in speed compared with normal black and white combination (Ling & Schaik, 2002).

From the above-mentioned literature, it can be seen that there are many existing studies to explore the colour influence on people’s performance. Previous studies are mainly focus on the impact of colour on people’s performance with clear target application area, rather limited attention has been paid on the theoretical research of how colour influences people’s performance. Nevertheless, to research on the fundamental theory of colour impact on impulsivity is very meaningful. In place of giving designers more suggestions on using colour in a proper manner and show designers scientific evidence of using colour in design to improve people’s life.

Although there are many evidences that colour can influence people's emotional state (Valdez and Mehrabian, 1994; Ou *et al*., 2004; Küller *et al*., 2009), there is a lack of research in how colour influences their mental state and bodily behaviour, such as impulsivity and arousal. This kind of study has the practical applications of supporting designers with more options of how to use colour in a scientific method in order to informing their design processes. Impulsivity is defined as the behavioural ability to respond quickly and without mental reflection (Murray, 1938). Arousal is the psychobiological state of alertness or excitation of a person, leading to a condition of alertness and readiness to respond (Berlyne, 1960; Colman, 2015). Extracting from the two descriptions of impulsivity and arousal, response time and error rate are two indicators from the cognitive aspect that can be combined used as determining impulsivity and arousal together (Barratt, 1972; Buss, 1975; Barratt, 1994; Colman, 2015). The difference between impulsivity and arousal is that high impulsivity reflects as quick response with high probability of making errors, and vice versa. While high arousal performs as quick response with low error rate, and vice versa. The only published study regarding the impact of colourful pattern on impulsivity is by Zentall *et al*. (1989), who investigated black-white and colourful sample’s influence on attention-problem children and adolescent. Zentall *et al*. (1989) used response time and error rate to measure impulsivity, and found that the colour impact on impulsivity was significant. Nevertheless, to the author’s knowledge, the fundamental theory of how hue and chroma influence on people's impulsivity and arousal status is still an unexplored area.

This study extract the research topic from the reviewed background above, aiming to investigate the impact of colour on people's performance, such as response time and error rate, in order to explore the influence of colour on impulsivity and arousal. Colour influence on emotion was a well-explored area so far with many exciting findings (Valdez, 1994; Ou, 2004; Xin, 2004). The explored emotion scales are warm-cool, active-passive, hard-soft, masculine-feminine, tense-relaxed, *et al*. As impulsivity and arousal are also two types of emotional expression, this study would build the relationship between the influences of colour on impulsivity and arousal with other colour emotions, to explore the colour influence both in physiology and in psychology.

1.2 Research Aims and Objectives

The main aim of this study is to investigate the impact of colour on impulsivity and arousal by using indicators as response time and error rate, meanwhile explore the relationship among colour impact on impulsivity, arousal and emotion. This study focuses on the psychophysical experimental method and the following research objectives will be explored:

- To investigate the influence of hue on impulsivity and arousal by using the response time and error rate as indicators.
- To explore the impact of chroma on impulsivity and arousal by using the response time and error rate as indicators.
- To compare the influence of colour on impulsivity and arousal with emotions.
- To link experimental findings with design applications.

1.3 Thesis Outline

The present thesis includes seven chapters as described below:

Chapter 1 Introduction

An introduction of the whole project is summarised.

Chapter 2 Literature Review

The relevant literature are reviewed, and presented as five sections: Human Vision and Colour; CIE Colorimetry and Colour Description; Colour Used in Functional Design; Impulsivity; Emotion and Colour Emotion. The research questions and hypothesis are identified from the research gaps from the reviewed literature.

Chapter 3 Materials and Methods

The materials and methods used in this study are described in detail. The applied materials used in this study is a LCD display. The characteristics of LCD display summarised. Preparation of three psychophysical experiments has been discussed in five sections for each experiment. They are participant's determination; experiment preparation; experiment procedure; colour evaluation and data analysis.

Chapter 4 The Influence of Hues

The results collected from the hue experiment are given and discussed in this chapter, to explore the hue influence on impulsivity and arousal. The data analysis and discuss was split into three parts: hue influence on response time; hue influence on error rate; hue influence on impulsivity and arousal respectively.

Chapter 5 The Influence of Chroma Levels

This chapter discusses the results collected from the chroma experiment, to explore the chroma influence on impulsivity and arousal. The data analysis and discuss was split into four parts: chroma influence on response time, chroma influence on error rate; chroma influence on impulsivity and chroma influence on arousal.

Chapter 6: Comparison of Colour Influence on Impulsivity, Arousal and Emotion

This chapter describes data collected from emotion experiment, to explore the influence of colour on emotion. In addition, Ou’s (2004) colour emotion models for single colours are assessed. The comparison and discussion of colour impact on impulsivity, arousal and emotions was shown in the chapter.

Chapter 7: Conclusions

This chapter summarises the main findings of present study and the proposed future work.

The achievement of the seven chapters in this thesis are summarised as the flowchart shown in Figure 1.1.

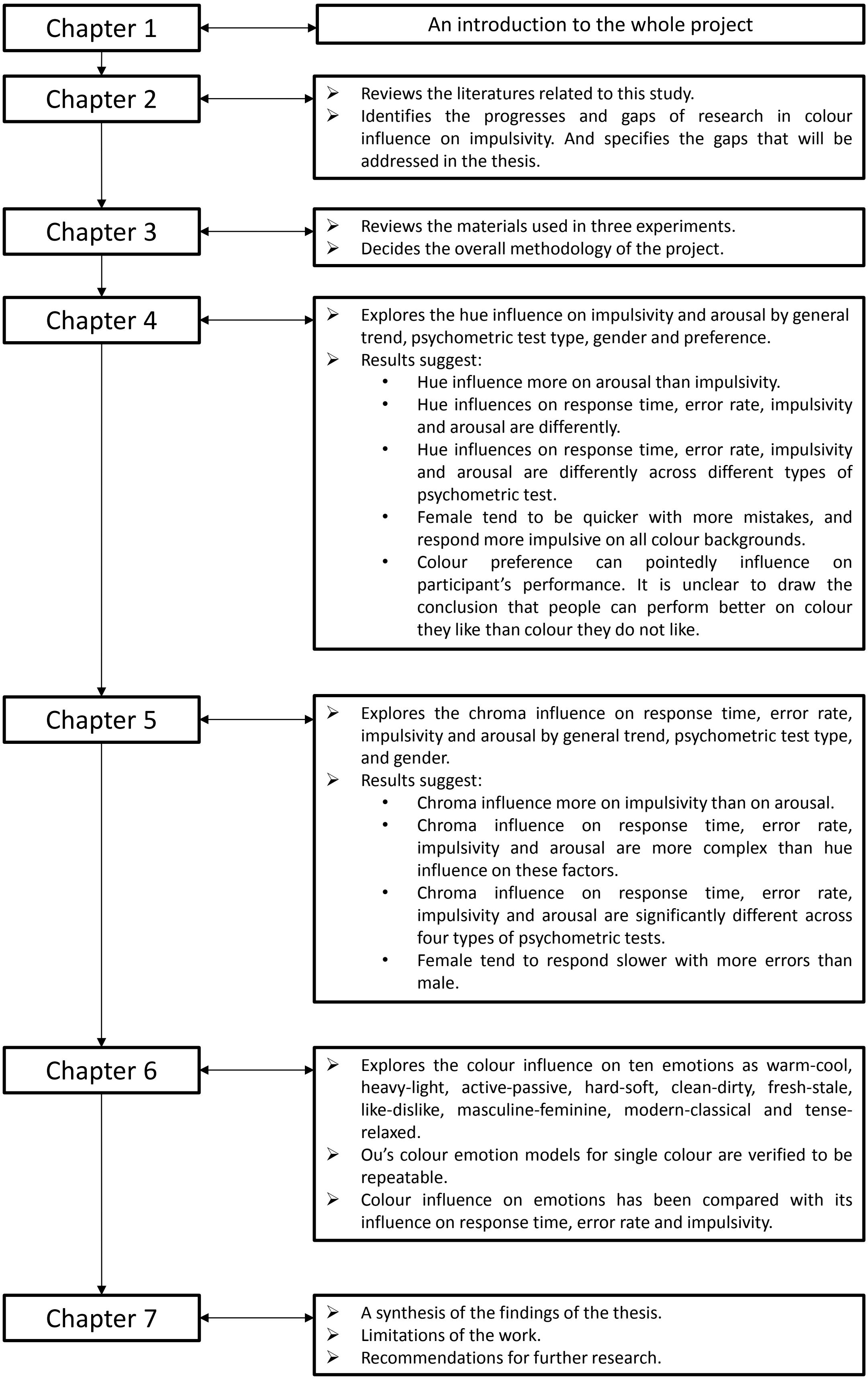


Figure 1.1 A flowchart of seven chapters and their achievement.

Chapter 2 Literature Review

The aim of this study is to investigate the impact of colour on impulsivity, arousal and emotion. A broad body of literature was reviewed in chapter 2, and this chapter is structured in five sections. This chapter provide a critical overview of colour vision, colour specification, colour in functional design, and the assessment to impulsivity, arousal and other emotions.

2.1 Human Vision and Colour

Colour: the quality or attribute in virtue of which objects present different appearances to the eye, when considered with regard only to the kind of light reflected from their surfaces.

Concise Oxford English Dictionary

2.1.1 Light Source

Light is considered as a strip of light, which Newton first called a spectrum. In the whole electromagnetic spectrum, the human visual system can only detect a small range of stimulus. Light is the visible radiation that a human can see, and it is within a narrow segment of wavelengths that lie between approximately 360 and 780 nanometres (nm). Because of different wavelengths, people can detect different colours. Within a single light beam from long wavelength to short wavelength are spectral colours from red to violet (Berns, 2000). Apart from the visible spectrum, there are other kinds of radiation include X-ray, ultraviolet, infrared, microwave and radio waves (Valberg, 2005). However, it is more common to use frequency to identify each part of the spectrum as the wavelength of light from any part of the spectrum decreases when it passes through a medium. The velocity also decreases in the same ratio as the spectrum, the frequency remains constant. Spectral power distribution (SPD) is the measurement used to quantify a light source. A spectroradiometer is normally used to measure the SPD of a light source

(Hunt, 2011). Figure 2.1 shows the visible range of the electromagnetic spectrum.

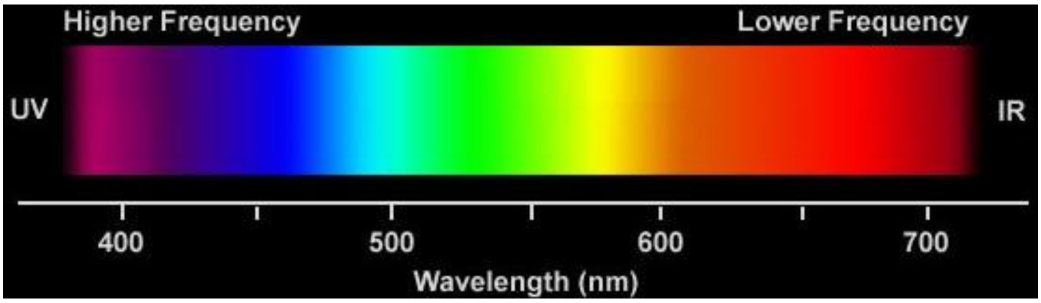


Figure 2.1 The visible range of electromagnetic spectrum (reproduced from the College of Liberal Arts and Sciences, 2013).

2.1.2 Materials and light

When light illuminates an object, some responses relevant to colour would happen based on different materials:

Transmission. Transmission describes the process when light transits through a material, which termed as transparent. (Berns, 2000).

Absorption. Apart from transmission, light can also be absorbed. Transparent materials could absorb part of the light and appeared as coloured; Black and opaque materials can absorb all the light. This process is named absorption (Berns, 2000).

Scattering. In spite of transmission and absorption, some light can also be scattered or reflected. When light illuminates a rough surface or a smooth surface object, radiation will influence a change in the direction of the light; and this process is scattering. Reflection is a special case of scattering (Kuehni, 2004).

2.1.3 Human Colour Vision

The human visual system can capture visual information based on light wavelength and this is how colour is seen. Physiologically the human visual system is the human eye and a particular part of the human brain. The visual system interacts with the environment by analysing data from visible light (Perez & Verdu, 2010; Kuehni & Schwarz, 2008).

2.1.3.1 Eye and Retina

The first section in human visual system to process images is the eye. An eyeball is spherical in shape, (Figure 2.2), and it consists of three different layers: sclerotic, choroid and retina (Perez & Verdu, 2010). Light passes through the lens, and points onto the retina, (Ebner, 2007). The retina is the layer at the back of the eyeball, which can itself separated into three layers: the retinal ganglion cells, which are located on the top of retina; bipolar cells in the middle of the retina; and the receptors, which are at the bottom. The three layers of retina are shown in Figure 2.3. The top two layers are lying above the receptor material, which can filter the incoming light to avoid any diffuse lighting. On the third layer, two groups of receptors are found; they are the rods and cones. (Ebner, 2007).

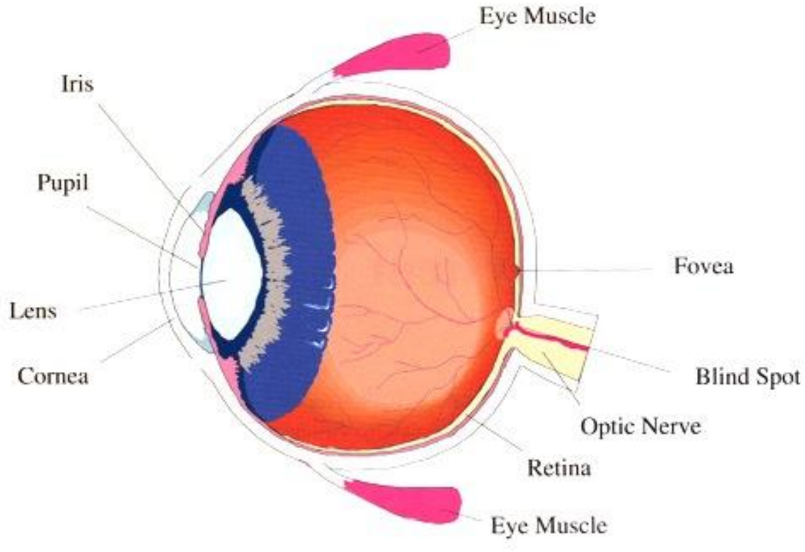


Figure 2.2 The eyeball (reproduced from Ebner, 2007).

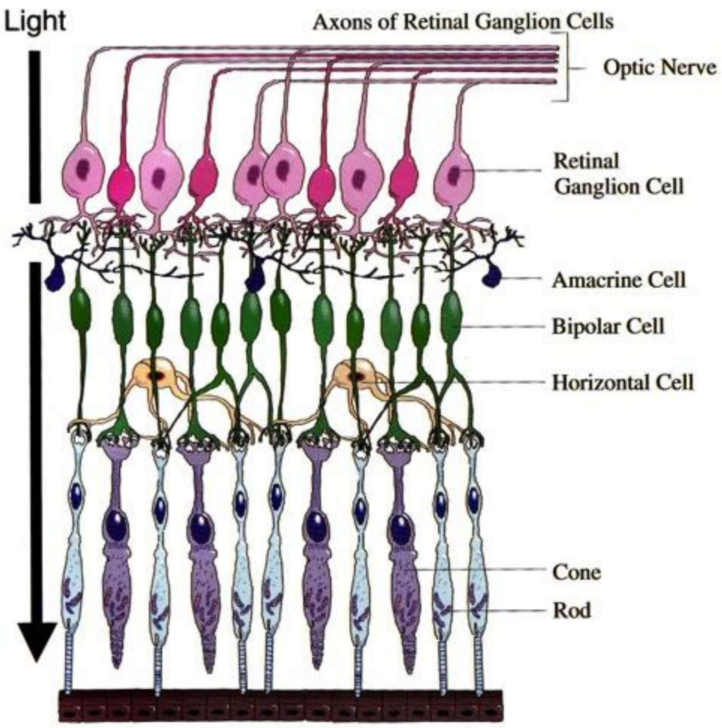


Figure 2.3 The retina, (reproduced from Ebner, 2007).

2.1.3.2 Rods and Cones

Humans (and many primates) have four receptor cell types: three types of cones that dominate daytime colour vision, and rods that dominant at night. This colour vision is called "trichromatic vision" (Kuehni & Schwarz, 2008). The rods and cones are named mainly based on their shape, and they are sensitive to light over different ranges. At night, rods could perceive very minor quantity of light, such as the glitter, starlight and moonlight and the surrounding environment can be only seen as grey colours (Berns, 2000; Hunt, 2011). Rods share the same spectrum range with those cones, which have short-wavelength sensitive and afford input to the red/green cones (Nerger *et al*., 2003). This enables rods to absorb light mostly in the blue-green part of the spectral band. Cones function under normal levels of lighting, typically daylight (Hunt, 2011). Three types of cones (L, M, S) are sensitive to different areas of the spectrum. Figure 2.4 shows the actual spectral position for each cone (Koenderink, 2010). They are maximally sensitive in the long, middle and short wavelength regions.

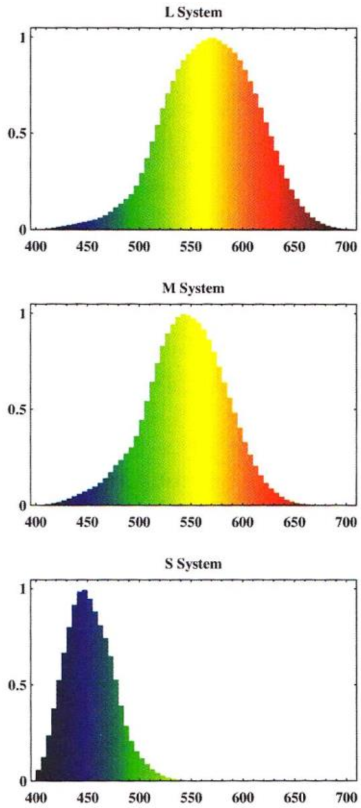


Figure 2.4 Spectral sensitivities for L, M and S cones (reproduced from Koenderink, 2010).

As seen from Figure 2.4, the three cones' spectral sensitivities overlap in some regions, especially the L and M cones. This phenomenon can increase colour discrimination. Conversely, if the cones do not overlap with each other, only three hues in the spectrum can be perceived (Berns, 2000).

2.1.4 Summary

In this section, the fundamental theory of human vision and colour are reviewed. The basics of light source, materials and light, and spectral sensitivity of the eye are summarised. A grasp of the basic knowledge and related literatures reviewed in this section provides the basic of the whole research such as supporting the experimental environment design.

2.2 CIE Colorimetry and Colour Description

Colorimetry is a synthesis of two words, colour and metrein (Greek meaning "to measure"). It is the science of colour measurement.

Berns, 2000, p45

The *International Commission on Illumination* (Commission International de l'Éclairage, or CIE) is an international commission of illumination. It aims to standardise photometry and colorimetry and to specify colour stimuli under precise viewing conditions.

2.2.1 CIE Standard Colorimetric System

CIE Standard Colorimetric System is an example of a stimulus system, which is based on additive colour mixture. In the CIE Colorimetric System, three key elements are standardised, which are light source, observers, and geometries.

Light Source

The light source is one of three essential elements of perceiving colour. It can be quantified by measuring its spectral power distribution (SPD), which is the power per unit area per unit wavelength of a visible spectrum (Hunt, 2011). Natural daylight is an important type of light source. However, daylight has three problems. Firstly, it is inconstant. Secondly, its SPD is complex. Thirdly, it is difficult to simulate this light source by using artificial incandescent sources. Therefore, the CIE introduced a series of standardised illuminants. Initially, illuminants A, B and C were introduced to represent incandescent light at temperature of about 2856K, direct sunlight at temperature of around 4874K, and average daylight at temperature of around 6774K. Later the CIE recommended a series of D illuminants to represent various phases of daylight including appropriate energy in the ultraviolet region. D65 is widely used in the paint, plastics and textile industries; and D50 is generally used in the graphic arts and computer industries (ISO/CIE, 2006(b)).

Standard Observers

There are two standard observers that have been used as the standard colour-matching functions: one is the 1931 CIE Standard Observer; and the other is the 1964 CIE Standard Observer (Berns, 2000).

The 1931 CIE Standard Observer refers to a *2° Observer* that has a visual field size ranging from 1° to 4°. The 1964 CIE Standard Observer refers to a *10° Observer* that has a visual field size greater than 4°. The colour-matching functions of *10° Observer* are notated as $\bar{x}_{10}(\lambda)$, $\bar{y}_{10}(\lambda)$ and $\bar{z}_{10}(\lambda)$, (CIE, 1988).

Standard Geometries

Apart from defining standard illuminants and standard observers, the CIE also defined the standard illumination and viewing geometries. Four geometries are introduced by CIE for measuring reflectance: 45°/Normal and Normal/45° (bidirectional geometries); Diffuse/Normal and Normal/ Diffuse (Berns, 2000; Hunt, 2011; Goodman, 2012).

Tristimulus Values

Tristimulus values (or colour matching coefficients) represent a series of primaries used to specify colour matches (Berns, 2000). The CIE named the three primaries as X, Y and Z, which can directly been calculated from the colour matching functions $\bar{x}(\lambda)$, $\bar{y}(\lambda)$ and $\bar{z}(\lambda)$ as follows:

$$X = k \int_{vis} \mathrm{R}(\lambda)\mathrm{P}(\lambda)\bar{x}(\lambda)\mathrm{d}(\lambda)$$

$$Y = k \int_{vis} \mathrm{R}(\lambda)\mathrm{P}(\lambda)\bar{y}(\lambda)\mathrm{d}(\lambda)$$

$$Z = k \int_{vis} \mathrm{R}(\lambda)\mathrm{P}(\lambda)\bar{z}(\lambda)\mathrm{d}(\lambda) \qquad (2.\ 1)$$

where k is a constant, $k = 100/\int_{vis} P(\lambda)\bar{y}(\lambda)\mathrm{d}(\lambda)$. P(λ) is the spectral distribution of the illuminating light and R(λ) is the spectral reflectance of the reflecting object. To calculate the tristimulus value of a 10° Observer: X_{10}, Y_{10}, and Z_{10}, $\bar{x}(\lambda)$, $\bar{y}(\lambda)$ and $\bar{z}(\lambda)$ are replaced by $\bar{x}_{10}(\lambda)$, $\bar{y}_{10}(\lambda)$ and $\bar{z}_{10}$ (λ) (CIE, 2011).

Chromaticity Diagram

The Chromaticity Diagram is designed to visually represent the tristimulus values and to calculate the relative tristimulus values. It is a two-dimensional space that has two co-ordinates: x and y. In a chromaticity diagram (Figure 2.5), x and y are indicated with a colour vector (X, Y, Z), X + Y + Z = 1.

$$x = \frac{X}{X + Y + Z}$$

$$y = Y/(X + Y + Z) \qquad (2.\ 2)$$

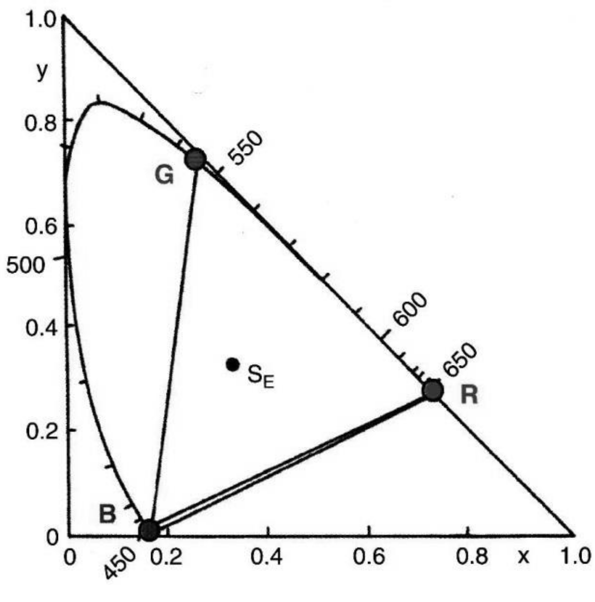


Figure 2.5 CIE x, y chromaticity diagram (reproduced from Hunt, 2011).

The curved line in Figure 2.5 is the spectrum locus, which shows the position of the colour spectrum (wavelengths are indicated in nanometres). The straight line connecting the red and blue ends of the spectrum is called the purple line. The area enclosed by the spectrum curve and the purple line indicates all real colours. Therefore, all colours can be shown on the chromaticity diagram by intersecting the x and y value. The three matching values R, G, and B have the wavelength 700nm, 546.1nm, and 435.8nm respectively (ISO/CIE, 2006(a)).

2.2.2 Uniform Colour Spaces – CIELAB and CIELUV

Although the chromaticity diagram is widely used, it suffers from some drawbacks. For example, this diagram is only suitable for colours that have the same luminance and luminance factor. It simply shows the proportions with no magnitude of tristimulus values. In addition, it is not a uniform colour space, such as the colour distribution in the space is not uniform (Goodman, 2012). Therefore, two alternative, almost-uniform colour spaces were recommended by the CIE. They are the CIE 1976 (L*a*b*) colour space (CIELAB colour space) and the CIE 1976 (L*u*v*) colour space (CIELUV colour space).

*CIE 1976 (L*a*b*) colour space (CIELAB colour space)*

The CIELAB colour space is shown by a set of three-dimensional orthogonal coordinates: L*, a* and b*. The L* axis is the vertical lightness axis, the a* and b* axes form the horizontal space perpendicular to the L* axis. The a* axis represents the redness to greenness of the colour and the b* axis represents the yellowness to blueness of the colour.

$$L^* = 116 f(Y/Y_n) - 16$$

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

$$b^* = 200[f(Y/Y_n) - f(Z/Z_n)] \qquad (2.3)$$

where $f(X/X_n) = (X/X_n)^{1/3}$ for $X/X_n > (6/29)^3$;

$f(X/X_n) = (841/108)(X/X_n) + 4/29$ for $X/X_n \le (6/29)^3$

and $f(Y/Y_n) = (Y/Y_n)^{1/3}$ for $Y/Y_n > (6/29)^3$;

$f(Y/Yn) = (841/108)\,(Y/Yn) + 4/29$ for $(Y/Yn) \leq (6/29)^3$

and $f(Z/Zn) = (Z/Z_n)^{1/3}$ for $Z/Z_n > (6/29)^3$;

$f(Z/Zn) = (841/108)\,(Z/Zn) + 4/29$ for $Z/Zn \leq (6/29)^3$.

The X, Y, Z and X_n, Y_n, Z_n are tristimulus values for the stimulus and reference white respectively.

The hue-angle (h_{uv}) can be defined as

$$h_{ab} = \arctan(b^*/a^*). \quad (2.\ 4)$$

The associate of chroma (C^*_{uv}) can be evaluated as

$$C^*_{ab} = (a^{*2} + b^{*2})^{1/2} \quad (2.\ 5)$$

*CIE 1976 (L*u*v*) colour space (CIELUV colour space)*

The second CIE colour space is the CIELUV colour space. This is a similar colour space to the CIELAB colour space, where L* represents lightness and u*, v* represent the redness – to – greenness and yellowness – to – blueness of colours.

$L^* = 116f(Y/Yn) - 16$

where $f(Y/Yn) = (Y/Y_n)^{1/3}$ for $Y/Y_n > (6/29)^3$;

$f(Y/Yn) = (841/108)\,(Y/Yn) + 4/29$ for $(Y/Yn) \leq (6/29)^3$.

$u^* = 13L^*\,(u' - u'_n)$

$$v^* = 13L^*\,(v' - v'_n) \quad (2.\ 6)$$

the u'_n and v'_n are the value of u' and v' for the properly chosen white reference.

$$u' = \frac{4X}{X + 15Y + 3Z}$$

$$v' = 9Y/(X + 15Y = 3Z) \quad (2.7)$$

The hue-angle (h_{uv}) can be defined as

$$h_{uv} = \arctan(v^*/u^*). \quad (2.8)$$

The associate of chroma (C^*_{uv}) can be evaluated as

$$C^*_{uv} = (u^{*2} + v^{*2})^{½} = L^* S_{uv} \quad (2.9)$$

$$S_{uv} = 13[(u'-u'_n)^2 + (v'-v'_n)^2]^{1/2} \quad (2.10)$$

All the quantifying equations for CIELAB: L* value, a* value, b* value, C^*_{ab}, h_{ab}; and for CIELUV: L* value, u* value, v* value, C^*_{uv}, h_{uv}, S_{uv} are referenced from *ISO 11664-4:2008 (E)/CIE S 014-4/E 2007* and *ISO 11664-5:2009 (E)/CIE S 014-5/E 2009*.

The CIELAB colour space is a commonly used uniform colour space in the graphic design and textile industries. It has a larger colour gamut than human colour vision, colour printing and colour displaying. In this research, the CIELAB colour space is selected due to its simple structure and used for specifying colour and analysing data.

2.2.3 Calculating Colour Difference

Defining the difference between two stimuli plays important role in colorimetry. The simplest way to define the colour difference is calculating the distance between the tristimulus values of the two stimuli. However, none of the colour spaces are exactly uniform even for the CIELAB and CIELUV colour spaces. The research in defining a more accurate calculation for colour difference is still continues. The CIELAB formula for calculating colour difference according to the CIELAB colour space is shown below (Berns, 2000).

CIELAB Formula:

$$\Delta \boldsymbol{E}^*_{\boldsymbol{ab}} = [(\Delta \boldsymbol{a}^*)^{\boldsymbol{2}} + (\Delta \boldsymbol{b}^*)^{\boldsymbol{2}} + (\Delta \boldsymbol{L}^*)^{\boldsymbol{2}}]^{\boldsymbol{1/2}} \quad (2.\ 11)$$

$$\Delta \boldsymbol{E}^*_{\boldsymbol{ab}} = [(\Delta \boldsymbol{L}^*)^{\boldsymbol{2}} + (\Delta \boldsymbol{C}^*_{\boldsymbol{ab}})^{\boldsymbol{2}} + (\Delta \boldsymbol{H}^*_{\boldsymbol{ab}})^{\boldsymbol{2}}]^{\boldsymbol{1/2}} \quad (2.\ 12)$$

where $L^* = Lightness$

$a^*, b^* = chromaticity\ coordinates$

$C^*_{ab} = chroma$

$\Delta H^*_{ab} = hue\ difference$

$$\Delta H^*_{ab} = [(\Delta E^*_{ab})^2 - (\Delta L^*)^2 - (\Delta C^*_{ab})^2]^{1/2}$$

Or $$\Delta H^*_{ab} = 2\left(C^*_{ab,1} - C^*_{ab,2}\right)^{1/2} sin(\Delta h_{ab}/2)$$

$C^*_{ab,1}$ and $C^*_{ab,2}$ are the values of C* of the two comparing samples, and Δh_{ab} is the values of the two samples' value difference (Robertson, 1977; CIE, 1995).

2.2.4 Colour Description

Hue, lightness and chroma or saturation are three basic terms to describe a colour. The difference between chroma and saturation is the ratio either to the brightness of a reference white for the samples (chroma) or to the brightness of the sample itself (saturation).

Hue: Attribute of a visual perception refereed to which an area performs to be related to red, yellow, green, or blue, or to a mixture of neighbouring two of these colours considered in a closed circle.

Lightness: The brightness of an area refereed according to the brightness of a similarly illuminated area (i.e. reference white) that exhibits as white or highly transmitting (i.e. from light to dark).

Brightness: An area, which appears more or less light.

Chroma: The colourfulness of an area that is judged in the proportion to the brightness of a similarly illuminated area (i.e. reference white) that performs to be white or highly transmitting (i.e. from strong to weak).

Colourfulness: An area exhibits more or less of its hue.

Saturation: The colourfulness of an area, which is judged in the proportion to the brightness of the area itself.

All the definitions for hue, lightness, brightness, chroma, colourfulness and saturation are referenced from *Berns' "Billmeyer and Saltzman's Principles of Color Technology"* (2000) and *Hunt's "Measuring Colour"* (2011).

2.2.5 Summary

This section summarised the basics of measuring colour, colour difference formulae, and describing colour. Knowledge reviewed in this section is of importance in this research. With the fundamental knowledge and basic rules, it is possible to prepare all the elements for the next experimental stage, such as selecting colour samples based on a standard colour system, measuring the accurate tristimulus value of different colour samples, and producing colours cross media.

2.3 Colour in Functional Design

Colour is widely used in our neighbourhood and daily life, in terms of graphics, paints, and products for both outdoors and indoors. Many researchers have discussed the function of colour in improving people's performance in different design areas, such as sportswear design, environment design and web design (Hanna, 2004; Barton and Hill, 2005; Küller, 2008; Strauss and LeiBing, 2008; Iwase *et al.*, 2010; Feltman and Elliot, 2011; Bonnardel *et al*. 2011; Al-ayash, 2013). In this section, some examples are presented to discuss how colour are used to improve people's performance in different design areas as sportswear design, environment design, and web design. From the review in this section, issues found from the present design cases can inform the research questions of this study.

2.3.1 Colour in Sportswear Design

The most widely researched area in fashion industry according to how colour used in clothing can influence people's performance is sportswear design. Rowe, Harris and Roberts (2005); Barton and Hill (2005); Iwase *et al*. (2010) all reported that colour of sportswear played an important role in affecting the behaviour and performance of competitors and athletes. Frank and Gilovich (1988) reported that professional sports players who wear black uniform were more aroused and aggressive. Hagemann, Strauss and LeiBing (2008) found that professional sports players wearing red performed better than those wearing blue. Some more research shown that colours such as black and red are usually reported to make competitors more impulsive and aggressive (Frank and Gilovich, 1988; Tiryaki, 2005; Hagemann, Strauss and LeiBing, 2008; Feltman and Elliot, 2011). All these findings pointed out that clothing colours such as red, blue and black not only affects people's own emotion and physical expression, it can also influence people who recognised these colours. It therefore can conclude that in professional sports games, clothing colour may be a deciding factor when competitors have similar abilities.

2.3.2 Colour in Environment Design

Colours such as yellow, orange, and red are often considered as warm and exciting; while green, blue-green, blue are regarded as cold and relaxing colours (Küller, 2008). Gerard (1958) conducted an experiment with red, blue green and white lights of equal luminance projected for 10 minutes on a circular translucent screen. People place themselves in the colour environment and some of their physiology indicators were collected. Wilson (1966) also carried out a similar experiment. The main findings from these two studies were (1) The cortical arousal, blood pressure, galvanic skin response, respiration rate, and frequency of eye blinks were different under the different colours and (2) The galvanic skin response was higher in the red than in the green condition. Jacobs and Hustmyer (1974) found that among the red, yellow, green and blue colours with the same luminance, red was the most arousing colour, followed by the green, yellow and blue. Some research has explored the influence of an interior space's colour on psychological mood of people in that space. Lightness, hue and saturation are the three important factors. They found that physical strength might be increased in a red compared to a blue environment (red referred to a warm environment and blue referred to a cool environment) (Küller, 2008). Kwallek (1990 – 2007) found that colours could influence people's screening ability. Compared to the low screeners, high screeners performed better in a red office and worse in a blue-green office. People in the red office made fewer errors than in the green and white office. Küller (2008) found that strong colours and patterns such as red put the brain into a more excited state, and sometime cause a slowing of the heart rate. In addition, he found that warm colours could be applied to add some extra arousal to a monotonous situation. Al-ayash (2013) found that people felt more relax, calm and pleasant under the light colour conditions, and the reading scores were significantly higher under the pure colour conditions. Hear rates were significantly affected by hue: they increased in the red and yellow conditions. Blue can increase relaxation and calmness feelings.

From the research in fashion design and environment design, although the target research areas are different, the findings from all these experiments are agreed well with each other. For example, in both fashion and environment design, red is the colour been studied very often that could arouse people's performance, and blue can usually influence people to be more calming and relaxing. As most of research refer red as a warm colour, blue as a cool colour, this phenomenon maybe can conclude as warm colours can influence people to be more arousal, while cool colours can relaxing people.

2.3.3 Colour in Web Design

Visual aesthetics play an important role in web page design. Colour is one element that can make important effort on. Website colour has shown to be a significant determination for both website trust and satisfaction (Karvonen, 2000; Cyr *et al*., 2010). It is reported that high contrast of colour combinations for background and text in web design improve the text readability and reduce the reading time (Ling & Schaik, 2002; Chen *et al*., 2005). Bonnardel *et al*. (2011) suggested orange is the colour that the majority of people would appreciated for web page background. People generally spend more time on orange background (which considered as warm background) than blue background (which considered as cool background). However on the other hand, the favoured of orange not only means people like to spend more time on orange webpage, but also means the memorisation and retrieval of information need more time from the orange website. Ling & Schaik (2002) reported that colour combination of web design impact both accuracy and speed of visual research. The green and red combination was relatively slow in speed, compared with black/white, and black/yellow combination. Hall & Hanna (2004) found that blue against black has the highest score on behavioural intention, followed by the cyan on black background. Positive colours make people feel more relaxed, which directly influence people's speed of perception. People under the positive colour condition perceived the page as downloading faster than negative colour condition (Gorn, *et al*. 2004). All these findings mentioned above indicate that colour has a significant influence on web design in terms of people's readability, behavioural intention and buying impulsivity.

2.3.4 Summary

The application of colour impact on people's performance is an area that has attract many researchers' attention. Researchers use the findings from their studies to choose the most appropriate colours in many design fields. However, there is a lack of study in studying the fundamental theory of colour's influence on people's impulsivity and performance. There is a need to study the fundamental theory of colour influence on impulsivity and people's performance without any target application area. From the published studies, it can be seen that, the colours normally used are divided into two groups: one is regarding to warm colour and cool colour, which is termed as hue; the other is based on the pure and light colour, which is chroma. In this study, colour is explored in terms of the widely used two indicators namely hue and chroma.

2.4 Impulsivity

Zentall and Dwyer (1989) described impulsivity as fast and inaccurate responding. Plutchik (1995) determined impulsivity with several characteristics: (1) Respond quickly without reflection; (2) Inability to maintain attention; (3) Aggression behaviours as suicide, homicide and sexually aggressive; (4) Impulsivity is a part of the aspect of friendliness; (5) Acting without thinking and tend to finish the things quickly. Impulsivity trait is interacted with other personality traits, which influence people’s everyday behaviours (Plutchik and Praag, 1995). Figure 2.6 shows a very high impulsive personality profile based on the emotion profile. From the figure, it can be seen that high impulsivity highly associated with decontrolled and aggressive.

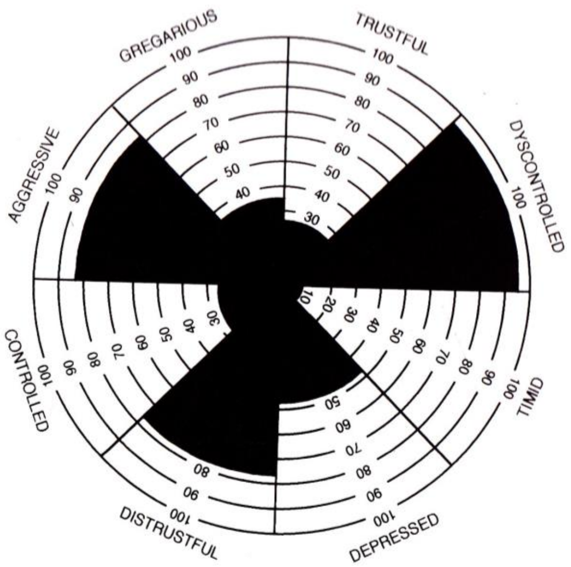


Figure 2.6 An example of a very high impulsive personality profile based on the emotion profile (reproduced from Barrett and Patton, 1983).

2.4.1 Measuring Impulsivity

Impulsivity is a common clinical problem, which implicated in a number of psychiatric disorders including mania, personality disorders and substance use disorders (International Society for Research on Impulsivity, 2016). A broad discussion regarding the exact definition of impulsivity, and how it can be measured never ending in the last several decades since people first determine the terminology of impulsivity. The normal measurements of impulsivity including neuropsychological test, behavioural tasks, self-report scales and observer-rated measures. The history of measuring impulsivity can be date back to 1960s. Eysenck and Eysenck (1963) started to consider establishing an independent impulsiveness scale to keep the research on impulsiveness orthogonal. This was the first well-established self-reported questionnaire for measuring impulsivity. Nearly the same time, Kagan (1964) and his team investigated the lab-based cognitive measure: matching familiar figures test, which is now probably the most widely used measure for studying impulsivity in children and teenager. Later, many other self-reported measure methods and cognitive measure methods were developed. For self-report measures, the most important two scales are I.7 impulsiveness questionnaire (Eysenck and Eysenck, 1978) and Barratt impulsiveness scale (Patton *et al*., 1995). The cognitive measures including a range of testing methods, such as the Matching Familiar Figure Test, Rorschach Test, the Porteus Maze Test, Trail Making Test, Wisconsin Card Sorting Task, Circle Tracing, Balloon Analogue Risk Task, Cued Go-No Go Test, and so on. They are all developed to measure some representations of impulsivity. Table 2.1 lists some typical self–report measures and cognitive measures of impulsivity.

Table 2.1 Summary of measuring impulsivity methods (summarised from Webster *et al*. 1997; International Society for Research on Impulsivity, 2016).

Self-report Measures	
(1) The I.7 Impulsiveness Questionnaire.	
Establisher & Year	Eysenck and Eysenck, 1978.
Assessment Factors	Impulsiveness; Venturesomeness; Empathy.

Example	Do you often long for excitement? (Impulsiveness)
(2) Barratt Impulsiveness Scale (BIS-11).	
Establisher & Year	Patton, Stanford, and Barratt, 1995.
Assessment Factors	Personality; Behavioural Construct of Impulsiveness.
Example	I plan task carefully. (1) Rarely/Never; (2) Occasionally; (3) Often; (4) Almost Always/ Always
Advantage & Disadvantage Of Self-report Measures	Advantage: short and easy to administer. Disadvantage: require advanced level of reading. The scores of this type of test depend on a subject's honesty and awareness of his or her behavior patterns. Impulsive subjects with little awareness of their behavioural tendencies will obtain spuriously low scores on the test.
Neuropsychological Cognitive Measures	
(1) Matching Familiar Figures Test (MFFT)	
Establisher & Year	Kagan, Rosman, Day, Albert, and Phillips, 1964.
Assessment Factors	Response time and errors.
Example Description	It consists of 12 match-to-sample trials. In each trial, the subject is required to search an array of pictures for the one that exactly matches a criterion picture.
Advantage & Disadvantage	Advantage: Most widely used measure in studies of impulsivity in children. Disadvantage: The poor performance may be attributable to deficits unrelated to impulsivity.
(2) Circle Tracing and Related Tasks	
Establisher & Year	Bachorowski and Newman, 1985.
Assessment Factors	Tracing time.
Example Description	The subject is requested to trace over a 0-inch circle as slowly as possible.
Advantage & Disadvantage	Advantage: Simple and easy to administer. Disadvantage: Speedy performance may also be attributable to factors other than impulsivity. The test may only detect the more severe forms of impulsivity.

(3) Trail Making Test	
Establisher & Year	Lezak, 1995.
Assessment Factors	Response time and errors.
Example Description	The test consists of two parts. In first part, the subject is asking to draw lines to consecutive connect randomly placed numbers as quickly and accurately as possible. In the second part, the subject is asking to connect consecutive numbers and letters in an alternating sequence as quickly and accurately as possible.
Advantage & Disadvantage	Advantage: The necessary materials can be easily assembled. Reliability coefficients are generally acceptable. Disadvantages: The main problem is the scores reflect multiple cognitive processes and abilities, including attention, short-term memory, visuomotor coordination *et al*. The test is weak to repeat owing to the long-term learning and memory.
(4) Balloon Analogue Risk Task (BART)	
Establisher & Year	Lejuez, Read, Kahler, Richards, Ramsey, Stuart, Strong, and Brown, 2002.
Assessment Factors	Risk taking behaviour.
Example Description	In the task, the participant is presented with a balloon and offered the chance to earn money by pumping the balloon up by clicking a button. Each click causes the balloon to incrementally inflate and money to be added to a counter up until some threshold, at which point the balloon is over inflated and explodes.
Advantage & Disadvantage	Advantage: BART score is related to self-reported engagement. Disadvantage: As BART mainly measure risk taking behaviour, there has some uncertain relation between risk taking and impulsivity.
(5) Cued Go No-Go Task	
Establisher & Year	Fillmore, 2003
Assessment Factors	Response Time and Errors.
Example Description	The task manipulates response prepotency by presenting a preliminary go or no-go cue before the actual go or no-go target is displayed.

Advantage & Disadvantage	Advantage: a simple task to assess the subject's impulse control in clinical. Disadvantage: Additional tasks are needed to assess other aspects of impulsivity.

The discussions of these different types of tasks are still on going, some studies suggested that as impulsivity is a multidimensional construct that is composed of several impacting factors, the widely used measures are not correlated well with each other (Barrett & Patton, 1983; Gerbing, *et al*., 1987; Webster, *et al*., 1997). It is therefore suggested that multiple techniques maybe a better choice to assess impulsivity in order to provide a more complete picture of the construct. Owing to the low correlation in-between different types of measures and the diverse possibility of laboratory-type cognitive measures, this research decided to measure impulsivity only with laboratory-type behavioural tests. Some of the laboratory-type tests are mainly used for children such as Draw a Person test, Bender-Gestalt test, and the Porteus Maze test (Oas, 1985). Some of the tests have different version with adults and children, such as the Matching Familiar Figures test and the Porteus Maze test. They all have an extended adult addition built on the children's version (Messer, 1976; Porteus, 1959). The Rorschach test, the Trail Making test and the Wisconsin Card Sorting test are mainly working with adults (Lysaker, 1995). Details of several different types of laboratory-type of cognitive measures (the Matching Familiar Figure Test, the Colour-Form Sorting Test, the Rorschach test, the Porteus maze test and the Trail Making test) are summarised in detail in the following sections.

The Matching Familiar Figures Test (MFFT)

There is an extensive body of research on the MFFT, with the original study dating back to 1964 (Kagan, 1964). Stanford (1996) reported that the MFFT was the instrument widely used in measuring reflection and cognitive impulsivity. Zentall and Dwyer (1989) were the only research groups that research on colour effects on impulsivity. The methods they chose to use is the MFFT. Figure 2.7 shows an example of a typical MFFT. In this test, participant is asked to select one of six alternative pictures that match a standard picture. Both total errors and the first response time are measured.

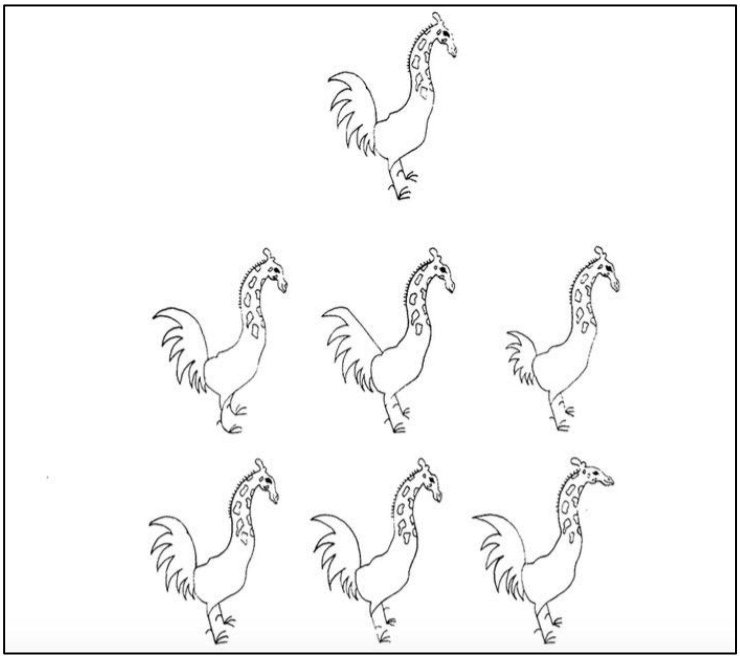


Figure 2.7 An example of Matching Familiar Figure Test (MFFT), (reproduced from Kagan, 1964).

Kagan's Matching Familiar Figures Test (MFFT) developed by Kagan and his co-workers (1964) was a method frequently used in reflection-impulsivity to distinguish an impulsive person from a reflective one. The MFFT consists of a series of 12 arrays. The children's version is asking children to choose one from an array of six outline figures, whereas the adult's version adding two more outline figures (totally eight) in the array. During the test, people are conducting the works individually, and individual score will compare to the average score of the whole group. There are two main indicators collect from the test: one is the average response latency (time to first response) based on the median split of the average response latency; the other is the total number of errors. Four cognitive styles can be classified according to these two indicators (Arizmendi, 1981):

- Impulsive: below the median in response time and above in errors.
- Reflective: above the median in response time and below in errors.
- Fast-accurate: below the median on both variables.
- Slow-inaccurate: above the median on both variables.

Although the MFFT is almost an exclusively method in researching impulsivity, some recent research focusing on both children and adult version of MFFT indicates that impulsive people do differ from reflective ones in their information-processing style (Davidson, 1984). There are some discussions involved in the critical reviews of this method. Gough (1965) pointed out that the MFFT serves as an aid to analyse the individual case rather than group data. Denny (1974) and Christos (1973) stated that in the MFFT response latency and error, no significant differences were found with differences in IQ, scholastic aptitude test scores, grade point average, or speed and accuracy of reading. However, Block (1974) showed that with children, the MFFT errors are only temperately correlated with the MFFT response latency, but the errors may arise from a number of factors including anxiety, low intelligence, misunderstanding of the instructions and so forth. Broek (1987), who found that the MFFT data with children is influenced by the general intelligence, supported Block's result (1974). The general intelligence may defeat impulsive and reflective, whilst these factors (e.g. IQ, and scholastic aptitude test scores) are not significantly influence the MFFT data with university students (Davidson, 1984). Weijiers (2001) confirmed from analysis of the MFFT with detoxified alcoholics, and found that impulsivity is closely linked to intelligence. Denny (1979, 1981-82) found that age effects significantly on both latency and errors: older participants exhibited greater response times and made more errors than younger ones.

There are also many discussions about the reliability of the MFFT data, including both test-retest and internal consistency of the MFFT, and the correlation of the latency and error in the MFFT. Originally, Kagan (1965) did a test-retest reliability test from three weeks to two and a half years, yielding a satisfactory reliability coefficient of 0.62 for latencies and 0.23 – 0.43 for error scores. Table 2.2 –

Table 2.3 summarised the repeatability, internal consistency, and error-latency correlation of the published studies on MFFT experiment. Ault (1976) suggested the lack of standardization of test items and test length in the MFFT could be a serious methodological problem. Nuessle (1972) found that reflective children are more accurate and take significantly higher time than impulsive children take in the MFFT. While Cámara and Cámara (1987) stated that inefficient performers (impulsive and slow-inaccurate one) have shorter latency than the efficient ones, although the relationship is poor. They explained that the poor relationship as short responses did not show that the items are randomly solved, and long times also did not mean the time is all used in evaluating the possible solutions. Broek (1987) mentioned that age and intelligence are important factors associated with the number of errors made on the test, while the latency is relatively independent of these factors. Block (1974) and Egeland (1980) indicated that the number of the MFFT errors is the most important variable, rather than the MFFT latency between reflective and impulsive children.

Table 2.2 The test-retest reliability of MFFT error scores.

Study	**Sex**	**Inter test Interval**	***r***
Adams 1972	F	3 weeks	0.39
Siegelman 1969	M&F	Not specified	0.43
Yando & Kagan 1968	M	Fall to spring	0.24
Yando & Kagan 1968	F	$2^1/_2$ years	0.33
Messer 1970	M&F	Fall to spring	0.23

Table 2.3 The internal consistency reliability of MFFT error scores.

Study and Approximate Age or Grade	**Coefficient**
Ault, R. L., unpublished data 1971, a, b: 3rd grade	0.57
Ault 1973, a, b: 1st grade	0.39
Ault 1973, a, b: 3rd grade	0.54
Ault 1973, a, b: 5th grade	0.50
Ault, R. L. & Crawford, D. E., unpublished data 1971, a, b, c: 1st grade	0.54
Ault, R. L. & Crawford, D. E., unpublished data 1971, a, b, c: 2nd grade	0.55
Ault, R. L., Mitchell, C., Smith, B. & Richardson, R., unpublished data 1975, a: 3rd grade	0.58
McKinney, J. D., personal communication, September 1974: 7 years	0.57
McKinney, J. D., personal communication, September 1974: 9 years	0.60
Messer, S., personal communication, October 1974, a, b: 2nd and 3rd grade	0.32
Rupert, P., personal communication, October 1974: 2nd and 3rd grade	0.61

Table 2.4 The error-latency correlations for MFFT data.

Study	Grade	Male	Female	Both
Ault 1973	1st	…	…	-0.55
Ault 1973	3rd	…	…	-0.57
Ault 1973	5th	…	…	-0.63
Denney 1973	2nd	…	…	-0.39
Eska & Black 1971	3rd	-0.69	-0.56	…
Hemry 1973	1st	-0.62	…	…
Kagan *et al*. 1964	3rd	-0.66	-0.47	…
Kagan *et al*. 1964	3rd	-0.57	-0.51	…
Kagan *et al*. 1964	4th	-0.65	-0.60	…
Kagan 1965	1st	-0.50	-0.61	…
Kagan 1965	2nd	-0.65	-0.65	…
Kagan 1965	3rd	-0.75	-0.47	…
Kagan 1965	3rd	-0.46	-0.62	…
Meichenbaum & Goodman 1969	K	…	…	-0.64
Messer 1970	3rd	-0.62	…	…
Ward 1968	K	-0.02	-0.39	…
Ward 1968	K	-0.39	-0.26	…
Yando & Kagan 1968	1st	-0.53	-0.59	…
Yando & Kagan 1968	1st	-0.37	-0.48	…

From the above discussion and tables it can be seen that, there is a widely discussion on weather latency and errors are two independent indicators, and if they are the only indicators could influence on impulsivity. Although the discussions shows various opinions, there is an agreement that latency and errors are two indicators widely used in measuring impulsivity, and they can generally represent impulsivity.

The MFFT with children may influenced by some more uncertainties than with adults. To obtain a higher rate of statistically significant between the MFFT latencies and errors, Cámara and Cámara (1987) suggested increasing the experiment items in order to isolate the randomly responding items. The cognitive-response item keeps a high statistically significant correlation of the latency and error. Arizmendi (1981) emphasized that there is a need for norms in the MFFT, such as standardising the test scores (wherein the items' IQ), and using the split-half method of reliability assessment instead of the test-retest technique as impulsivity style changes developmentally. Ault (1976) found the methods to resolve the low error reliability from several aspects including repeated measures control groups, increasing sample size, and increasing the test length. A test of 80-96 items would be necessary to increase the reliability from current average of 0.52 to 0.90.

Why does the MFFT still used? The possible reasons are summarised:

- The procedure of the MFFT is simple and inexpensive, which is beneficial for doing a large amount of repeat tests.
- Many empirical evidences support that the MFFT is a reliable method for differentiating extreme levels of reflection and impulsivity.
- The MFFT does not rely on subjective ratings of an item's behaviour. Both a behavioural and cognitive level of impulsivity can be observed during the MFFT.
- The MFFT test is very difficult to fake as it is judged by performance rather than opinion.
- The MFFT scores appeared to be reliable prognosticators of impulsivity behavioural outside the testing environment even the research on predictive validity is lacking.

Usually the MFFT works in a traditional way, which is the experimenter controlled MFFT. It also can be conducted in a computerised way by using the Apple MacIntosh (MacMFFT). No differences are found between test-retest reliabilities and internal consistencies of the MacMFFT and the traditional way (Merriënboer, 1989).

As mentioned above, the MFFT is still a fundamental and widely used behavioural method in measuring reflection-impulsivity. There are some other attempts to distinguish colour and shape influence on reflection-impulsivity, such as the Colour-Form Sorting test and the Rorschach Test. The indicator of these tests is the latency differences that people react to different colour and shape.

The Colour-Form Sorting Test and the Rorschach Test

Apart from the MFFT, the Colour-Form Sorting test is another type of test that determines the differential development of reflection-impulsivity. This test is designed to determine whether young children have a preference of sorting solid colour figures based on colour and form that perceiving motion. Research shows that with the increase in age, children are more likely to form sorting than colour sorting (Murray, 1964; Katz, 1971).

Another colour and shape based test is the Rorschach test, which is also known as the inkblot test, normally using ten black printed inkblots on 7" by 9 *3/4*" white cards. Participants are required to point out what the inkblot seems to resemble. Rorschach and his followers showed that the visualisations of the inkblot are unique to participant's personality. Figure 2.8 is one sample of ten Rorschach inkblot patterns. Rorscharch (1921) suggested that people who gave pure colour responses in inkblots are impulsive, hotheaded, hyper-aggressive, and irresponsible. However, a review by Cerbus (1963) indicated that there is no support for the common hypothesis that response to colour is associated with impulsivity or relative variables. As the Rorschach test suffers from a low reliability, it is suggested that personality measures might be developed from Colour-Form Sorting test. Younger children generally have greater difficulty controlling impulse than older children do. Therefore, it is reasonable to conclude that one child can make quicker responses with the decrease in age as no inhibition or colour responses are required. Some researchers found that there was a significant decline in speed of adults sorting the shapes than colours (Katz, 1971; Murray, 1964; Hamlin, 1955). However, Katz (1971) claimed that, as there was a lack of theoretical explanation, research on colour-form sorting method failed to explain the trend.

Figure 2.8 An example of the Rorschach Test (reproduced from the Medical Futurist and Webicina Kft., 2016).

The Porteus Maze Test

The Porteus maze test is to assess impulsivity with qualitative score using the given weights attached to each type of error made by participants when they trace the way out of maze (Porteus, 1973). Figure 2.9 shows an example.

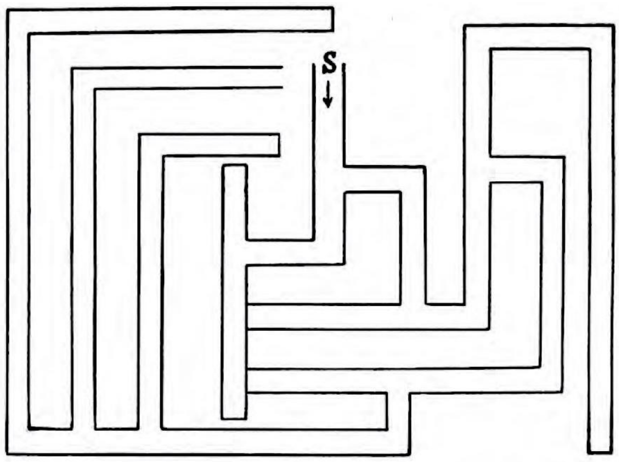


Figure 2.9 An example of Porteus Maze Test, (reproduced from Porteus, 1973).

The Trail Making Test-forms A and B (TMT)

The TMT test mainly assesses visual-motor scanning ability and attention. For form A test, participants are required to connect numbered circles in ascending order within the shortest period of time. For form B test, participants are asked to connect the numbered circle to the lettered circles in ascending order (Figure 2.10). The average response time for parts A and B tests, and the different response time between the two are measured (Glicksohn, 2006).

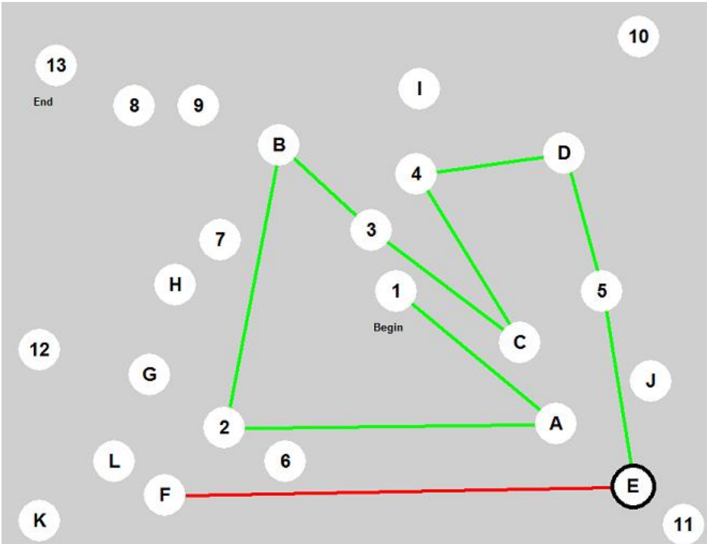


Figure 2.10 An example of Trail Making Test (TMT), (reproduced from DYNSEO, 2014).

2.4.2 Colour and Impulsivity

Studies on colour and impulsivity are very limited. Zentall *et al*. (1985) studied colour effects on impulsivity with attention-problem adolescents, using black and white and colourful patterns to make comparison. They found that colour stimulation reduced errors for the attention-problem adolescents. Zentall *et al*. (1989) conducted a continuous similar research with hyperactive children, by using the MFFT experiments and indicators such as response time and errors to measure impulsivity. The results showed that for hyperactive children, the effects of colour stimulation were similar to those of the stimulant medication. Colour has the ability to extract the attention of children, making them less straightforward. The comparison of black and white pattern with colourful pattern showed that high chroma pattern (the colourful pattern) has significantly different influence on children's impulsivity, compared with the low chroma pattern (the black and white pattern). Children were less impulsivity with colourful patterns when they did the tests. To the author's knowledge, rather limited research has been done to explore the influence of colour on people's impulsivity, Zentall was the only case.

2.4.3 Arousal

Arousal is the physiological and psychological state of being awoken. This reaction involves activation of the reticular activating system in the brainstem, the autonomic nervous system and the endocrine system, resulting in increased blood pressure, heart rate and a condition of sensory alertness, mobility and readiness to respond. Arousal is important in regulating consciousness, attention, alertness and information processing (Colman, 2015). From daily life, to be aroused means to be wide-awake, alert, vigorous, excited and full of pep (Thayer, 1989), whereas to be unaroused means to be sleepy, sluggish, tired, and relaxed. Literally, arousal or activation defines a situation regarded to vary in a continuum from a low point in sleep to a high point in extreme effort or intense alertness (Duffy, 1962).

2.4.3.1 Measuring Arousal

Arousal is considered as a fundamental emotion related to performance and behaviour. There are numerous methods to measure arousal, and the three main types are (Andrea, 2005):

1) Self-reporting method, such as verbal scales, non-verbal scales.
2) Psychophysical measures, such as the paper-folding and cutting task.
3) Psychophysiological measures, such as EEG, heart rate, and EDA, or studies with brain-imaging technologies.

Similar with measuring impulsivity, response time and number of errors are normally used indicators for the psychophysical method to measure arousal (Husain, 2002; Sykes, 2003; Küller, 2008; Bakker *et al*., 2014). A fundamental theory of emotion, the three faces of emotion law, might explain the similarity of measuring impulsivity and arousal. Figure 2.11 shows the three face of emotion (the PAD emotional state model). In the PAD emotional state model, impulsivity has an almost equal positive contribution from trait Dominance and trait Arousal (Mehrabian, 1996). People with higher impulsivity level are more dominant and more arousal. To be more dominant indicates that people are not being discouraged by social or situational constraints in expressing their attitudes and emotions. To be more arousal indicates that people are by greater unpredictability of their emotional expressions. If impulsivity is a more negative response, arousal represents a much positive response.

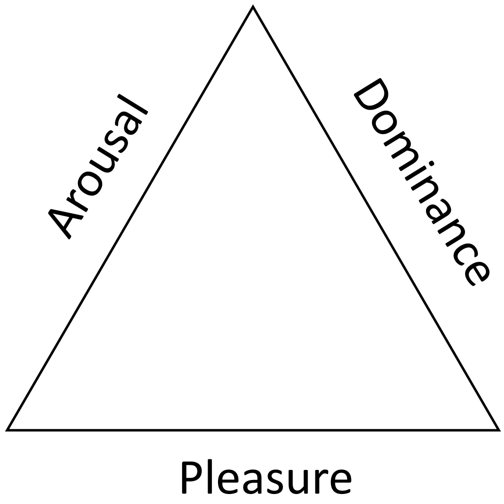


Figure 2.11 The three face of emotion, the PAD emotional state model, reproduced from Mehrabian, 1996.

2.4.3.2 Colour and Arousal

The classic Yerkes-Dodson law specifies that the impact of arousal on performance have a reversed U-shaped function, with peak performance at intermediate levels of arousal and decrements at very low or high levels (Berlyne, 1967; Sarason, 1980). For example, watching violence video game is found to make people more arousal and aggressive. Colour influence on arousal cannot reach the same high level as violence video game, which is more likely between low to intermediate levels.

Chromatic colours seem to be more arousing than monochromatic colours, which is possibly due to greys, browns, and blacks prone to be insignificant than the constant colourful background objects. Among the chromatic colours, the emotional impact of the warm hues toward the red end of the spectrum generally outweigh that of colder hues at the other end. One possible reason is that green and blue dominated in natural environments of aquatic and terrestrial animals living among vegetations under the open sky. The warm colours are rarer and more concentrated which more likely to represent something that requires action, such as fire. Colours such as red, yellow and orange are usually referred to as exciting; while blue, green and blue-green colours are considered as relaxing (Küller, 2008). There is some evidence showing that the colours of an interior space or a piece of cloth can influence the psychological mood and the central and autonomic nervous system of people (Jacobs and Hustmyer, 1974; Goldstein, 1942; Schauss, 1979; Gerard, 1958).

2.4.4 Summary

In this section, impulsivity and its characteristics, methods to measure impulsivity, influence of colour on impulsivity and arousal are reviewed and discussed. Self-report measures is the simple way to measure adult's impulsivity status, however it is a subjective method which is highly depending on participant's integrity. Observer-rated measures are more suitable for research with target subjects of children. Owing to the limitations of available facilities, the neuropsychological test is difficult to conduct in the present stage of this study. Therefore, this study will focus on exploring colour influence on impulsivity with cognitive and behavioural tasks.

From the reviewed literature, there are some major gaps worth further exploring. First, there is a need to decide a proper method for measuring both impulsivity and arousal. The two factors used in behavioural tasks for measuring impulsivity and arousal are speed of response and errors made. The theoretical basis dates back to Kagan (1964), who developed the theory of four quadrants of impulsivity. The four quadrants of impulsivity defined by Kagan (1964) are determined by response time and error rate, which are:

- First quadrant: quick response, high errors (High Impulsivity).
- Second quadrant: quick response, low errors (Medium Impulsivity).
- Third quadrant: slow response, high errors (Medium Impulsivity).

- Fourth quadrant: slow response, low errors (Low Impulsivity).

The four quadrants of impulsivity clearly described the characteristics of high impulsivity and low impulsivity. However, there were two types of reaction grouped in medium impulsivity quadrants, which lead to very different results. There is still a lack of study in distinguishing the two different behaviours both categorised into medium impulsivity quadrants. When considering the definition, the two categories with medium impulsivity were highly are associated with arousal status: high arousal showing quick response and fewer errors in performance; and low arousal showing slow response and high error rate in performance. It is worth measuring and discussing colour influence on impulsivity and arousal together based on error and speed indicators. Figure 2.12 shows an example of the Error/Speed Space designed for this study.

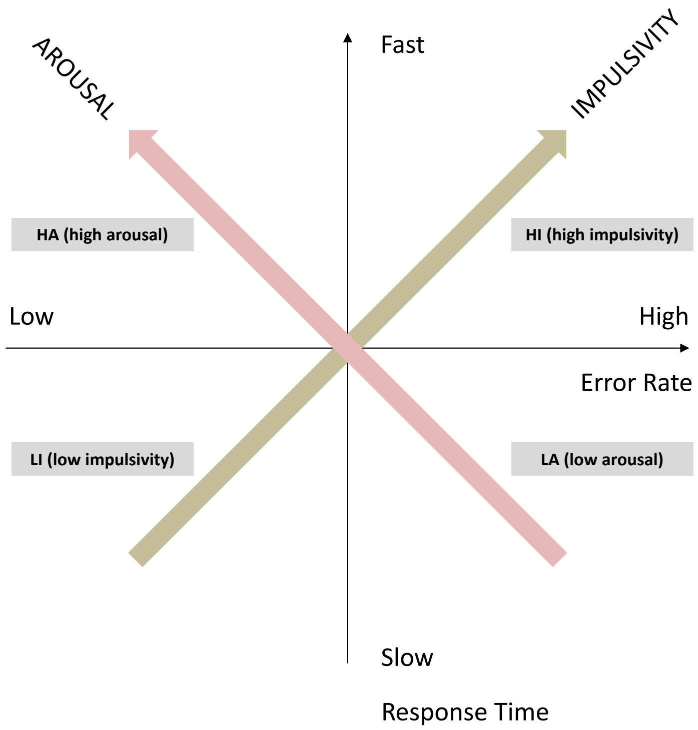


Figure 2.12 The Error/Speed Space in predicting impulsivity and arousal status.

2.5 Emotion and Colour Emotion

Emotion: a mental feeling or affection (e.g. pain, desire, hope, etc.) as distinct from cognitions or volitions.

Oxford English Dictionary

It is well known that the widely used terms associated with emotion are happy, sad, anger, fear and so forth. Emotion is a kind of feeling existing in the human brain, but can cause a distinct bodily expression. A certain arrangement of colours, sounds or patterns to some extent can arouse movement in people's body or face, pulse, breathing and so on (James, 1884).

This section reviews and concludes literature on emotion. The theory of emotion dates back to Charles Darwin, who named the theory of emotion as "Evolutionary Tradition". Darwin found that the evolution is not only about the physical structures of animals, but also includes the mental life. Then in the 19th century, another famous psychologist philosopher William James proposed the "Psychophysiological Tradition" theory. Walter B. Cannon put forward the third important theory in emotion study, known as the "Neurological Tradition". The fourth theory is named as the "Dynamic Tradition", which was raised in 1895 by Sigmund Freud. These four traditions are foundation of emotion study (Plutchik, 1980) and will be discussed in detail as following.

2.5.1 Four Traditions in Emotion Study

Evolutionary Tradition

Evolutionary Tradition was first proposed by Darwin, in which emotion is expressed as a signal or preparation for action. For example, when a dog is attacked, the emotion of fear and anger would be the signal before it makes some reaction. In Darwin's view, emotion might be only understood within the species. For example, a cat can feel the emotional signal from another cat, but cannot recognise it from humans. In addition, Darwin found that not all the emotional expressions are untrained. Animals learn it in order to meet the demands of adapting to the environment. Darwin's tradition provides a basic for another three studies in emotion (Arnold, 1970).

Psychophysiological Tradition

Twelve years after Darwin published his study on emotion; James presented a new way of understanding emotion, which is Psychophysiological Tradition. James thought that bodily changes directly followed by the consciousness of an exciting event, and the feeling of these bodily changes are emotion. The bodily changes can be reacted as blood pressure, heart rate, breathing, and muscle tension. His tradition provides a new viewpoint for later researcher to build upon, the proper sequence of reaction. The subjective feeling of an emotion comes first or the bodily changes associated comes first (Plutchik, 1980a).

Neurological Tradition

W. B. Cannon proposed the third tradition, namely Neurological Tradition. In his theory, the hypothalamic part of the brain is the response part for both emotional feeling and bodily changes. After hypothalamus receiving the reaction, hypothalamic arousal could lead to emotional feeling and bodily changes at the same time (Plutchik, 1980b).

Dynamic Tradition

S. Freud put forward the fourth tradition named the Dynamic Tradition. Emotion in this theory is regarded as part of a biological reaction, which could experience various transformations including suppression, distortion, repression, and modification of adaptation in people's life. For example, sometimes people have an emotion without notice it or cannot be explained. The emotion depends on an individual's past life experience, especially formative experiences during their childhood. From this tradition it can be seen that various uncertainty could be involved in the emotional expression, which is difficult for researchers to measure emotion. Nevertheless, some subjective feelings are always visible and can be acted as indicators of people's emotions (Arnold, 1970).

2.5.2 Emotion Experiments

Other than understanding the fundamental tradition of emotion study, this section focuses on how to design an experiment to explore the emotion. Experiments of measuring emotion have been conducted in many aspects, Cupchik (1994) introduced the reactive and reflective models (Figure 2.13), in which he found that pleasure and arousal are two most important responses in the reactive model; while the reflective model explained how emotional reactions act in the multiple meanings in art. These two models are based on James's "Psychophysiological Tradition". As for the reactive model, the primary's high-quality feelings could lead to dimensional bodily feelings and producing configurations of features. As for the reflective model, the secondary low-quality feelings are received, and people respond by blending with the primary affects, and eliciting the stimuli, then creating the contextual meanings. Both the reactive model and reflective model have inspired research in colour emotion experiments, such as Ou (2004).

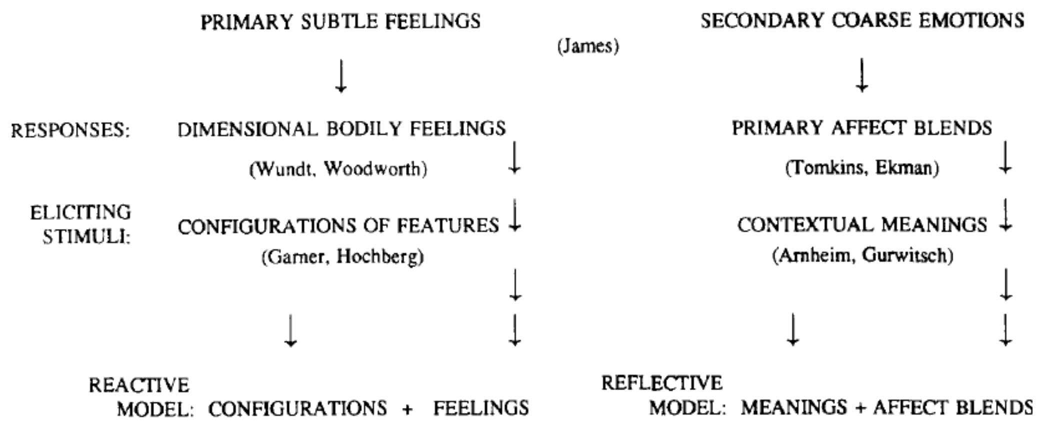


Figure 2.13 Reactive and reflective models (reproduced from Cupchik, 1994).

Table 2.5 40 bipolar scales (reproduced from Arnold, 1970).

1.	Controlled	-uncontrolled	21.	Amazed	-understanding
2.	Indifferent	-involved	22.	Dull	-clear
3.	Aggressive	-friendly	23.	Calm	-excited
4.	Sleep	-tension	24.	Free	-oppressed
5.	Abandonment	-reserve	25.	Gross	-subtle
6.	Authoritarian	-submissive	26.	Approach	-withdrawal
7.	Startled	-relieved	27.	Soft	-hard
8.	Artificial	-natural	28.	Kind	-unkind
9.	Unpleasant	-pleasant	29.	Worrying	-Light hearted
10.	Closed	-open	30.	Moved	-unmoved
11.	Energetic	-tired	31.	Simple	-complicated
12.	Derisive	-mild	32.	Disappointed	-hopeful
13.	Attention	-disinterest	33.	Deep	-shallow
14.	Cool	-Warm	34.	Childish	-adult
15.	Admiring	-despising	35.	Directed	-undirected
16.	Frightened	-carefree	36.	Self-assured	-insecure
17.	Hesitant	-determined	37.	Hurt	-flattered
18.	Sad	-happy	38.	Introverted	-extraverted
19.	Tense	-relaxed	39.	Angry	-sympathetic
20.	eagerness	-distaste	40.	Content	-discontented

The bipolar scale is an experimental method normally used in emotion study in order to quantifying people's emotional feeling. The basic rule is to select the words that suitable for emotion study. Forty widely used bipolar scales are summarised by Frijda (1970) and the details are shown in Table 2.5. Osgood also summarised a list of bipolar scale recommended for the experiments of emotion (Table 2.6).

Table 2.6 25 bipolar scale introduced by Osgood (reproduced from Arnold, 1970).

1.	happy	2.	sad	3.	calm	4.	disgust
5.	surprise	6.	bitter	7.	attention	8.	fear
9.	pride	10.	irony	11.	anger	12.	insecure
13.	moved	14.	aggrieved	15.	gay	16.	pain
17.	guilty	18.	scepticism	19.	disinterested	20.	distrust
21.	childish	22.	amusement	23.	pondering	24.	curiosity
25.	reserve						

2.5.3 Colour Emotion

Emotion is a complicated subject that involves various factors such as a stimulus event, people's cognition of this stimulus, physiological reactions, feeling, and behaviour. In addition, many uncertain factors, such as childhood experience, unconscious, repression, resistance, transference and so on would be hard to quantify. However, by using an appropriate experimental method, researchers can indirectly test people's subjective feeling, which is a reflection of the emotion.

Colour causes many feelings such as soft, firm, heavy, light, masculine, feminine and so forth. It can to some extent impact customers' making decisions. The feelings aroused by colours and colour combinations are colour emotions (Ou, 2004). In this section, some recent research related to colour emotion are reviewed and discussed.

2.5.3.1 Colour Emotion for Single Colours

In general, the emotion of single colours is related to colour brightness, saturation and hue (Valdez, 1994). Age, culture, gender, education and working background can influence user's preference to colour (Manav, 2007). A well-known viewpoint by Itten (2001, 2004) is that colour has emotion contrast, such as Light-Dark and Cold-Warm. Colour is also associated with shapes (Figure 2.14), for example, red is associated with square and blue is associated with circle. One important matter about colour emotion that should be taken into consideration is selecting colour emotion scales. Hogg (1969) classified 12 colour emotion scales and 4 factors: "impact, usualness, evaluation and Warmth" by using principal component analysis. Hogg *et al*. identified five factors, as "dynamism, spatial quality, emotional tone, complexity, and evaluation" when studying colour emotions for interior design. Wright and Rainwater (1962) concluded 48 colour emotion scales into six factors: "happiness, showiness, forcefulness, Warmth, elegance, and calmness". Hsiao *et al*. (2008) conducted experiments based on aesthetic measurement to select five emotional pairs from 35 pairs as “masculine-feminine, straight-curviform, strong-weak, old-young, and peaceful-vivacious” (Hsiao, 2008). Kobayashi (1981) suggested three key measurements of colour emotions as warm-cool, soft-hard, and clear-greyish linking with hue, lightness and chroma respectively. Table 2.7 summarises the colour emotion word scales used in previous studies.

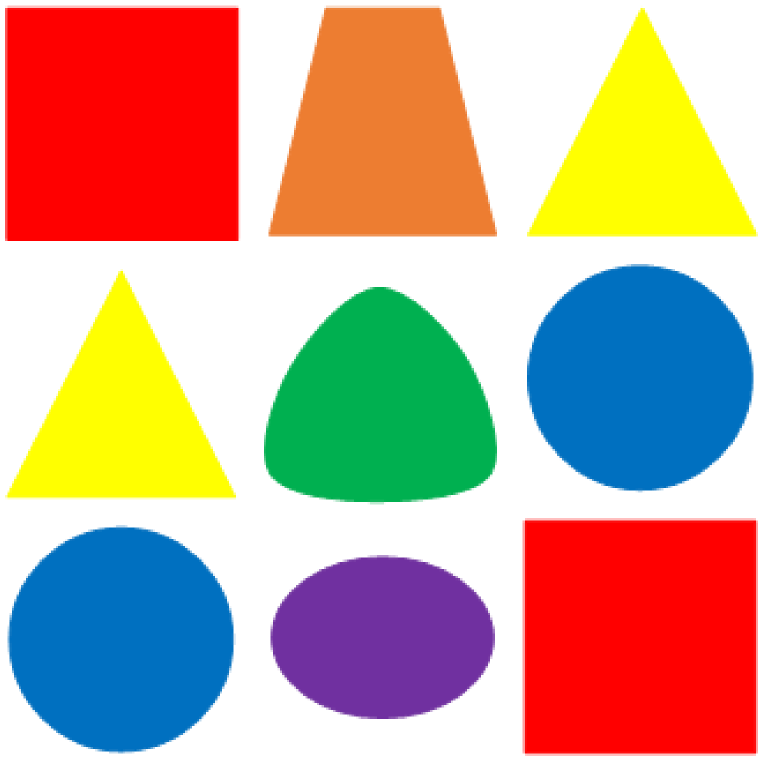


Figure 2.14 Colour and its corresponding shapes (reproduced from Itten, 2004).

Table 2.7 Colour emotion word scales.

B. Wright (1962)	*Froh/ traurig, Jung/ alt, Frisch/ abgestanden, Rein/ trüb, Gesellig/ einsam, Anmutig/ plump, Auffällig/ unauffällig, Auffallend/ normal, Erregend/ beruhigend, Stark/ schwach, Energisch/ zaghaft, Warm/ kalt, Voll/ leer, Gesund/ krank, Festlich/ alltäglich, Vornehm/ einfach, Stark/ schwach, Beruhigend/ erregend (all in German); Happiness, Showiness, Forcefulness, Warmth, Elegance, Calmness*
J. Hogg (1969)	Blatant/ muted, Hot/ cold, Pleasant/ unpleasant, Hard/ soft, Active/ passive, Lush/ austere, Strong/ weak, Exciting/ calming, Obvious/ subtle, Sharp/ dull, Vibrant/ still, Usual/ unusual
C. Osgood (1973)	Potency, Activity, Evaluation
S. Kobayashi (1981)	Dark/ light, Safe/ dangerous, Soft/ hard, Retentive/ forgetful, Weak/ strong, Cool/ Warm, Stylish/ rustic, Modern/ conservative, Valuable/ worthless, Sad/ happy, Familiar/ unfamiliar, Polite/ vulgar, Unstable/ stable, Feminine/ masculine, Unknown/ known, Dynamic/static, Large/ small, Unpleasant/ pleasant, Reliable/ unreliable, Wild/ cultivated, Slow/ quick, Young/ old, Good/ bad
S. Kobayashi (1991)	Pretty, Casual, Dynamic, Gorgeous, Ethnic, Romantic, Natural, Elegant, Chic, Classic, Dandy, Formal, Clear, Cool-Casual, Modern (total 180 sub-words)
P. Valdez (1994)	Pleasure-Arousal-Dominance
S. Hsiao (1995)	Hard/ soft, Warm/ Cool, Elegant, Delicate, Fresh, High Grad, Friendly, Lively, Romantic, Modern, Pretty, Dynamic
K. Cheng (2002)	Light/ dark, Soft/ hard, Warm/ Cool, Turbid/ transparent, Deep/ pale, Vague/ distinct, Heavy/ light, Vivid/ sombre, Strong/ weak, Passive/ dynamic, Gaudy/ plain, Striking/ subdued
J. Xin (2004)	Light/ dark, Soft/ hard, Warm/ Cool, Turbid/ transparent, Deep/ pale, Vague/ distinct, Heavy/ light, Vivid/ sombre, Strong/ weak, Passive/ dynamic, Gaudy/ plain, Striking/ subdued
L. Ou (2004)	Clean/ dirty, Fresh/ stale, Like/ dislike, Heavy/ light, Hard/ soft, Masculine/ feminine, Warm/ Cool, Modern/ classical, Active/ passive, Tense/ relaxed
K. Yildirim (2006)	Roomy/ cramped, High/ low, Pleasant/ unpleasant, Attractive/ unattractive, Interesting/ boring, Imposing/ poor-looking, Calm/ restless, Warm/ cold
X. Gao (2007)	Light/ dark, Soft/ hard, Warm/ Cool, Turbid/ transparent, Deep/ pale, Vague/ distinct, Heavy/ light, Vivid/ sombre, Strong/ weak, Passive/ dynamic, Gaudy/ plain, Striking/ subdued
T. Clarke (2008)	Warm/ Cool, Active/ passive, Heavy/ light, Anger, Passion, Deep, Comfortable, Soothing, Peaceful, Sad, Calm, Relax, Neutral, Plain, Pure, Happiness, Feminine, Boring, Positive, Potentially, Strong, Powerful, Inactive, Pure, Innocence
L. Ou (2009)	Active/ passive, Heavy/ light, New/ old, Masculine/ feminine, Happy/ sad, Fresh/ stale, Kind/ cruel, Large/ small, Modern/ classical, Safe/ dangerous, Rounded/ angular, Soft/ hard, Clean/ dirty, Beautiful/ ugly, Complex/ simple, Full/ empty, Strong/ week, Humorous/ serious, Warm/ Cool, Like/ dislike
Y. Shin (2009)	Romantic, Natural, Casual, Elegant, Chic, Classic, Dandy, Modern
M. Solli (2010)	Harmonious/ disharmonious, Passive/ active, Heavy/ light, Cool/ Warm
L. Ou (2011)	Warm/ Cool, Heavy/ light, Active/ passive, Like/ dislike, Harmonious/ disharmonious
L. Ou (2012)	Warm/ Cool, Heavy/ light, Active/ passive, Like/ dislike

Although the emotional scales are not universal in all disciplines, researchers choose various emotional scales because of the different aims of their research. Some similar colour emotion factors are evaluative, potency and activity (Ou, 2004). After selecting the emotion scale, researchers began to set up colour emotion space based on their selected colour emotion factors. For instance, Sato *et al*. (2001) developed a series of colour emotion formulae used for single colours. If the testing colour is located near the referencing colour in a uniform CIELAB colour space, the colour-emotion value would increase and the referencing colour are considered as relevant with the highest colour emotion value. Xin and Cheng (2000) established their own colour emotion formulae and calculated colour emotions using the CIELAB colour space (with values L*, C*, and h). Amongst the four factors as Warm-Cool, Heavy-Light, Active-Passive and Soft-hard, Heavy-Light has the best performance for forecasting (Xin and Cheng, 2000). Ou (2004) analysed the emotion for colour pairs with factor analysis method (FA) and independent component analysis method (ICA). They developed a three-dimensional colour emotion space based on three factors such as colour heat, colour weight and colour activity. Four emotional scales as “Warm-Cool, Heavy-Light, Active-Passive and Hard-Soft” were analysed. Hue angle and chroma were mainly linked to the scale Warm-Cool; lightness was the only factor relevant with Heavy-Light; the colour difference between medium grey and a test colour lead to Active-Passive; both chroma and lightness are judging Soft-Hard. Based on the results found in the colour emotion for single colour research, more studies were carried out to analyse colour emotion for colour combinations (Ou, 2004) as following:

Warm-Cool

$$\boldsymbol{WC = -0.5 + 0.02(C^*)^{1.07}\cos(h - 50^\circ)} \quad \boldsymbol{R^2 = 0.74} \tag{2. 19}$$

Heavy-Light

$$\boldsymbol{HL = -2.1 + 0.05(100 - L^*)} \quad \boldsymbol{R^2 = 0.76} \tag{2. 20}$$

Active-Passive

$$\boldsymbol{AP = -1.1 + 0.03[(C^*)^2 + (L^* - 50)^2]^{\frac{1}{2}}} \quad \boldsymbol{R^2 = 0.75} \tag{2. 21}$$

Hard-Soft

$$\boldsymbol{HS = 11.1 + 0.03(100 - L^*) - 11.4(C^*)^{0.02} \quad R^2 = 0.73} \tag{2. 22}$$

Then Ou (2004) identified three general axes as "colour activity, colour weight, and colour heat", which are:

Colour Activity

$$\boldsymbol{= -2.1 + 0.06\left[(a^* - 3)^2 + (L^* - 50)^2 + \left(\frac{b^* - 17}{1.4}\right)^2\right]^{\frac{1}{2}} \quad R^2 = 0.93} \tag{2. 23}$$

Colour Weight

$$\boldsymbol{= -1.8 + 0.04(100 - L^*) + 0.45\cos(h - 100°) \quad R^2 = 0.73} \tag{2. 24}$$

Colour Heat

$$\boldsymbol{= -0.5 + 0.02(C^*)^{1.07}\cos(h - 50°) \quad R^2 = 0.74} \tag{2. 25}$$

Sato (2001):

Warm-Cool

$$WC_{CIELAB} = 3.5[\cos(h - 50) + 1]B - 80 \quad R^2 = 0.69 \tag{2. 26}$$

Heavy-Light

$$HL_{CIELAB} = -3.5L^* + 190 \quad R^2 = 0.76 \tag{2. 27}$$

Active-Passive

$$DYP_{CIELAB} = \{[0.6(L^* - 50)]^2 + [4.6(1 - \Delta h_{290}/360)C^*]^2\}^{1/2} - 115 \quad R^2 = 0.59 \tag{2. 28}$$

Soft-Hard

$$SH_{CIELAB} = \{(3.2L^*)^2 + [2.4(1 - \Delta h_{290}/360)C^*]^2\}^{1/2} - 180 \quad R^2 = 0.53 \tag{2. 29}$$

Xin & Cheng (2000):

Warm-Cool (2. 30)

$$WC_{0^\circ \leq h \leq 180^\circ} = 0.154L^* + 39.378C^{*(0.372)} - 0.303h - 113.855$$

$$WC_{180^\circ \leq h \leq 360^\circ} = 0.355L^* + 23.476C^{*(0.429)} - 0.159(360^\circ - h) - 105.710$$

Heavy-Light (2. 31)

$$HL_{0^\circ \leq h \leq 180^\circ} = -3.340L^* + 0.476C^* + 0.037h + 175.467$$

$$HL_{180^\circ \leq h \leq 360^\circ} = -3.477L^* - 0.264C^* + 0.072(360^\circ - h) + 182.866$$

Active-Passive (2. 32)

$$DyPa_{0^\circ \leq h \leq 180^\circ} = -0.296L^* + 3.162C^{*(0.931)} - 0.073h - 68.835$$

$$DyPa_{180^\circ \leq h \leq 360^\circ} = -0.120L^* + 4.385C^{*(0.864)} + 0.032(360^\circ - h) - 84.791$$

Soft-Hard (2. 33)

$$SH_{0^\circ \leq h \leq 180^\circ} = 2.900L^* - 0.510C^* - 0.051h - 146.700$$

$$SH_{180^\circ \leq h \leq 360^\circ} = 2.953L^* + 0.424C^* - 0.020(360^\circ - h) - 159.795$$

2.5.3.2 Colour Emotion for Colour Combinations

In daily life, colours are never separated from each other and are always presented together. Therefore, evaluating the impact of emotion on colour combination is more practical than only with single colours. Some studies have been designed related to colour emotions for multicolour combinations. For example, Hogg (1969) explored 12 colour emotions and 4 factors as “active-potency, emotional tone, evaluative, and usual/obvious”. Sivik and Hård have investigated a series of rules for colour combinations based on the NCS colour system. Ou applied his colour emotion model for single colour on combined colour pairs (Ou, 2004). Moreover, Ou suggested a relationship between single-colour and colour-combination emotions, which is:

$$\boldsymbol{E} = (\boldsymbol{E_1} + \boldsymbol{E_2})/\boldsymbol{2} \quad (2.\ 34)$$

where E is the colour emotion (z score) for a colour pair, E_1 is the colour emotion for colour 1 and E_2 is the colour emotion for colour 2.

Solli (2011) applied Ou's colour emotion method in researching multi-coloured images; a psychophysical experiment with three emotional factors as "activity, weight and heat" has been designed. Researchers believed that emotion for colour combinations are related to the emotion for single colours.

2.5.3.3 The Factors Influencing Colour Emotion

From the studies of colour emotion for single colours and colour combinations, some researchers have investigated whether age, gender, geographic conditions, race and culture, colour preference, shape and texture could influence colour emotion. Studies based on factor analysis aimed to investigate the inner relationship between colour emotion and different factors, in order to study colour emotion in more depth. Cultural difference was researched more often than other factors. For instance, Xin (2004) designed an experiment to explore the similarities and differences of colour influence on people's emotion cross-regions (in Hong Kong, Japan and Thailand). The conclusions can be found as: culture and geographical difference can powerfully effect the colour emotional reaction. Thais are more sensitive with the lightness of colours, and chroma is more affective to both Japanese and Thais. Hue is a less influential factor on colour emotions than lightness and chroma. Gao (2007) investigated the cross-cultural (in 7 regions as Hong Kong, Japan, Thailand, Taiwan, Italy, Spain and Sweden) influence on colour emotion. More conclusions related to hue, chroma and lightness have been summarised in the research. Ou *et al*. (2012) also conducted a research on cross-cultural colour emotion for two colour combinations. Eight regions are involved and four emotional scales as "Warm-Cool, Heavy-Light, Like-Dislike and Active-Passive" have been selected and analysed. Ou contradicts Xin's research, and found that colour emotion has no influence by gender and has little influence by cultural difference (such as for Warm/Cool and heavy/light and active/passive). However, for Like-Dislike (colour preference), a strong effect of culture, gender, professional background and age have been found. For instance, observers with a design background prefer colour pairs with lower-chroma colours or with similar hue than non-design observers; older observers prefer colour pairs with higher lightness or higher chroma than young observers. During the similar time, Ou (2012) conducted another two experimental studies (for single colours and colour pairs) of age effects on colour emotion and preference. Some findings from his research are:

1) Colour emotion responses could change with different age ranges.
2) The colour emotion differences between two age groups are not significant.
3) The colour preference difference between two age groups are related to the colour emotion difference in active/passive response.
4) The age effects on colour emotion and preference for single colour and colour pairs are correspond well.

Tangkijviwat (2008) and Clarke (2008) have researched the relation between colour preference and mood, and the emotional connotations between colours. The former research evaluated the link between colour appearance mode and colour preference; the later research focused on the multiple meanings of a single colour and viewer's perspective. Fortmann (2013) conducted a gender-based colour preference research on twitter. Some observable conclusions are summarised as: magentas are more preferred by females; dark colours are more preferred by males. Zentner (2001) focused on the age group of 3 to 4 years old, and designed an experiment to investigate their preference for colours and colour combinations. Conclusions can be found as: red is preferred for both girls and boys; brighter colours represent happy and darker colour represent sad. No findings can support the stereotypes as pink for girls and blue for boys.

Lee *et al*. (2009) have investigated the relation between colour with 2D and 3D shapes. This research is based on Ou’s colour emotion model and analysed five emotion scales. Findings from this research can be summarised as: activity, weight and heat scales are determined by colour; shape has impact on softness and complexity. There is no finding to show that colour and shape can affect the same emotion scale together.

Chang *et al*. (2008) designed a research to test Ou's colour emotion, colour preference and colour harmony models by using samples with various texture. In this research, colour emotion models have been proved to have little texture impact; however, colour preference and colour harmony models can be influenced by texture. Lucassen *et al*. (2011) found that texture can strongly affects colour emotion. For instance, texture fully determines the responses of Hard-Soft scale. In addition, adding the texture can decrease the weight of models as Heavy-Light, Warm-Cool and Masculine-Feminine. Ou (2011) explored the colour harmony for fashion design. Three types of fashion clothing with different colour combinations have been shown to the observers to evaluate whether fashion style and colour could affect the harmony response. From this research, fashion style and colour are all have significant impact on harmony. However, their impacts are independent. Shin *et al*. (2010) designed an emotion forecasting system to forecast particular human emotions from a given textile.

2.5.3.4 Colour Emotion Models

The final step in researching colour emotion is to build colour emotion models. Apart from the colour emotion models introduced in section 2.5.3.1 and 2.5.3.2, two more models will be presented in this section. "The Pleasure-Arousal-Dominance (PAD) Emotion Model" has been mentioned in section 2.4.3 was firstly introduced by Valdez & Mehrabian in 1994. The detail about PAD Emotion Model is pleasure (+P) versus displeasure (-P), arousal (+A) versus non-arousal (-A), and dominance (+D) versus submissiveness (-D), which shown in Table 2.8.

Table 2.8 The PAD Emotion Model.

+P+A+D	*Admired, bold, creative, powerful, vigorous*
+P+A-D	Amazed, awed, fascinated, impressed, infatuated
+P-A+D	Comfortable, leisurely, relaxed, satisfied, unperturbed
+P-A-D	Consoled, docile, protected, sleepy, tranquilized
-P+A+D	Antagonistic, belligerent, cruel, hateful, hostile
-P+A-D	Bewildered, distressed, humiliated, in pain, upset
-P-A+D	Disdainful, indifferent, selfish-uninterested, uncaring, unconcerned
-P-A+D	Bored, depressed, dull, lonely, sad

The equations for P, A, D are:

$$Pleasure = 0.69B + 0.22\,S$$

$$Arousal = -0.31B + 0.60S$$

$$\boldsymbol{Dominance = -0.76B + 0.32S}$$

where S is saturation and B is brightness (2. 35)

Lee & Lee (2006) have designed an emotion model for interior design in Korea. This model has three axes as "soft-hard", "light-heavy", and "splendid-sober". The advantage of this model is that this is a one-to-multiplicity structure links colour combinations and emotion factors. The study is based on the real interior design factors rather than only in the laboratory. This model can be used in the industrial interior design field based on Korean customers.

2.5.3.5 The Application of Colour Emotion

The principle of colour emotion research can be used in many disciplines. Interior designers are more often to use colour emotion design method in their design. Manav (2007) has carried out a colour emotion study in interior design, which aimed to use colours to satisfy human needs in residences. The results shown that value and saturation of colour are dominating people's emotional reactions. Yildirim *et al*. (2007) have conducted a research on how colours of the wall in a restaurant could influence people’s emotion. When testing yellow walls against violet walls in a restaurant, viewers showed more positive preference to violet interiors than yellow ones. Küller (2009) also did a series of research according to the colour of wall’s influence on emotion. There are two experiments, the first one compared a colourful room with a grey scale room; the second one compared a red painted room with a blue painted room. The aim of the research was to test a viewer's mood according to different colour surrounding. From all these research, a significant influence of colour hue and chroma on emotion can be found in design.

There are also many other interesting usage of colour emotion in various discipline. For example, Lechner *et al*. (2012) have brought the concept of colour emotion into the pharmaceutical industry. In addition, they have explored the links of colour and emotional factors when designing the colour of drugs. Ough (1967) researched on the relationship between preference colour and the taste of rose wine. Prokop (2013) explored the influence of animal's fur colour on human's willingness to protect the animals. It is found that children showed a considerably stronger willingness to protect aposematic animals than inconspicuous, cryptic animals. Females showed a more negative willingness to protect danger animals.

2.5.4 Summary

This section has summarised the existing colour emotion studies. They can be classified into two different research focuses: one group of researchers classified and quantified the colour emotion scales, in order to build the quantification colour emotion models. Another group of researcher focused on the application of colour emotion. Numerous research tried to apply the emotion of colour in a certain application area, which shows a trend that emotion of colour is not only a theoretical research, but the importance of its application has increased

2.6 Overall Summary

The aim of this study is to investigate the impact of colour on impulsivity, arousal and emotion. According to the aim, literature related to the topics has been reviewed in this chapter. In section 2.1 and 2.2, basic knowledge on human vision and colour, CIE colorimetry and colour description were reviewed. In section 2.3, the previous study on colour used in functional design has been introduced. From the section 2.3, research question was bring up according to the research gap existing in the study field. In section 2.4, basic knowledge on impulsivity and arousal, how to measure impulsivity and arousal, and research on colour influence on impulsivity and arousal has been explored. In section 2.5, emotion, measuring emotion, colour influence on emotion have been introduced respectively.

From all the discussions, four hypotheses can be arise as described. Figure 2.15 shows an overall flowchart of this study.

- Colour influence on impulsivity and arousal can be determined by colour influence on response time and error rate.
- The impact of colour on impulsivity and arousal can be divided in two factors as hue and chroma.
- The effect of colour on impulsivity and arousal are different according to different thinking manners, such as logical, spatial, detail and so on.
- Colour influence on impulsivity and arousal has relationship with colour influence on emotion.

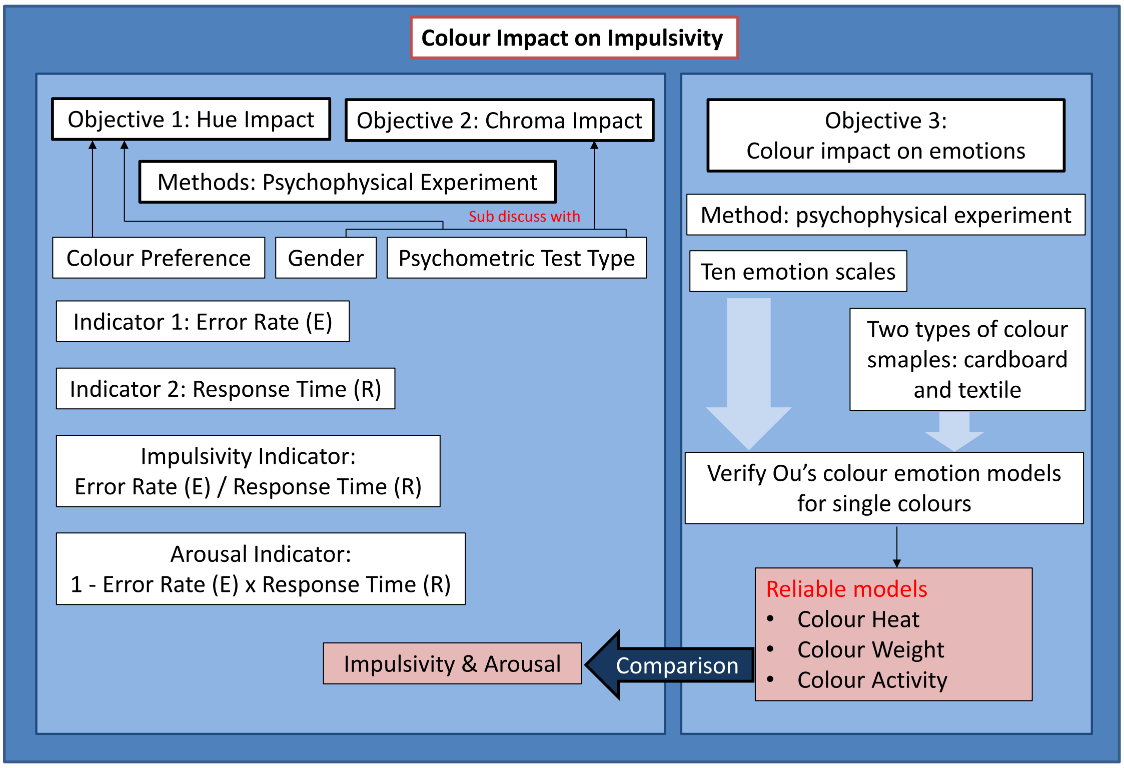


Figure 2.15 Overall flowchart of the study.

Chapter 3 Materials and Methods

3.1 Introduction

From the literature summarised in Chapter 2, there are many studies focusing on the application of colour influence on people's performance, body expression, emotion and intellectual ability. However, the fundamental research in how colour influence on impulsivity is lack of study. Therefore, the purpose of current research is to explore in depth whether colour could have an influence on people's impulsivity and arousal, and how colour could have an influence on people's impulsivity and arousal. The aims of this research are to investigate the impact of colour on impulsivity and arousal by using influence factors as response time and error rate. In doing so, the relationship between colour influence on impulsivity and arousal with colour emotion will be explored.

To investigate the impact of colour on impulsivity and arousal, the present research is based on three main characteristics of colour: hue (°), chroma (C*) and lightness (L*). This is to explore whether changing one or two characteristics among the three will influence people's impulsivity status.

When exploring the colour environment influence on people's performance, the psychometric test is a broadly used experimental method in psychology studies to explore people's psychological and physical performance. In addition, the TV screen is a normally used equipment to produce colour environment. As it is the simplest way to control the factors of colour accurate, such as the hue, chroma, and lightness. In addition, when people focus on the screen to solve the test, they concentrate all on the screen, thus the colour of the screen can fully influence on their performance.

Three psychophysical experiments were conducted to study the influence of hue on impulsivity and arousal (hue experiment), the influence of chroma on impulsivity and arousal (chroma experiment), and the influence of colour on emotions (emotion experiment) respectively. In the hue experiment, participants were required to do six types of psychometric tests on seven coloured backgrounds. In the chroma experiment, participants were required to do four types of psychometric test on thirteen coloured backgrounds. The reaction time and error rate for each participant's performance were two indicators to measuring impulsivity and arousal. Another experiment (emotion experiment) was conducted to study the colour effect on emotion, in order to compare colour influence on impulsivity and arousal with emotion. In the emotion experiment, participants were required to give their response on ten emotion word pairs according to twenty colours. Details of experiment design are summarised in Table 3.1. In this chapter, the general experiment preparation for this research are described in two sections: experimental setup and methods. Details of these two sections are summarised in Table 3.2.

Table 3.1 Outlines of experimental conditions.

Experiment	Method of measuring impulsivity response	Imaging Device	Stimuli
1	Psychophysics • Response time • Error rate	Display	7 coloured backgrounds (different in 6 hues + reference white) × 6 types of psychometric tests (3 tests for each type)= total 126 tests
2	Psychophysics • Response time • Error rate	Display	13 coloured backgrounds (different in 3 hues × 4 chroma levels + reference white) × 4 types of psychometric tests (3 tests for each type)= total 120 tests
3	Psychophysics • preference	Printed and textile samples	20 coloured printed cardboard and textile samples, in total 40 colour samples × 10 emotion words = total 400 decisions

Table 3.2 Summary of general experiment preparation.

Experimental Setup	Colour Measuring Equipment	• Minolta CS-1000 tele-spectroradiometer • GretagMacbeth Color-Eye® 7000A Spectrophotometer
	Equipment	• 40” SAMSUNG (LCD) TV screen • HP Designjet Z3200 Photo Printer
Methods	Experiment 1	• Participants determination • Experiment preparation • Experiment procedure • Colour Evaluation • Data analysis
	Experiment 2	• Participants determination • Experiment preparation • Experiment procedure • Colour Evaluation • Data analysis
	Experiment 3	• Participants determination • Experiment preparation • Experiment procedure • Data analysis

3.2 Experimental Setup

Two types of equipment are used in this experiment. They are image device: LCD TV screen and photo printer; colour measuring equipment: the Minolta CS-1000 tele-spectroradiometer and the GretagMacbeth Color-Eye® 7000A Spectrophotometer. The LCD TV screen is used as the main imaging device throughout the hue and chroma experiments. The photo printer is used to print out the cardboard colour samples used in emotion experiment. The CS-1000 is used for measuring the XYZ tristimulus values of the colours presented on the LCD display and the GretagMacbeth Color-Eye 7000A Spectrophotometer is used for measuring the XYZ tristimulus values of the colours of textile samples in order to create the printed cardboard samples in similar colours. Characteristics of these four equipment will be discussed in detail in this section.

3.2.1 Colour-measuring Equipment

3.2.1.1 Minolta CS-1000 tele-spectroradiometer (TSR)

A Minolta CS-1000 tele-spectroradiometer (TSR) is mainly used in hue and chroma experiments to evaluate the display and determine the tristimulus values of colour stimuli (Figure 3.1). The function of CS-1000 is to measure the XYZ tristimulus values for a set of uniform colour patches presented on the LCD display used in the experiments. These values can use to evaluate characteristics of the display and to measure the stability of display during the experiment.

Figure 3.1 Colour - measuring instrument: Minolta CS-1000 used in the experiment.

To check the reliability of spectroradiometer, four measurements has been done. Firstly, different spectroradiometers such as the Minolta Old, Minolta New, PR650 and the Bentham has been compared, and the luminance gauge has been measured to make sure the reliability in the vertical axis. Secondly, CL-Hg Line Source were measured by using Bentham measurements, and different LED lights in red, yellow, and blue has been measured to make sure the reliability in the horizontal axis. According to the measurement described above, the CS-1000 tele-spectroradiometer used in this experiment is reliable.

3.2.1.2 GretagMacbeth Color-Eye 7000A Spectrophotometer

The colour measurement instrument used in the emotion experiment is a GretagMacbeth Color-Eye 7000A Spectrophotometer. This is a market leading spectrophotometer, widely used in measuring the colour of paints, textiles, inks and plastics. Figure 3.2 is an image of the Color-Eye 7000A Spectrophotometer. It has two spectral analysers which enable measuring the sample and the internal reference in either a single flash or multiple flashes. It also has an added xenon light source which could help to balance the two spectral analysers.

Figure 3.2 A GretagMacbeth Color-Eye 7000A Spectrophotometer.

The reliability of spectrophotometer has been checked by using green reference tile compared with BCRA tiles (12 colours in matt and gloss finish). From the measurement, the spectrophotometer used in this experiment is reliable.

3.2.2 Equipment

The experiment equipment used in this study is an imaging device: LCD TV screen. The characteristics and related calibration are summarised in this section.

Characteristics of the Imaging Device

The display used in the current research is a 40” (diagonal screen size) liquid crystal display (LCD) TV screen with full HD pixel format (1920×1080 pixel resolution), SAMSUNG LE40F71BX. The aspect ratio of it is 16:9 and it is able to address 10 bits of colour depth levels per each channel and the light sources in the backlighting of LCD are cold cathode fluorenscent lamps (CCFL).

In this section the colorimetric performance of this LCD wil be explored. All measurements were taken place on a square colour patch (pixel size: 200×200) located in the centre of the LCD with a grey background having RGB equal to (128,128,128) using the TSR in a dark room.

Temporal Stability

The colours show on the LCD require a certain period of time to stablilise. It is because the CCFL lamps in the backlight of an LCD need a period of time to constant in terms of their luminance. To measure the temporal stability, the luminance for the centre position of the screen showing a full white colour was examined for a two hour period at one minute intervals. The CS-1000 TSR was used to measure this stabilisation time. The results are shown in Figure 3.3. From the figure it can be seen that colour change in luminance level increase quickly after tuning on, then slowly increase from 40 minutes and stable at appoximatly 60 minutes. Therefore, all experiments including instrument measurement and psychophysical experiments are suggested to carried out after 60 minutes from tuning on.

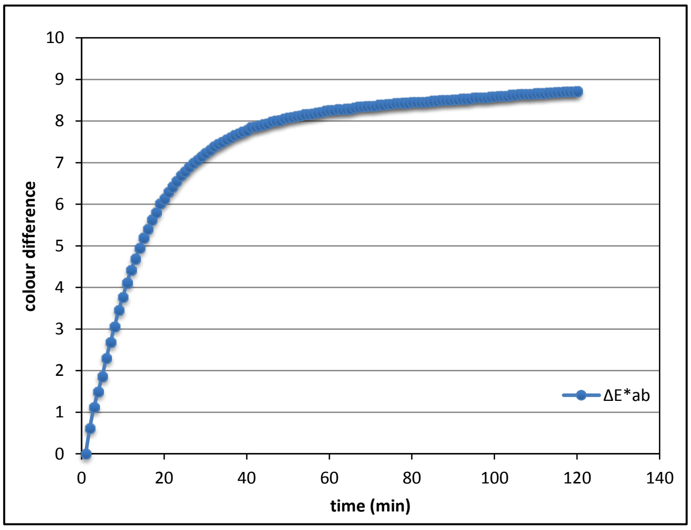


Figure 3.3 Test results of stabilisation time for the LCD used.

Repeatability

Repeatability of the display was examined by measuring seven test colours used in the psychometric experiment. They were colours with different hue angles, which aim to test performance of the characterisation model for this display. Table 3.3 clarifies measurement results in terms of ΔE*ab computed between the first measurement and the following days measurements. The measurements were taken place in 14 days period. The overall average colour difference is 1.01 ΔE^*_{ab} over the testing period. Both the display and the measuring device may cause this difference.

Table 3.3 Average colour differences of seven colours for repeatability of colour reproduction.

Time interval		**14 days**
Colour difference (ΔE^*_{ab})	**Mean**	1.01
	Standard Deviation	0.55

Colour Gamut

In colour reproduction, colour gamut is a certain range of colours that can be accurately represented in a given colour reproduction intermediary under a specified set of viewing circumstance. The colour coordinates of the display RGB primaries were measured under dark surrounding and plotted in the *u'v'*-

diagram, as shows in Figure 3.4. The colour gamut of the LCD display is found to be larger in the red and green regions than sRGB, while it is a little smaller in the blue region. This white point of the LCD display is used all through the display assessment.

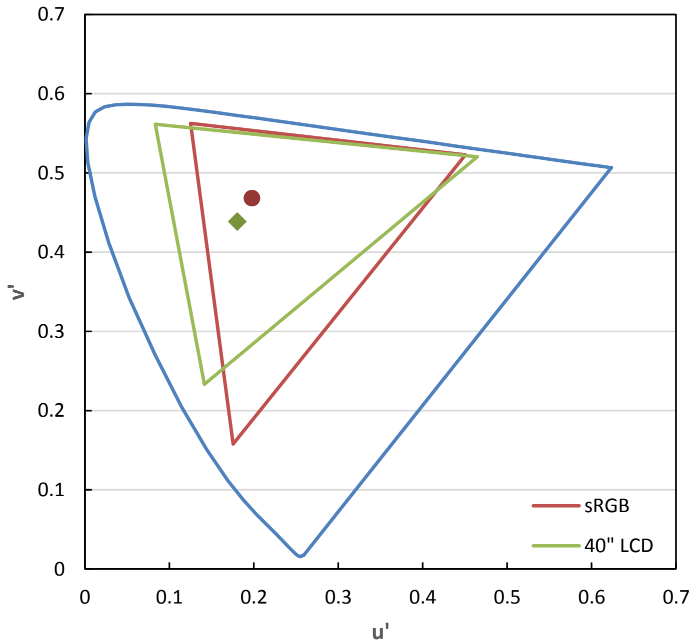


Figure 3.4 Colour gamut of LCD display (green line) and white point (green rhombus in the centre) compared with sRGB (red line and circle) as plotted on a CIE 1976 *u'v'* diagram.

Spatial Uniformity

There is often a lack of spatial uniformity in the large displays caused by the shape of light sources and geometry in the backlight. The spatial uniformity of the display was evaluated by measuring nine points of full white pattern within a 9 × 9 grid fulfilled the screen. Colour differences ΔE^*_{ab} are calculated between the eight surrounding positions and centre positions, as show in Table 3.4. The maximum colour difference for the eight surrounding points is 1.82 ΔE^*_{ab} locates at upper left and upper centre corner, and the smallest difference is 0.24 ΔE^*_{ab} posits at middle right grid. The average colour difference for the eight surrounding grids is 1.04 ΔE^*_{ab}.

Table 3.4 Nine points used for spatial uniformity measurement and the result in terms of ΔE^*_{ab}.

1 (1.82)	2 (1.82)	3 (1.31)
4 (0.64)	5 (0.00)	6 (0.24)
7 (1.11)	8 (0.67)	9 (0.75)

Angular Variation

The angular variation is often happened in large displays caused by the angle of light sources and geometry in the backlight. The angular variation of the display was assessed by either turning the screen 15° clockwise and anticlockwise or 30° clockwise and anticlockwise, and measured the centre point of a completely white pattern on the screen. Table 3.5 shows the colour differences ΔE^*_{ab} of the centre white point between the four angles and original (no degree). Turning the screen at 15° of either clockwise and anticlockwise are having a not detectable colour difference as the ΔE^*_{ab} for 15° clockwise and anticlockwise are 0.68 and 1.07 separately. When turning the display 30°

Table 3.5 Four degrees used for angular variation measurement and the result in terms of ΔE^*_{ab}.

Angle	30 degree clockwise	15 degree clockwise	15 degree anticlockwise	30 degree anticlockwise
ΔE*ab	5.10	0.68	1.07	2.37

The display setting used throughout the hue and chroma experiments are summarised in Table 3.6.

Table 3.6 Settings parameters for the LCD display.

Controls	Standard Setting	Range
Contrast	50	0-100
Brightness	67	0-100
Colour	50	0-100
Tone	Cool 1	warm1/ warm2/ normal/ cool1/ cool2

The colour backgrounds used in the experiment were decided by choosing colours according to the RGB values of the colour backgrounds. The XYZ values of the colour backgrounds were measured each time by using the CS – 1000 tele-spectroradiometer. After the measurement, the L*, C* and h values were calculated accordingly. Compared the L*, C* and h values of the colour backgrounds times by times, finally the colour stimuli can be decided according to the similar L* and C* values with different h values in the hue experiment, or similar L*, different h values and four levels of C* values in the chroma experiment.

3.3 Methods

In this section, detail of experimental design will be discussed. Three experiments are conducted as main experiments in this study. The first two experiments are aiming to explore the hue influence and chroma influence on impulsivity respectively. The third experiment is designed to explore the colour influence on emotion and the repeatability of Ou's colour emotion models for single colours. Under experiment setup section for each experiment, how the participant's criteria was decided (such as number of participants, nationality, gender *etc*.), the psychometric tests and colours used in each experiment, experiment procedure and the evaluation of colours after each experiment will be discussed respectively.

3.3.1 Experimental Set Up for Hue Experiment

The aim of hue experiment is to reveal the relationship of hue impact with response time and error rate. To be more specific, the hue influence on response time and error rate according to different gender; hue influence on response time and error rate under different types of psychometric test; also individual's preference of hue influence on response time and error rate are all explored in this experiment. To achieve these objectives, hue experiment are carefully designed, in order to ensure the reliability of the data collected from this experiment. In the preparation of hue experiment section, the psychometric test and colours used in this experiment, experiment procedure and the colour evaluations will be introduced in detail.

3.3.1.1 Selecting Participants

Number

Participants were all Chinese students from the University of Leeds, aged between twenty and thirty-eight years (average age: 26) with normal colour vision according to Ishihara Colour Vision Test (1993). They were approximately equally balanced with male and female in number. Some of the participant's criteria need to be further clarified in detail in this section. They are number, gender and nationality of participants.

Before the main experiment, a small range of trials have been conducted with 18 participants in order to predict the range of participants needed in this experiment. Eighteen participants have joined in this small trials. Before doing the trails, all observers passed the Ishihara Colour Vision Test (1993) for colour deficiency. They were required to do the psychometric tests on four colour backgrounds. The four colours were actual blue (97,142, 255), green (70, 205,145), orange (211, 141, 83) and red (232,104,113) used in the main experiment. Response time and errors they made were two sets of data collected from the experiment.

When looking at data sets of every single colour, the fluctuation of standard error can indicate the smoothness of each colour. Standard error with group of 2 to 18 participants of response time and error rate has been calculated and is summarised in Figure 3.5, also Table 3.7 and Table 3.8. A steady trend for both response time and error rate for all four colours begin at approximately the point of 16 participants (standard error ≤ 0.01). This indicates that when the number of participants increases, data points are closer to the mean value. Meanwhile, along with the increase of sample size, the standard error value tends to be stable. In this experiment, the sample size of participants more than 16 is essential.

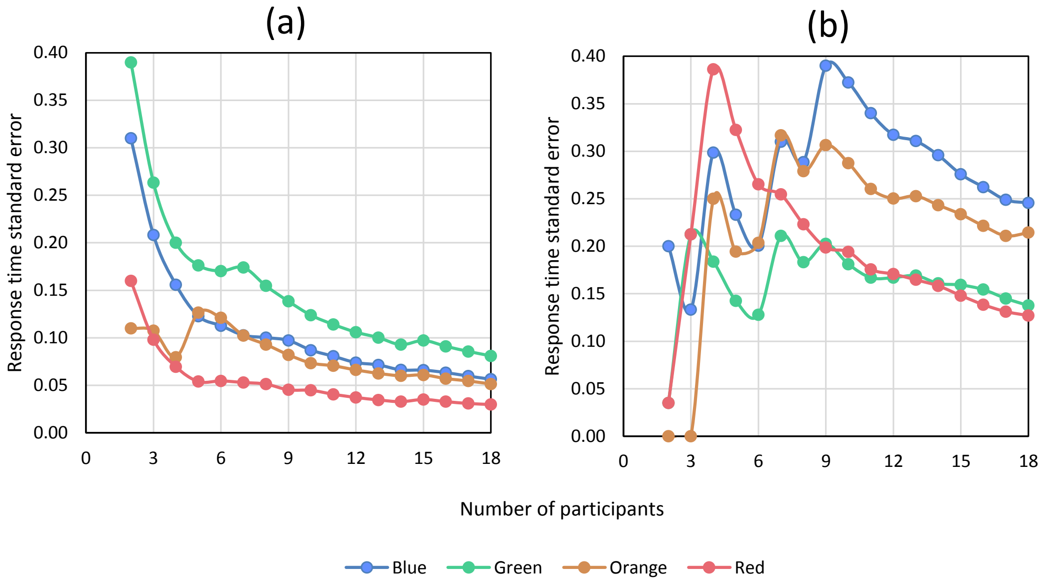


Figure 3.5 (a) Response time standard error decrease figure; (b) Error rate standard error decrease figure.

Table 3.7 Response time standard error decrease table.

Response time	**Blue**	**Green**	**Orange**	**Red**
12 groups	0.07	0.11	0.07	0.04
15 groups	0.07	0.10	0.06	0.04
16 groups	0.06	0.09	0.06	0.03
17 groups	0.06	0.09	0.05	0.03
18 groups	0.06	0.08	0.05	0.03

Table 3.8 Error rate standard error decrease table.

Error rate	**Blue**	**Green**	**Orange**	**Red**
12 groups	32%	17%	25%	17%
15 groups	28%	16%	23%	15%
16 groups	26%	15%	22%	14%
17 groups	25%	15%	21%	13%
18 groups	25%	14%	21%	13%

In the hue experiment, twenty-seven participants, including fourteen female and thirteen male Chinese subjects took part in the hue experiment. This is a sample size generally used by research in colour psychology (AL-Ayash, 2015; Jun, 2011; Ou, 2004; Ling, 2001; Read, 1999).

Gender

This study involves equal number of female and male participants, aims to explore whether the gender could influence the experimental result.

Nationality

All the participants involved in the study were Chinese, having English as their second language, as culture difference is a controlled factor and no translation is needed during the test. In addition single nationality was used because the experiments are testing participant's logical thinking, spatial imagination and mathematics abilities. The approached to solving these psychometric tests are more or less influenced by their elementary-education background. For control this variable, all selected participants are finished their high-school education in mainland China.

3.3.1.2 Experiment Preparation

Psychometric test types

Reviewed from literature, the MFFT is the one type of test select to use in the study. Reasons for using it can be summarised as:

- The procedure of the MFFT is simple and inexpensive. With items in a young age or need to do a large amount of repeat, simplicity is crucial.
- Many empirical evidences proved that the MFFT is a reliable method at least for differentiating extreme levels of reflection and impulsivity.
- The MFFT does not rely on subjective ratings of an item's behaviour; both a behavioural and cognitive level of impulsivity can be observed during the MFFT.

- The MFFT test is very difficult to fake as it judged by performance rather than opinion.
- The MFFT scores appeared to be reliable prognosticators of impulsivity behavioural outside the testing environment even the research on predictive validity is lacking.

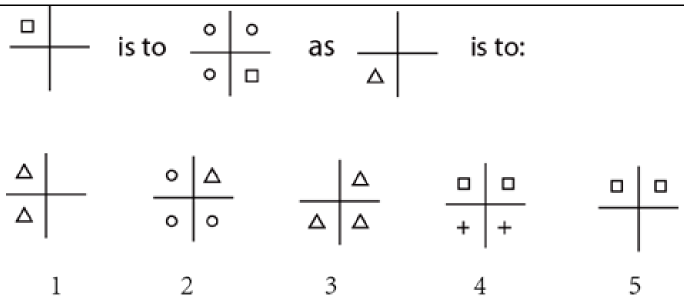
Following the literature (see section 2.4.1), the laboratory experiment aims to use MFFT as one means of measuring, to measure participant's reaction time and errors made during the experiment, in order to measure impulsivity and arousal. Since fast and inaccurate performance on the MFFT is expected to indicate impulsivity, as defined by lack of cognitive control over responding. It is assumed that the subject is unable to delay a response during analysing the stimuli and searching for the correct alternative (Webster & Jackson, 1997). While fast and accurate performance on the MFFT indicates arousal. In this study, other types of psychometric test apart from the MFFT have been involved to explore diverse aspects of participant's thinking process. Six types of psychometric tests are used in this experiment. They are: Logical Rule Test, Spatial Structure Test, Rotation Test, Mathematics Sequence Test, Odd One Out Test and Same Detail Test (MFFT). The six types of psychometric tests can be extracted into three groups according to different test factors and thinking processes:

- Logical ability (Logical rule and Mathematics sequence).
- Spatial imagination ability (Spatial structure and Rotation).
- Detail ability (Odd one out and Same detail).

Here are example tests for the six psychometric tests (Table 3.9).

Table 3.9 The six types of psychometric tests. (a) Logical Ability Tests; (b) Spatial Imagination Ability Tests; (c) Detail Ability Tests.

(a) Logical Ability Test

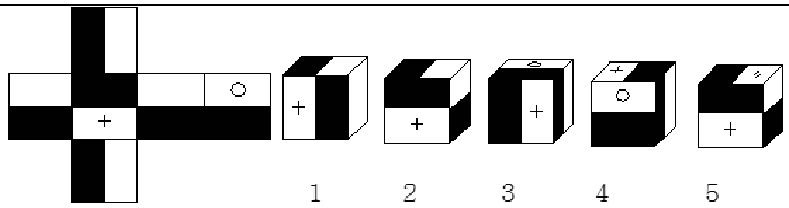


Logical Rule: In this type of test, you are required to choose, from a set of alternatives, which diagram will complete a similar analogy to the first example.

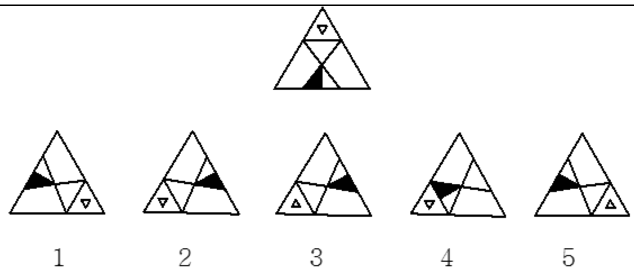
9	16	25	36	?
47	48	49	50	51
1	2	3	4	5

Mathematics Sequence: In this type of test, you are given a string of numbers. You have to work out the number that is missing from the string (marked ?).

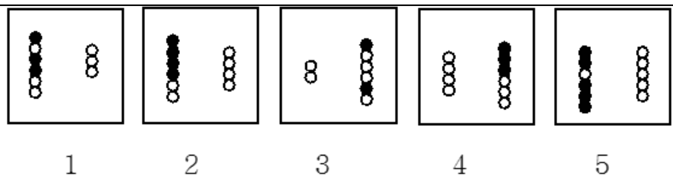
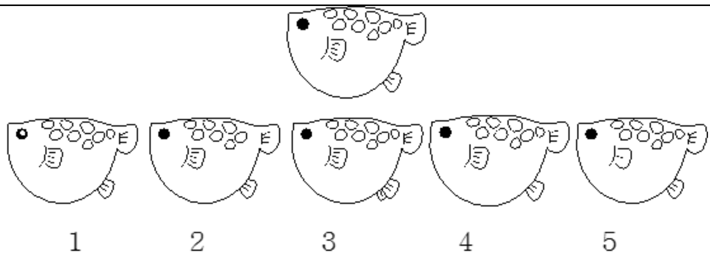
(b) Spatial Imagination Ability Tests



Spatial Structure: In this type of test, you need to look at the unfolded shape, and then choose which of the objects below would best represent the first object if it were folded.



Rotation: In this type of test, you are shown a shape in the middle of the page. Below they are five other shapes. You have to decide which of the alternatives is identical to the original shape. It will still be identical to the original if it has been turned around. It will not be the same as the original if it has been turned over, or the proportions, parts have been changed.

(c) Detail Ability Tests

Odd One Out Test: In this type of test, you need to decide which of the objects is the "odd one out".

Same Detail Test: In this type of test, you are shown a pattern in the middle of the page. Below they are five other patterns. You have to decide which of the alternatives is exactly the same to the original pattern.

This set of psychometric tests is evaluating not only participant's attention, such as the detail ability tests, but also testing participant's logical thinking and spatial imagination abilities. Therefore, how colour could influence people's performance on different type of thinking ability, and to what extend colour could influence on people's impulsivity can be explored and discussed in this study. In the first experiment, there are three tests for each type, hence in total each participant need to finish 126 psychometric tests in one experiment.

Colours

Six most commonly used coloured backgrounds – red, orange, yellow, green, blue, and purple – having the samilar luminance and chroma and an equally luminous reference white colour (used as a control) are used in the experiment. The CIEL*a*b* values of the seven colours are determined by the measurement using a CS-1000 spectroradiometer. The L* and C* values of all the seven coloured backgrounds are both fixed at around 66 (±2). The characteristics of these seven colours and the position in CIEL*a*b* colour space are shown in the Table 3.10 and Figure 3.6. To measure these coloured backgrounds, the spectroradiometer is at the same position when the participants performing the experiment.

Table 3.10 The characteristic of selected seven colours.

Colours	L*	h (°)	C*	a*	b*
Visual Reference White	69.71	29.10	0.48	0.42	0.23
Red	69.63	34.24	68.58	56.69	38.59
Yellow	70.71	98.78	70.97	-10.83	70.14
Blue	67.29	286.76	67.11	19.36	-64.25
Green	67.73	176.98	68.33	-68.24	3.60
Orange	71.17	67.83	67.07	25.31	62.11
Purple	67.96	321.03	68.17	53.00	-42.88

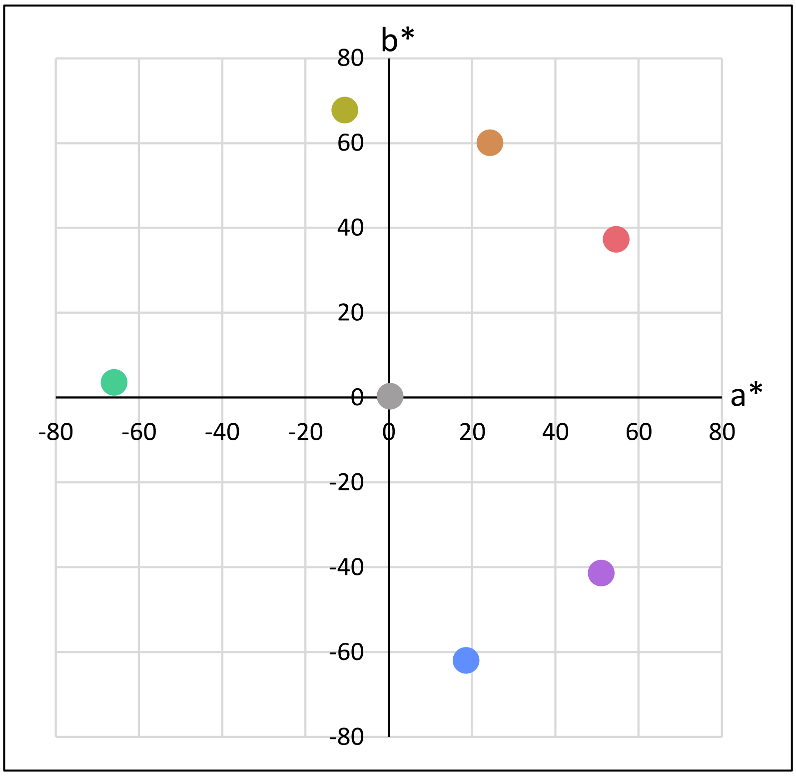


Figure 3.6 The seven colours in the CIE L*a* b* colour space.

3.3.1.3 Experiment Procedure

The psychophysical experiments were carried out in a dark room. Participants were tested individually in the room. For the first time experiment, when they came into the room, they were required to do the Ishihara Colour Blindness Test first. After passing this test, they were asked to read the instructions, which explain the completely experimental procedure. Later, six examples according to each type of psychometric tests were introduced to participants for them to warm up and allowed them to familiarise with the psychometric tests before the real experiment. The real experiment began five minutes after they came into the dark room in order to adapt the room conditions. Each participant sat at a fixed distance, about 75cm away from the display. This is illustrated in Figure 3.7. The actual screen used which shown in the experiment shows in Figure 3.8.

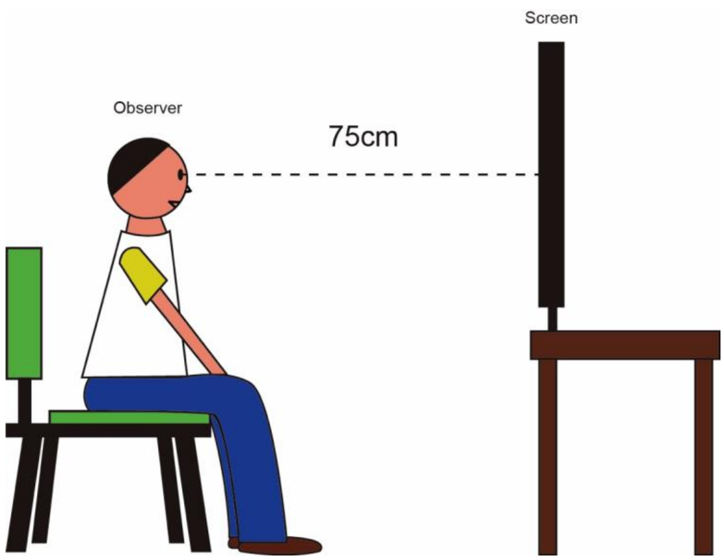


Figure 3.7 The experimental environment.

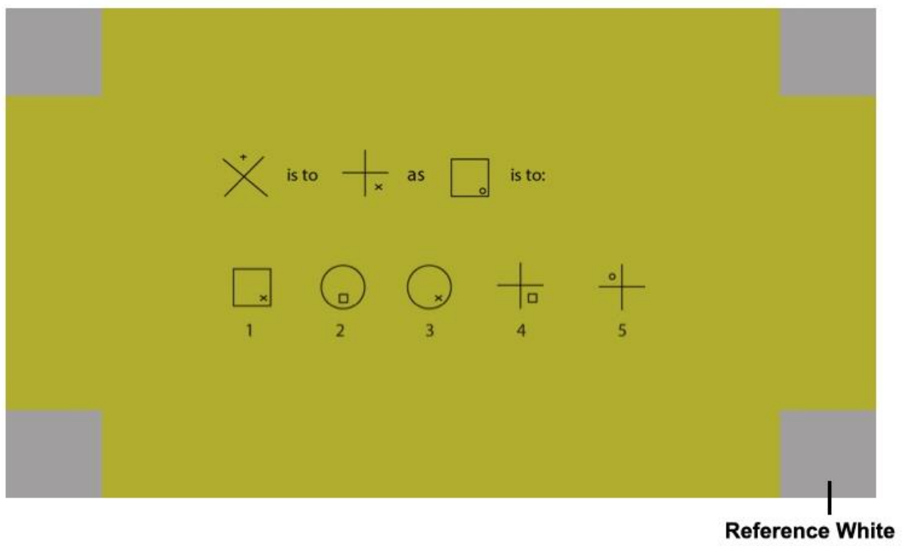


Figure 3.8 The actual screen show in the experiment.

Table 3.11 Settings parameters for the LCD display.

Controls	Standard Setting	Range
Contrast	80	0-100
Brightness	50	0-100
Colour	50	0-100
Tone	Cool 1	warm1/ warm2/ normal/ cool1/ cool2

During this experiment, participants are required to look at the reference white background for two minutes to adapt the experiment environment before the real test. For each test, they were required to speak out the answer with no chance to change their mind. Because measuring the errors under time pressure is part of the experiment. After their responding, they moved on to the next test. Each time, all types of psychometric tests appeared on the reference white background first, and then six coloured backgrounds (with four reference white patches in the corners) shown in a random sequence. The whole experiment took approximately one hour for each observer. Every day after finishing all the experiments, the seven colours were re-measured at the same distance to the display as participant (75 cm) to ensure the repeatability of the coloured backgrounds. Two weeks after the first time experiment, which works as a break to reduce carry-over effect from one experiment to the next one, they were required to repeat the experiment once more to assess their repeatability.

3.3.1.4 Colour Evaluation

Table 3.12 summarises the deviation of the actual seven colours' characteristic values measured every day from the original colours' characteristic values. The deviations for each colour were measured with the square root of the mean squared difference between each day's test data and the standard (original) value. The L*, C* and h(°) values for all colours measured after every experiment day have a small deviation of less than 8% of the original colour values, which means that all seven colours were stabled at each experiment day.

Table 3.12 The colour deviation for each colour during the experiment days.

	L*	h(°)	C*
Visual Reference White	69.71±0.41	29.10±3.74	0.48±0.16
Red	69.63±0.22	34.24±0.09	68.58±0.63
Yellow	70.71±1.19	98.78±0.16	70.97±2.84
Blue	67.29±0.94	286.76±0.69	67.11±1.36
Purple	67.73±0.67	321.03±0.14	68.33±1.09
Orange	71.17±0.69	67.83±0.20	67.07±0.61
Green	67.96±0.36	176.98±0.28	68.17±0.35

3.3.1.5 Data Analysis

Paired t-test

The paired t-test is normally used to compare the values of means from two related samples (Bryman & Cramer, 2009). In this experiment, paired t-test is conducted to analyse the differences in response time and error rate for different treatments.

Dimensionless

A dimensionless quantity is a quantity to which no physical dimension is applicable. Statistical method of dimensionless used in this experiment is extremum method:

$$x_i' = \frac{x_i}{\max x_i} \tag{3. 1}$$

where x_i' is the dimensionless data, $\max x_i$ is the maximum value of the whole data set of response time and error rate respectively.

3.3.2 Experimental Set Up for Chroma Experiment

The aim of the second experiment is to explore the chroma influence on impulsivity and arousal. After fully analysing the data collected from the hue experiment, according to the results and further questions, the chroma experiment has be planed. Details of the preparations of the chroma experiment have been summarised in the following four sections as the psychometric test type, colours, experiment procedure and the colour evaluation after the experiment.

3.3.2.1 Selecting Participants

Similar to the hue experiment, twenty-eight participants, including fourteen female and fourteen male Chinese subjects are selected to take part in the chroma experiment.

3.3.2.2 Experiment Preparation

Psychometric test types

In the second experiment, the type of psychometric tests has been reduced to two groups (four types) based on the result from the hue experiment. Participants' performance on the detail ability (Odd one out and Same detail) tests were less influenced by colour than other four tests, therefore this group of tests has been removed from the chroma experiment. The psychometric tests used in the chroma experiment are:

- Logical ability (Logical rule and Mathematics sequence).
- Spatial imagination ability (Spatial structure and Rotation).

In this experiment, participants needed to finish thirty tests for each type of test. In total, each participant needed to solve 120 psychometric tests in the chroma experiment.

Colours

Three hues (red, orange and yellow) are being explored as three typical colours influent differently on impulsivity. For each hue, four levels of chroma are selected - 100%, 75%, 50% and 25% - in the experiment together with the visual reference white (0% chroma). In total, thirteen coloured backgrounds used in the chroma experiment. They are colours have similar in lightness, decreased in four chroma levels, and in red, orange and yellow. An equally luminous visual reference white colour (used as a control) was also used in this experiment. The CIELAB values of the thirteen coloured backgrounds are determined from the measurement by the CS-1000 tele-spectroradiometer. The lightness of all the thirteen coloured backgrounds are fixed at around 71 (±2).The chroma of each level are fixed at around 100%: 69 (±2); 75%: 52 (±2); 50%: 35 (±2); 25%: 16 (±2). Table 3.13 and Figure 3.9 show the characteristics of these thirteen colours and their position in the CIEL*a*b* colour space. The tele-spectroadiometer CS-1000 is located at the same position as participants performing the chroma experiment to measure these coloured backgrounds.

Table 3.13 The characteristic of selected thirteen colours.

Colours	**L***	**h (°)**	**C***	**a***	**b***
Visual Reference White	69.71	29.10	0.48	0.42	0.23
Red 100%	69.63	34.24	68.58	56.69	38.59
Red 75%	71.30	32.12	53.92	45.67	28.67
Red 50%	72.49	34.73	33.25	27.32	18.94
Red 25%	71.67	32.59	13.64	11.49	7.35
Orange 100%	71.17	67.83	67.07	25.31	62.11
Orange 75%	72.69	68.43	50.16	18.44	46.64
Orange 50%	70.20	66.74	35.31	13.94	32.44
Orange 25%	69.16	68.91	18.40	6.62	17.17
Yellow 100%	70.71	98.78	70.97	-10.83	70.14
Yellow 75%	68.56	99.49	52.83	-8.71	52.11
Yellow 50%	69.13	99.21	36.40	-5.83	35.93
Yellow 25%	68.60	96.83	17.44	-2.07	17.32

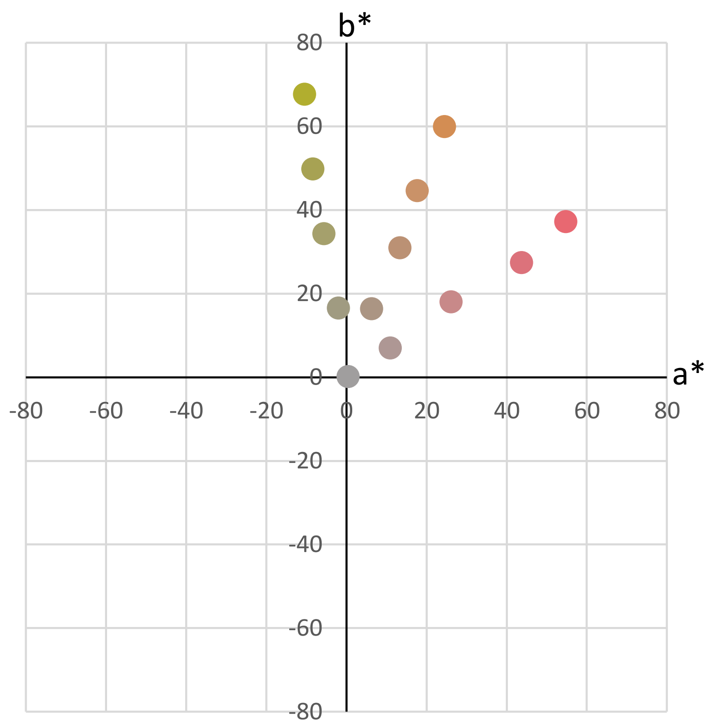


Figure 3.9 The thirteen colours in CIE L*a*b* colour space.

3.3.2.3 Experiment Procedure

An exactly same experiment procedure was carried out in the chroma experiment. The experiment environment was a dark room. Participants were tested individually in the room. The Ishihara Colour Blindness Test was required to test new participants who had not participated in the first experiment before. After passing the colour vision test, they were required to read the instructions and familiarise with each type of psychometric test. The total warm up time before the real experiment was about 5 minutes, which allowed participants to adapt to the dark environment. Each participant sat at a fixed distance of 75 cm from the display as in the first experiment. The same LCD display was used in this experiment.

3.3.2.4 Colour Evaluation

After each day's experiment, all the test coloured backgrounds were measured by using the CS-1000 tele spectroradiometer at the same position as where participants sat (75 cm away from the display) to make sure the stability of the colours every day. Table 3.14 summarises the deviation for each colour apart from the original colours during the experiment period. The following equation is used to calculate colour characteristic values (L*, C* and h°) for each colour.

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x_0)^2}{n}} \qquad (3.\ 2)$$

where x0 is the L*, C* and h(°) value for thirteen original colours respectively.

From the table, the deviation of each colour's characteristic values is less than 10% of the original values, which means that all thirteen colours are stable across each day of the experiment.

Table 3.14 The colour deviation for each colour during the experiment days.

	L*	h(°)	C*
Reference White	69.71±0.54	29.10±2.60	0.48±0.28
Orange100%	71.17±0.71	67.83±0.36	67.07±1.34
Orange75%	72.69±0.50	68.43±0.31	50.16±0.96
Orange50%	70.20±0.65	66.74±0.62	35.31±1.50
Orange25%	69.16±0.59	68.91±1.55	18.40±1.76
Red100%	69.63±0.51	34.24±1.04	68.58±3.29
Red75%	71.30±0.63	32.12±0.30	53.92±1.26
Red50%	72.49±0.53	34.73±0.50	33.25±0.68
Red25%	71.67±0.50	32.59±4.37	13.64±0.43
Yellow100%	70.71±1.40	98.78±0.22	70.97±2.75
Yellow75%	68.56±0.51	99.49±0.28	52.83±2.21
Yellow50%	69.13±0.78	99.21±0.28	36.40±0.61
Yellow25%	68.60±0.47	96.83±3.33	17.44±1.44

3.3.2.5 Data Analysis

Same method as the paired t-test is conducted to analyse the differences in response time and error rate for different treatments. The dimensionless method has also been used to normalise response time and error rate data to compare them using the same scale.

3.3.3 Experimental Set Up for Emotion Experiment

The aim of the third experiment is to explore the influence of single colours on emotion, and evaluate Ou's (2004) colour emotion models for single colours. A comparison between colour influence on response time, error rate and emotion will be discussed in later chapter. In this section, colours used in this experiment, participant's criteria and experiment procedure will be discussed in detail.

3.3.3.1 Selecting Participants

Twenty-one observers with normal colour vision are selected from the University of Leeds. They came from different countries, with different genders, study backgrounds and age ranges. The reason to choose a range of observers having difference between cultural, gender and age is to collect experimental data with more possibility without considering cultural difference, gender difference, and age difference; also without specifying average or typical customers. Consequently, if there are fewer than four exceptions to a trend through 21 samples (which is more evident in binomial expansion test at $p < 0.02$), it is considered to be a "potential universal" although some exceptions can be found because of rare cultural factors (Engeldrum, 2000). Information about all the observers is summarised in Table 3.15. The observers participating in the repeat experiments are summarised in Table 3.16.

Table 3.15 Observer groups.

Gender	Female: 18; Male: 3
Nationality	Chinese: 15; Thai: 3; British: 1; Korean: 1; Iranian: 1
Age	20-30: 15; 30+: 6
Education Background	Study in subjects within colour science, textile technology and design: 10; Study in subjects apart from colour science, textile technology and design: 11

Table 3.16 Observer groups for repeat experiments.

Gender	Female: 10; Male: 2
Nationality	Chinese: 11; Iranian: 1
Age	20-30: 10; 30+: 2
Education Background	Study in subjects within colour science, textile technology and design: 5; Study in subjects apart from colour science, textile technology and design: 7

3.3.3.2 Experiment Preparation

Colours

Summarised from the previous research, Valdez (1994) has chosen seven single colours in the emotion research; Ou (2004, 2011, and 2012) has chosen 20, 12 and 30 single colours respectively in his emotion. In this experiment, 20 colours have been used according to the commonly used colour sample size.

The 20 colours were first selected based on textile samples because there were limited colours that provided by the fabric company. The L*, a* and b* values of textile samples were measured, and these colours were then printed on cards with the same L*, a* and b* values. The printer used in the emotion experiment to reproduce experiment sample is an HP Design jet Z3200 printer. The 20 colours were either dyed on the terylene fabric with dobby pattern texture or printed on the cardboard were then cut into 8cm × 8cm samples. The specifications of the 20 colours and the positions of these colours in the CIELAB colour space of paper samples are shown in Table 3.17 and Figure 3.10. Figure 3.11 shows the 20 printed colour cards laying in the viewing cabinet. The specifications of the 20 colours and the positions of these colours in the CIELAB colour space of textile samples are shown in Table 3.18 and Figure 3.12. Figure 3.13 shows the physical textile samples laying in the viewing cabinet.

Table 3.17 Specifications of the 20 printed colour samples.

Number	L*	a*	b*	C*	h (°)
1	85.72	1.06	-2.77	2.97	290.94
2	81.87	-0.47	36.80	36.80	90.73
3	76.02	8.84	45.41	46.26	78.98
4	67.30	15.26	37.12	40.13	67.65
5	53.31	14.61	20.58	25.24	54.63
6	74.43	19.63	9.10	21.64	24.87
7	57.94	30.37	14.93	33.84	26.18
8	43.83	46.75	28.72	54.87	31.56
9	43.70	38.96	16.26	42.22	22.65
10	49.72	-15.74	-26.61	30.92	239.40
11	43.29	2.46	-25.18	25.30	275.58
12	40.59	-0.47	-33.70	33.70	269.20
13	37.75	3.30	-30.02	30.20	276.27
14	28.91	2.01	-13.26	13.41	278.62
15	69.68	-15.97	12.00	19.98	143.08
16	60.60	-33.78	8.08	34.73	166.55
17	50.49	-28.02	-7.06	28.90	194.14
18	35.35	-16.54	9.79	19.22	149.38
19	46.34	-2.87	18.09	18.32	99.01
20	26.17	1.52	-2.81	3.19	118.41

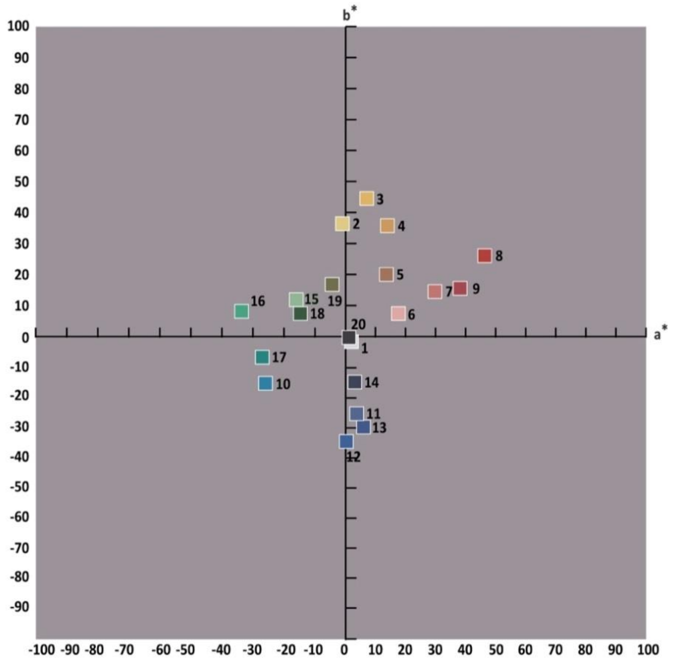


Figure 3.10 The 20 colours of printed samples plotted in the CIE L*a*b* colour space.

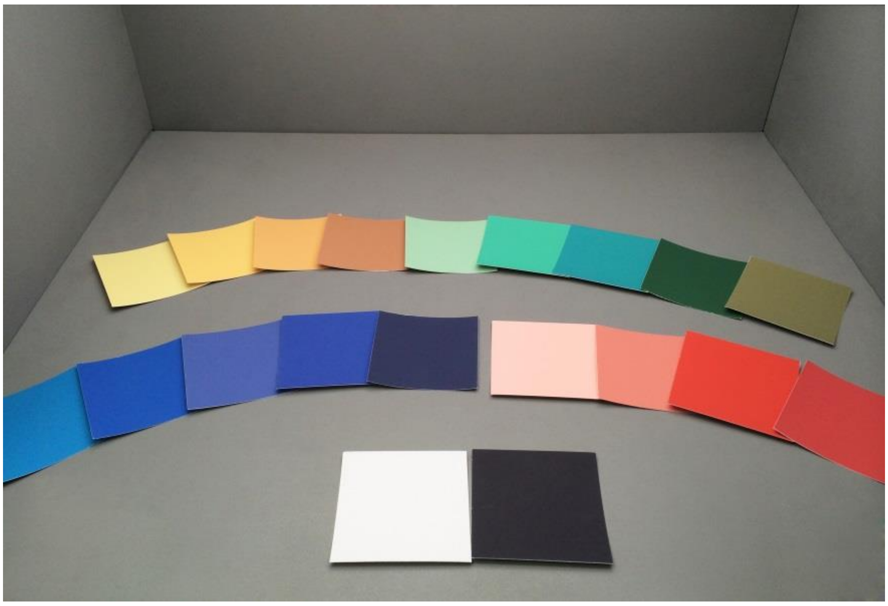


Figure 3.11 20 colour printed samples laid in the viewing cabinet.

Table 3.18 Specifications of the 20 textile colour samples.

Number	L*	a*	b*	C*	h (°)
1	89.62	-0.70	3.34	3.42	101.87
2	85.94	-2.91	43.23	43.32	93.86
3	78.53	9.54	51.15	52.03	79.44
4	68.63	15.33	42.58	45.26	70.20
5	53.25	13.35	25.96	29.19	62.79
6	77.01	19.72	14.41	24.42	36.16
7	59.22	31.89	19.60	37.43	31.58
8	46.31	49.03	33.13	59.17	34.05
9	44.42	41.79	20.66	46.62	26.30
10	47.57	-18.53	-27.64	33.28	236.16
11	39.72	5.39	-27.64	33.28	236.16
12	36.20	1.30	-36.44	36.46	272.04
13	31.44	5.40	-32.78	33.22	279.36
14	21.33	3.39	-14.16	14.56	283.48
15	69.36	-19.30	16.58	25.45	139.33
16	59.38	-39.66	12.54	41.60	162.45
17	48.31	-34.70	-3.38	34.86	185.56
18	31.57	-18.76	10.80	21.65	150.07
19	44.22	-3.62	22.62	22.91	99.08
20	17.60	1.07	-1.30	1.69	309.50

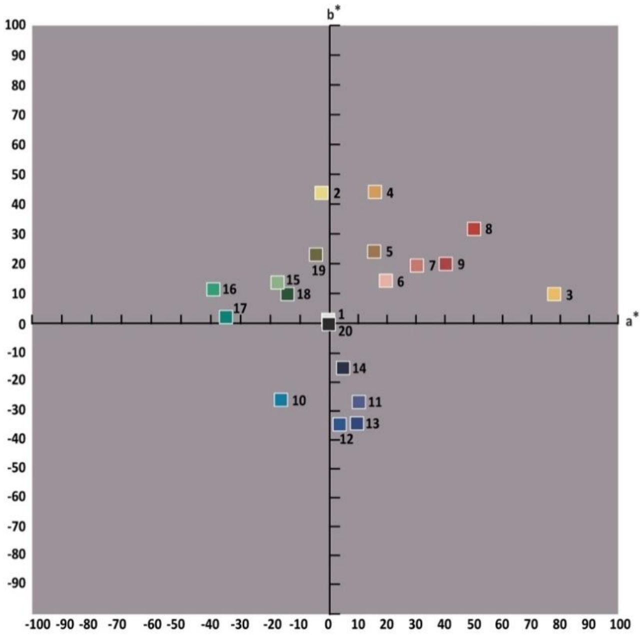


Figure 3.12 The 20 colours of textile samples plotted in the CIE L*a*b* colour space.

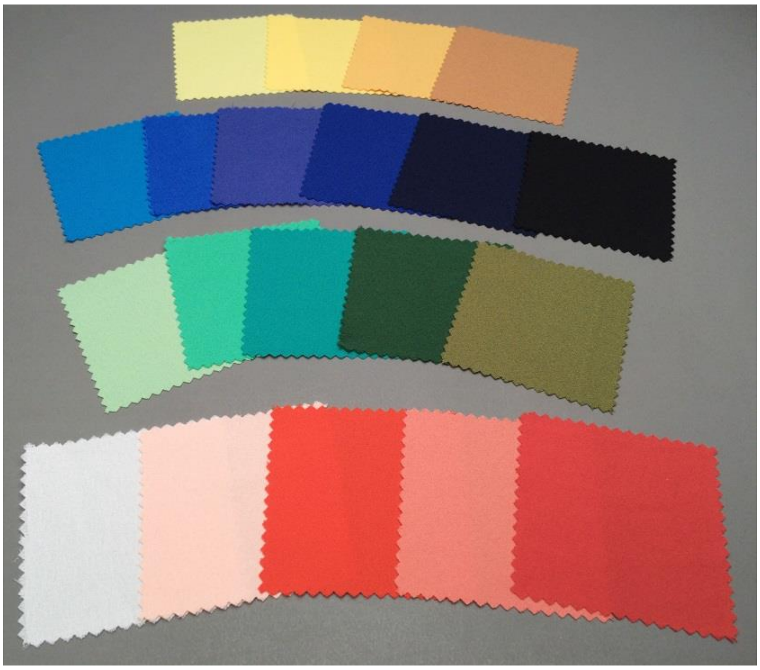


Figure 3.13 The 20 textile samples laid in the viewing cabinet.

Colour measurement is an important part in this research as all the models are built based on accurate colorimetric data collected by colour measurement. Owing to the different colour gamut between print ink and dye material, a noticeable colour difference existing and have been summarised in Table 3.19. The colour difference shown in the table indicates the 20 colours on paper samples and textile samples are similar colours but not the same colours.

Table 3.19 CIELAB Colour difference between colour printed on colour patches and dyed on fabric patches.

Colour	ΔE^*_{ab}	Colour	ΔE^*_{ab}
Colour 1	7.46	**Colour 11**	5.23
Colour 2	7.99	**Colour 12**	5.47
Colour 3	6.30	**Colour 13**	7.20
Colour 4	5.62	**Colour 14**	7.76
Colour 5	5.53	**Colour 15**	5.67
Colour 6	5.90	**Colour 16**	7.48
Colour 7	5.08	**Colour 17**	7.93
Colour 8	5.55	**Colour 18**	4.50
Colour 9	5.28	**Colour 19**	5.06
Colour 10	3.67	**Colour 20**	8.71

Word Pairs

Looking back to the previous studies of colour image scale (see more detail in section 2.5.3), a wide time and geography span can be found. In their studies, an extensive range of word to describe colour and image were introduced (see more detail in section 2.4.1). The words used in this research project are selected from these previous studies summarised in Table 3.20:

Table 3.20 The summary of word related colour emotion experiments.

Region	Year	Researchers
UK	1969	J. Hogg
	2008	T. Clarke
	2004, 2011, 2012	L. Ou
US	1973	C. Osgood
	1994	P. Valdez
Germany	1962	B. Wright
Turkey	2006	K. Yildirim
Sweden	2010	M. Solli
Hong Kong	2002	K. Cheng
	2004	J. Xin
	2007	X. Gao
Japan	1981, 1991	S. Kobayashi
Taiwan	1995	S. Hsiao
Republic of Korea	2009	Y. Shin

Ten most frequently used word pairs are selected from these studies, and used in the emotion experiments with paper and textile samples. They are all expressed in English, as all the observers have the ability to understand the meaning of the word pairs through the definition in English. The word pairs are summarised in Table 3.21.

Table 3.21 Summary of the word pairs used in two parts of experiments.

Clean - Dirty (CD)	Tense - Relaxed (TR)
Fresh - Stale (FS)	Masculine - Feminine (MF)
Like - Dislike (LD)	Warm - Cool (WC)
Heavy - Light (HL)	Modern - Classical (MC)
Hard - Soft (HS)	Active - Passive (AP)

3.3.3.3 Experiment Procedure

The psychophysical experiments used a similar procedure as Ou *et al.* (2004). The visual assessment is based on a two-categories category judgment procedure. The experiment was conducted in a dark room and the samples were presented in the viewing cabinet with the standard D65 simulator. Inside of the viewing cabinet was painted with a uniform grey colour at L* of 50. The viewing distance from observer to the colour patch was 60 cm. An experimenter was set beside the observer to record their results. Figure 3.14 and Figure 3.15 illustrate the experiment environment. Before the experiment, observers were required to fill in the observation answer pack, which including the personal information sheet and the experiment consent sheet. All observers had to pass the Ishihara colour vision test, read instructions and the definition of the 10 word-pairs. The definitions of the 10 word-pairs were from Cambridge Advanced Learner's Dictionary (2013). Figure 3.16 illustrates an observer reading the instructions and carrying out the Ishihara colour vision test. After fully understanding the instructions and passing the colour vision test, they were required to begin this two-categories category judgment procedure. The objective of the experiment was to compare a colour-emotion word pair and to pick one of them in association with the colour presented. For example, they would be asked the question: "which word is most closely associated with the colour presented?" In total 420 observations were processed in the emotion experiment with paper samples and textile samples.

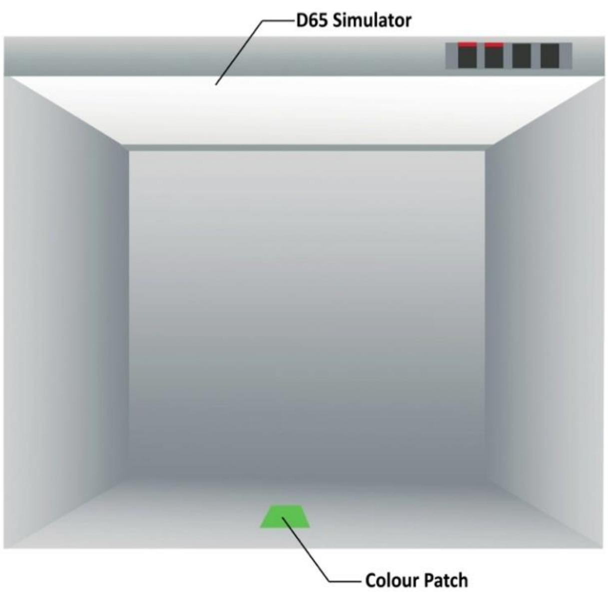


Figure 3.14 Simulated device set-up: observer's view.

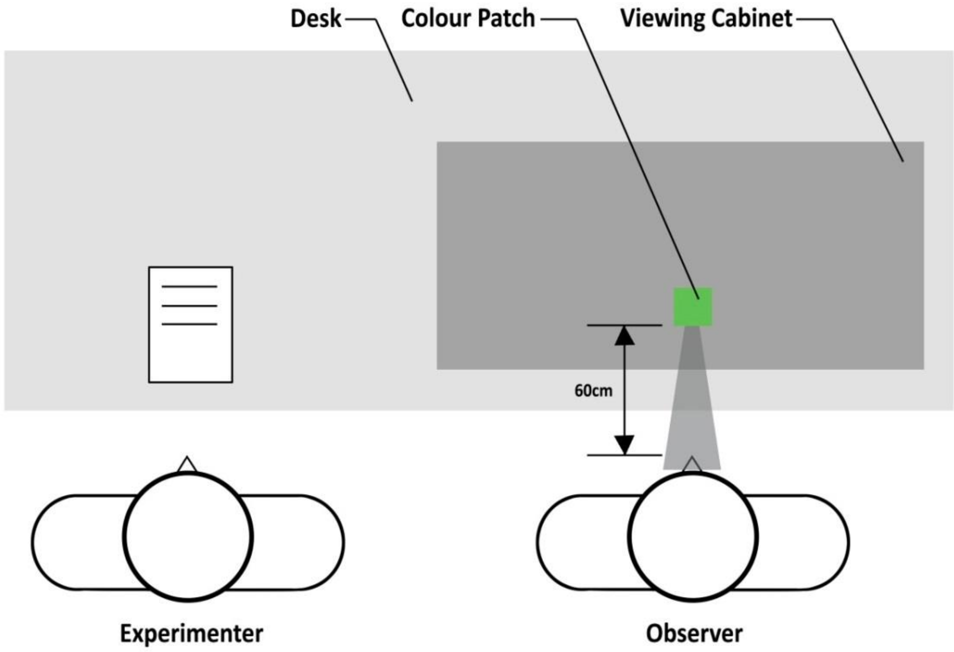


Figure 3.15 Simulated device set-up: top view.

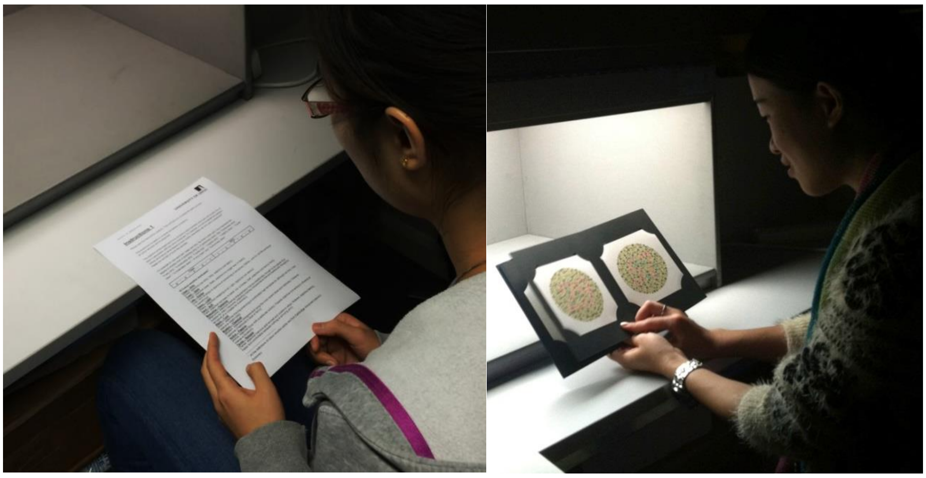


Figure 3.16 An observer reading the instruction and doing the Ishihara colour vision test (reproduced from Ishihara, 1996).

Three weeks after finishing the first round, 12 out of 21 observers were asked to repeat this experiment to enable the reliability and repeatability to be assessed. In total 420 (12 × 20) observations were processed in the repeat experiments.

In the repeat experiments, the same 20 colours were used as observation objects, 10 word-pairs were used to judge the emotion of the 20 colours, but the 2-point category judgement procedure has been changed to 10-point category judgment. The purpose of using a 10-point category judgment is to obtain information that is more detailed from observers about the emotion of the colours (see more detail of the introduction of repeat experiments in Appendix C). An example of the scale used in the repeat experiment is shown in Table 3.22.

Table 3.22 An example of a 10-point category scale (Clean-Dirty) used in the repeat experiment.

Clean					**Dirty**				
-5	**-4**	**-3**	**-2**	**-1**	**1**	**2**	**3**	**4**	**5**

3.3.3.4 Data Analysis

For analysing the experiment data, the category values for each sample will be transferred into interval-scale values. For each sample, the psychological scale value is transferred into the average (mean or median) category value of this sample (Gescheider, 1997). Torgerson’s Law of Categorical Judgement is normally used in analysing data collected from the categorical judgement experiment. There are four conditions of the Law of Categorical Judgement. They are summarised in Table 3.23.

Table 3.23 Torgerson’s Four Conditions of the Law of Categorical Judgement (reproduced from Engeldrum, 2000).

Condition	Correlation Coefficient	Variances	Model Equation
A	$\rho_{jg}\sigma_j\sigma_g = C1$	$\sigma_g^2 \neq \sigma_j^2$	$t_g - S_j = z_{jg}\sqrt{\sigma_j^2 + \sigma_g^2 - 2\rho_{jg}\sigma_j\sigma_g}$
B	$\rho_{jg} = 0$	$\sigma_g^2 = C2$ $\sigma_g^2 = 0$	$t_g - S_j = z_{jg}\sqrt{\sigma_j^2 + C2}$ $t_g - S_j = z_{jg}a_j$
C	$\rho_{jg} = 0$	$\sigma_g^2 = C3$ $\sigma_g^2 = 0$	$t_g - S_j = z_{jg}\sqrt{\sigma_g^2 + C3}$ $t_g - S_j = z_{jg}b_g$
D	$\rho_{jg} = r$	$\sigma_j = k1$ $\sigma_g = k2$ $\sigma_j = \sigma_g = 0$	$t_g - S_j = z_{jg}\sqrt{k1^2 + k2^2 - 2rk1k2}$ $t_g - S_j = z_{jg}$

where conditions B, C, and D have wide practical application. Condition D is the simplest condition, conditions B and C are more complex.

Factor Analysis

Factor analysis is a statistical method widely used in the social science and psychology. It is a method to simplify a large set of interrelated variables into a small set of independent ones (Kline, 1994). It has been used in Ou's colour emotion research, and also widely used in other research studying colour emotion, such as Chang (2008), Lee (2009), and Lucassen (2011), to classify colour emotion scales. The determination of eigenvectors and eigenvalues of a covariance matrix is the principal of factor analysis. The principal of factor analysis can be explained by the following equation:

$$Rv_k = \lambda_k v_k \qquad (k = 1 \dots n) \tag{3. 3}$$

where R is a matrix with n × n size; v_k are eigenvectors of the matrix A and λ_k are the associated eigenvalues (Kim, 1078). In both Ou's research and this study, A is the covariance matrix of experimental data (z-scores).

3.4 Summary

In this chapter, the aims of current study, the psychophysical experiments conducted in current study and experiment preparation of three psychophysical experiments were summarised. Three experiments were conducted in this study to explore the colour impact on impulsivity. Equipment used in these three experiments were LCD TV screen. This chapter also introduced the evaluation of the equipment used in this study. Meanwhile, the experimental procedure of three experiments was described in detail. This included participants selection, experiments preparation, the experiment procedure, colour evaluation and data analysis.

Chapter 4 The Influence of Hues

4.1 Introduction

The aim of this experiment was to explore hue influence on people's response time and error rate in order to discuss hue influence on impulsivity and arousal status. To achieve this goal, psychophysical methods were used to examine the impact of colour environment on two main indicators – response time and error rate. A psychophysical experiment was designed to examine whether, in a particular colour environment, the response time and error rate were different. Participants were required to look at the TV screen with different colour backgrounds to complete a range of psychometric tests. In other words, in this study, the colour environment is provided by the colour of the display screen. During the experiment, participants were required to give their response to the psychometric test as quickly and accurately as possible. Hue influences on response time, error rate, impulsivity and arousal will be discussed respectively in depth with consideration of psychometric test types, gender difference and colour preferences in this chapter. In this chapter, the following will be discussed: the reliability of the data, influence of hue on response time, influence of hue on error rate, and influence of hue on impulsivity and arousal. Figure 4.1 summarises the experimental method.

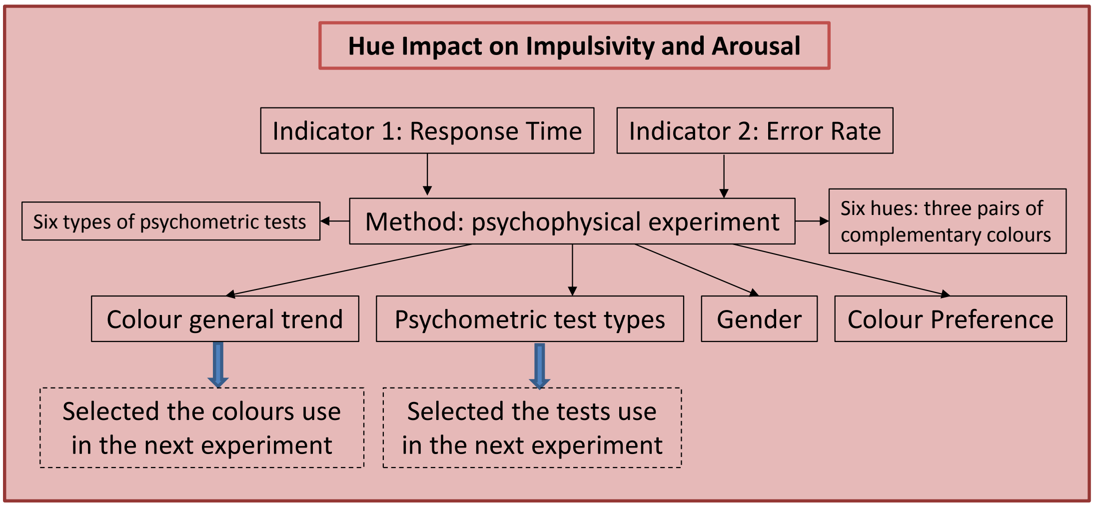


Figure 4.1 A flowchart of the method of hue experiment.

4.2 Observer Repeatability and Impulsivity Status

Observer repeatability indicates how well the observer's two times experiment (the first time experiment and the repeat experiment that taken placed two weeks after) agree with each other and how well individual observers agreed with majority decisions of the group.

The participant's performance on Error/Speed space was determined as: (1) LI, longer response time and smaller error rate; (2) HI, shorter response time and higher error rate; (3) HA, quicker and smaller error rate, and (4) LA, slower and higher error rate (all compared with mean). Figure 4.2 clarifies the three impulsivity status in this experiment. From the figure it can be seen that either the first time experiment or the repeat experiment, participants' performances were all evenly distributed in four quadrants, which means they were filled nicely into four impulsivity/arousal status groups.

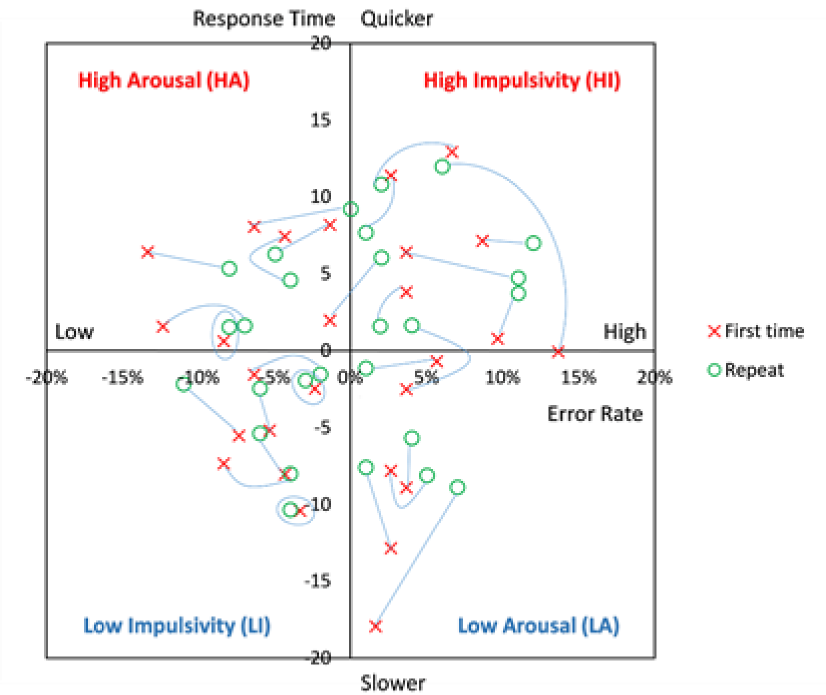


Figure 4.2 The Error/Speed space and participants' performance in hue experiment.

Figure 4.3 summarises the frequency of participants’ impulsivity status for original and repeat experiments in hue experiment. LI is low impulsivity, HA is high arousal, LA is low arousal and HI is high impulsivity. From the data in Figure 4.3, some participants performed even better in original experiment than the repeat experiment, as there were more participants in HA group and less participants in HI group in original experiment than the repeat. This may indicates that some of the participants were more concentrate in the original experiment than the repeat experiment.

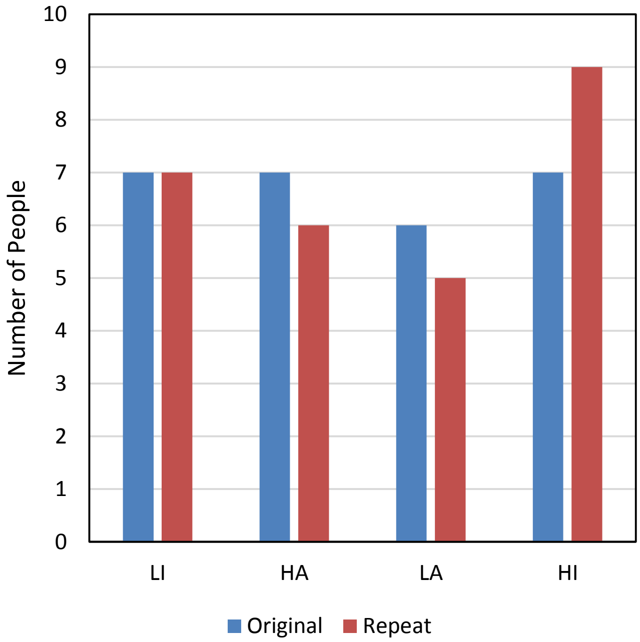


Figure 4.3 The frequency of participants’ impulsivity status for original and repeat experiments in hue experiment.

The two times of observer's experiment performances are summarised in Table 4.1. Table shown that participants’ performance all did not have a big jump (a big jump means from HI to LI, which means participant performed worse with more guessing in the first time while they learned the method to solve the question and began to consider more in the repeat experiment) in impulsivity status from the original experiment to the repeat. This means these participants do not need a long term training to complete the psychometric tests in this experiment.

Table 4.1 Summary of participant's repeatability and their impulsivity/arousal status.

Gender	Original			Repeat		
	Response Time	Error Rate		Response Time	Error Rate	
F1	33.5	15%	LI	26.25	6%	LI
F2	33.16	17%	LI	26.54	11%	LI
F3	19.8	21%	HA	17.81	12%	HA
F4	28.04	36%	HI	12.09	23%	HI
F5	30.44	20%	LI	26.01	14%	LI
F6	20.85	31%	HI	17.1	29%	HI
F7	28.66	28%	LA	25.23	18%	LA
F8	36.87	26%	LA	29.76	21%	LA
F9	15.02	29%	HI	13.27	19%	HI
F10	40.83	25%	LA	31.66	18%	LA
F11	27.2	32%	HI	20.37	28%	HI
F12	29.52	16%	LI	25.62	15%	LI
F13	16.56	25%	HI	16.41	18%	HI
F14	21.56	9%	HA	18.74	9%	HA
M1	26.01	21%	HA	18.05	19%	HI
M2	45.91	24%	LA	32.96	24%	LA
M3	36.01	18%	LI	29.46	11%	LI
M4	35.3	14%	LI	32.09	13%	LI
M5	19.92	16%	HA	14.9	17%	HA
M6	20.56	18%	HA	19.5	13%	HA
M7	21.58	26%	HI	19.35	28%	HI
M8	27.37	14%	HA	22.55	9%	HA
M9	38.37	19%	LI	34.41	13%	LI
M10	30.48	26%	LA	22.44	21%	HI
M11	35.78	25%	LA	32.18	22%	LA
M12	24.16	26%	HI	22.51	19%	HI
M13	26.4	10%	HA	22.46	10%	HA

LI=low impulsivity, HI=high impulsivity, LA=low arousal, HA=high arousal.
F=female, M=male.

The mean four status categories are summarised in Table 4.2. HI group was the biggest impulsivity status group among the four. The average response time of HI group was 20 ±1 seconds; the average error rate of HI group was 26% ±1 %. There were 14 participants grouped into LI group. The response time of LI group was 31 ±1 seconds and the average error rate of LI group was 14% ±1. Participants with low arousal status and high arousal status were lesser than those with high impulsivity and low impulsivity status. The response and error rate for LA group were 34 ± 2 seconds and 23% ±1% respectively. The response time and error rate for HA group were 21±1 seconds and 24% ± 1% respectively. The response time for LI and LA were similar; and the response time for HA and HI were similar. The error rate for LI and HA were similar while the error rate for HI and LA were similar.

Table 4.2 The mean response time and error rate for four status.

Variables	Impulsivity Status	Number	Mean± STD error
Response time (sec)	LI	14	31±1
	HA	13	21±1
	HI	16	20±1
	LA	11	34±2
Error rate (%)	LI	14	14±1
	HA	13	14±1
	HI	16	26±1
	LA	11	23±1

Abbreviations: LI, Low Impulsivity; HI, High Impulsivity; HA, high arousal; LA, low arousal.

According to the discussion above, data collected from the hue experiment was repeatable, the four groups as LI, HI, LA and HA were distinguishable. Data collected can be used in the next stage of analysis.

4.3 The Influence on Response Time

4.3.1 Colour General Trend

The experimental data has been analysed by different background colours. Figure 4.4 summarises the absolute value of response time for each colour. Error bars are standard errors through the figures in the whole chapter.

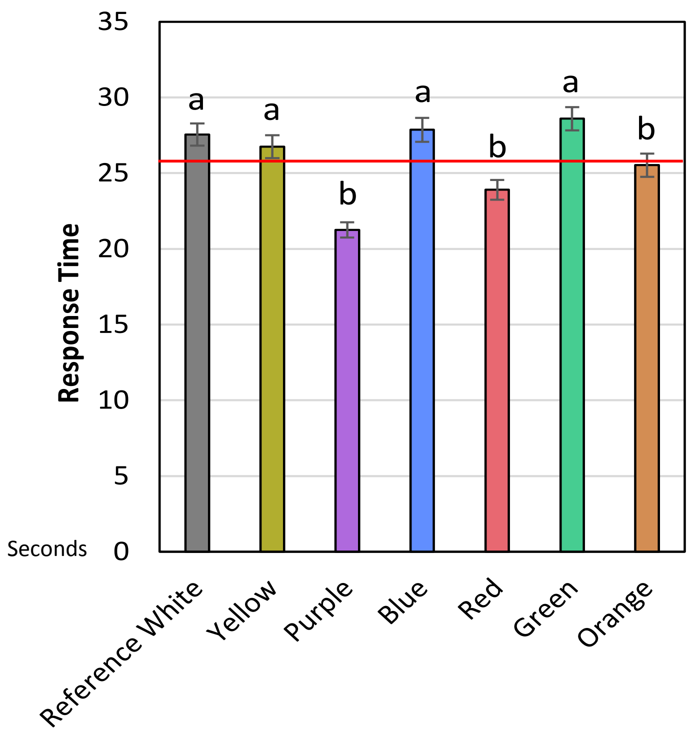


Figure 4.4 Response time by background colour. The red line in figure represents the average line. Letters a and b refer to data sets shown to be significantly different to each other (at the P=0.05 level).

From the general trend shown in Figure 4.4 participants responded slowest on green background and quickest on purple background at 29 seconds and 21 seconds respectively. The average of six colour backgrounds' response time was 26 seconds which was the red line shown in Figure 4.4. From statistical analysis, the response time can be divided into two groups: participants responded similar in time on yellow, blue and green backgrounds; they reacted nearly equally in times on purple, red and orange backgrounds. The performance on purple, red and orange backgrounds were significantly quicker than on yellow, blue and green backgrounds as all $P < 0.05$ in between colours in these two groups. These two groups of hues can be referred to two groups according to the spectrum range. Participants responded slower with middle part of spectrum as blue, green and yellow, whilst responded quicker with two ends of spectrum as purple, orange and red. Colours in middle part of spectrum can help participants to think and focus longer on the tests; while they may feel more difficult to concentrated on the tests with colours in short and long parts of spectrum or these colours may help with improving their thinking speed.

4.3.2 Response Time by Test Type

Experimental data has been also analysed by different psychometric tests to clarify the interrelations between coloured backgrounds and participant's performance on certain types of psychometric tests. Figure 4.5 summarised the response time for each type of psychometric test.

From the figure, it can be seen that participants performed differently for all six colours according to test types. They respond the slowest on yellow for the Logical Rule Test, the slowest on yellow for the Mathematics Sequence Test, on green for the Rotation Test, on orange for the Spatial Structure Test, on purple for the Odd One Out Test, and on green for the Same Detail Test respectively. According to statistical analysis, in the Logical Rule Test, response time for yellow is significantly higher than other five colours as $P < 0.05$. Follow by red, orange, blue and purple. Participants respond significantly quicker on green than other five colours in the Logical Rule Test as $P < 0.05$. In the Mathematics Sequence Test, response time for yellow and blue backgrounds are similar, as $P = 0.20$. Green, purple and red are all having similar response time. Orange has the response time significantly quicker than other five colours (all $P < 0.05$) and is nearly half of the response time of yellow. Participants respond similar among purple, red and orange with the response time at around 18 seconds for these three colours. The response time for yellow and blue has no significant difference, as P value is 0.21. Green is the slowest colour on the Rotation Test, and it is pointedly slower than other five colours as all $P < 0.05$. Yellow and purple are the colours participants respond quickest with the Spatial Structure Test, and the performance on these two colours are significantly quicker than other four colours with all $P < 0.05$. Orange is the colour participants respond significantly the slowest. The response times for the Odd One Out Test are highly similar for all six colours. However, purple still significantly slower than other five colours with all $P < 0.05$. Participants respond similarly on green, orange, and blue backgrounds for the Same Detail Test, but yellow is considerably quicker than other five colours with all $P < 0.05$.

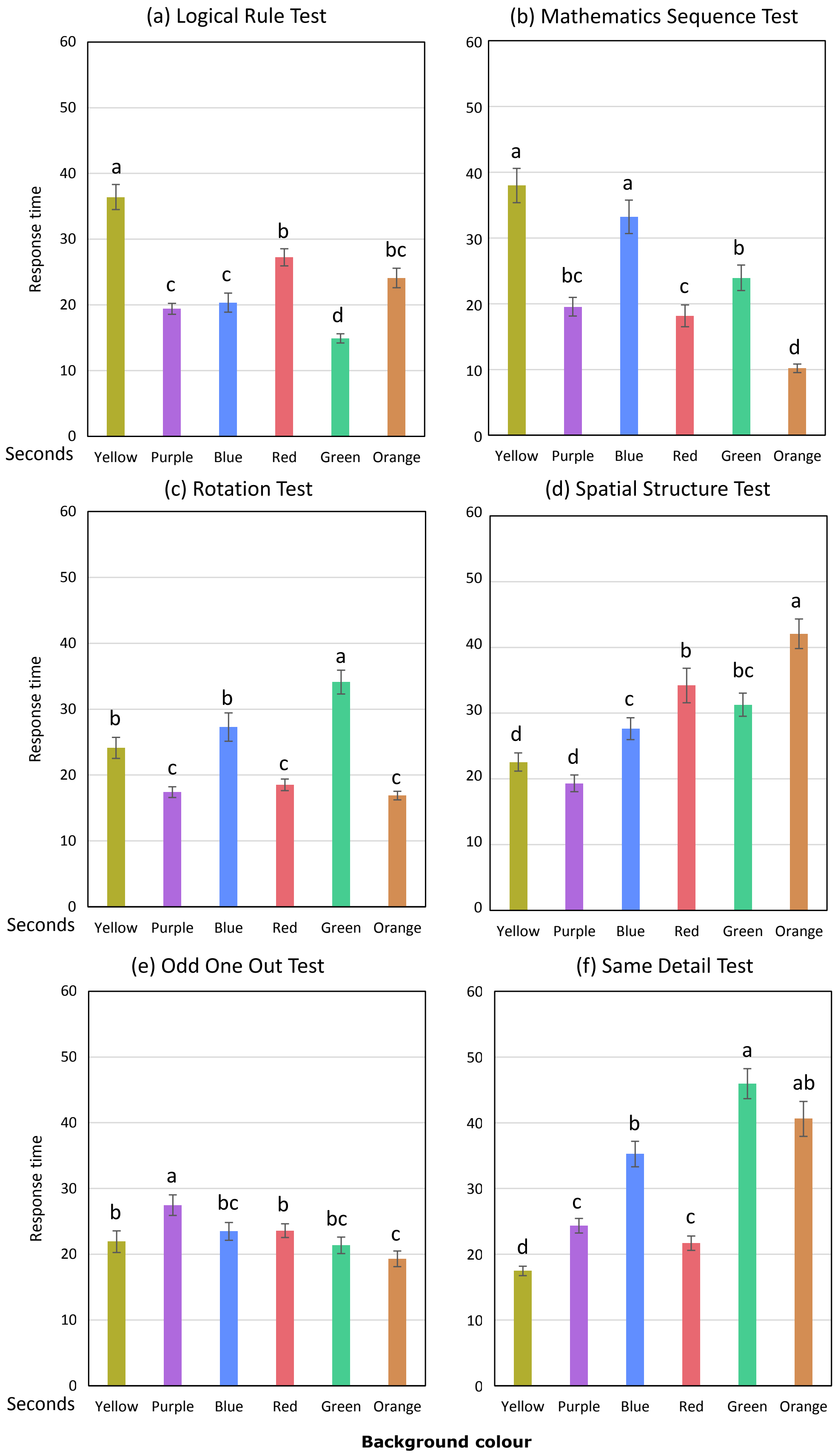


Figure 4.5 (a-f) Response time by test. Letters a-d refer to data sets shown to be significantly different to each other (at the P=0.05 level).

Six psychometric tests can be divided into three groups. (1) Logical ability (Logical Rule and Mathematics Sequence); (2) Spatial imagination ability (Spatial Structure and Rotation); (3) Detail ability (Odd One Out and Same Detail). On yellow and purple backgrounds, participants responded similar on the tests within the three groups. The value of response times for yellow and purple backgrounds for the logical ability tests were around 37 and 20 seconds; for the spatial imagination ability tests, participants had a response time at approximately 23 and 18 seconds; for the detail ability tests the response time were about 20 and 26 seconds. There was no clear trend for the other four colour backgrounds according to different test types. With the first group of tests, compare with general trend, red and purple were not the colours that participants responded quickest among the six. Green was the colour that participants responded to the quickest on the Logical Rule Test with a response time of 15 seconds. For the Mathematics Sequence Test, orange was the colour that participants responded quickest with a response time of 10 seconds. Participants responded quickest to the purple background when they solved Rotation Test and Spatial Structure Test. They responded similarly for red and orange backgrounds with purple when they solved the Rotation Test; yellow and purple also have similar lowest response times for Spatial Structure Test. The differences of hue influence on response time with odd on out test are not significant. Participants reacted quickest for orange with a response time of 19 seconds, they responded slowest for purple with a response time of 28 seconds. The response time difference between the quickest and slowest were less than 10 seconds. Therefore, colour may not have a significant influence on a participant’s response time when they solving the Odd One Out Test. Participants responded quickest for yellow, and slowest for green on Same Detail Test; the response times were 18 and 46 seconds respectively.

From the discussion above, hue influence on impulsivity varies across different types of psychometric tests. Red and purple are not the colours that participants respond the quickest all the time across six types of psychometric tests. For example, green is the colour with the quickest response in the Logical Rule Test, orange is the colour with the quickest response in the

Mathematics Sequence Test, Rotation Test, and Odd One Out Test. Yellow is the colour with the quickest response in the Same Detail Test. For some of the tests as Logical Rule Test, Mathematics Sequence Test, Spatial Structure Test and Same Detail Test, a big variation can be found according to different colours (say the difference between slowest and quickest was bigger than 20 seconds). Other types of psychometric tests as Rotation Test and Odd One Out Test, participants respond very close in response time with different colours.

4.3.3 Response Time by Gender

Hue influence on response time has also be discussed between genders. From Figure 4.6, there is a trend that male participants responded slower than female participants. However the trend is not significant as the error bars were overlapped between male and female across most of the colours. Male participants respond slowest for the blue background with a response time of 30 seconds, while for male participants the response time for purple was quickest at 23 seconds. Female participants responded slowest on green background (27 seconds) and quickest on purple (21 seconds).

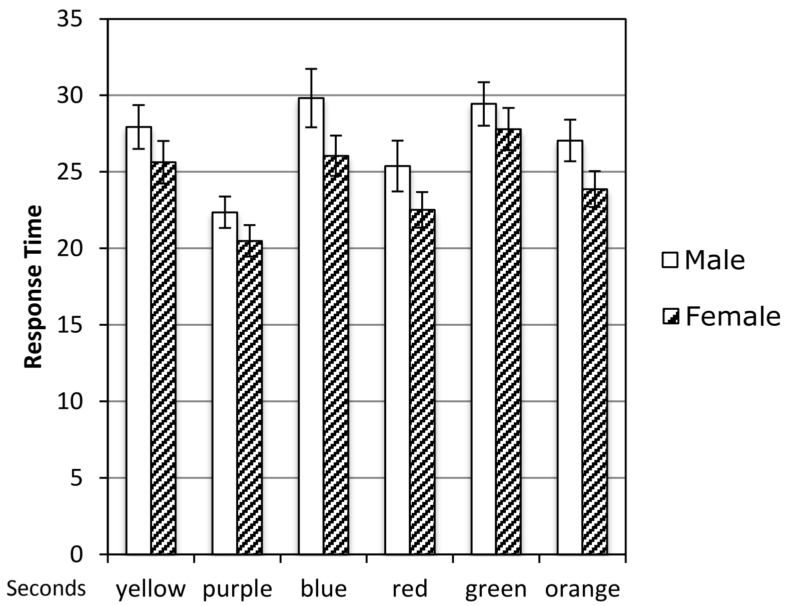


Figure 4.6 Response time by gender.

4.3.4 Response Time by Preference

During the experiment, participants were asked which colour out of the six was their favourite. Yellow was the colour most participants preferred (33% of the participants preferred yellow), followed by blue (22%), orange (15%), green(11%), purple (11%), and red(7%). Further investigations on influence of colour preference on participant's performance were calculated. Figure 4.7 shows a comparison of response time between colours the participants preferred and did not prefer. From the figure, there is a clear trend showing that the colour they liked could influence their performance. Apart from yellow and blue, on the rest of colour backgrounds participants all performed quicker on the colour they preferred than they were not preferred, but the difference is not big. The value of difference between colour they preferred and did not prefer is between 0.2 seconds. As apart from red, orange and blue, most of the error bars overlapped; it might be concluded that the difference of colour preference can only be seen significantly for red, orange and blue backgrounds.

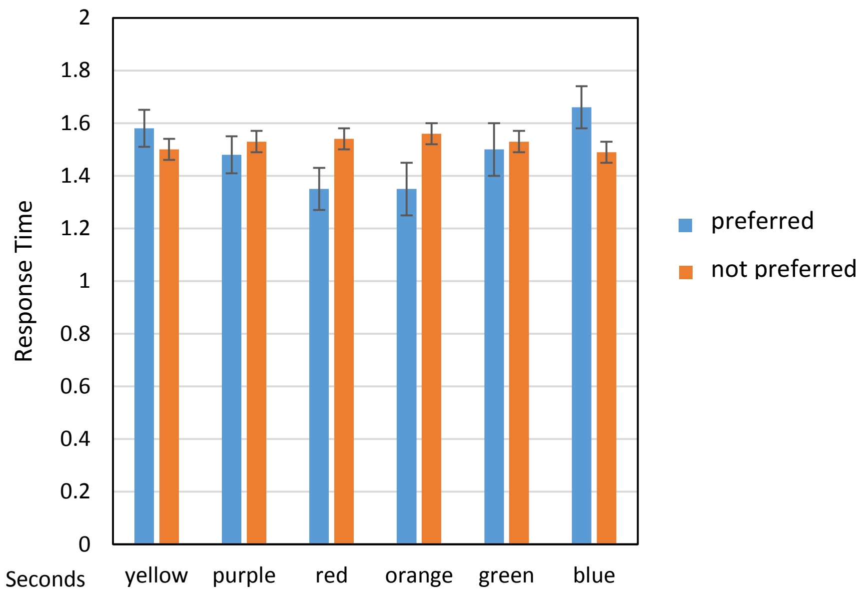


Figure 4.7 Response time by colour preference.

Although it cannot conclud that participants performed quicker on all the coloured background they liked, the connection between hue preference and response time was obvious.

4.4 The Influence on Error Rate

4.4.1 Colour General Trend

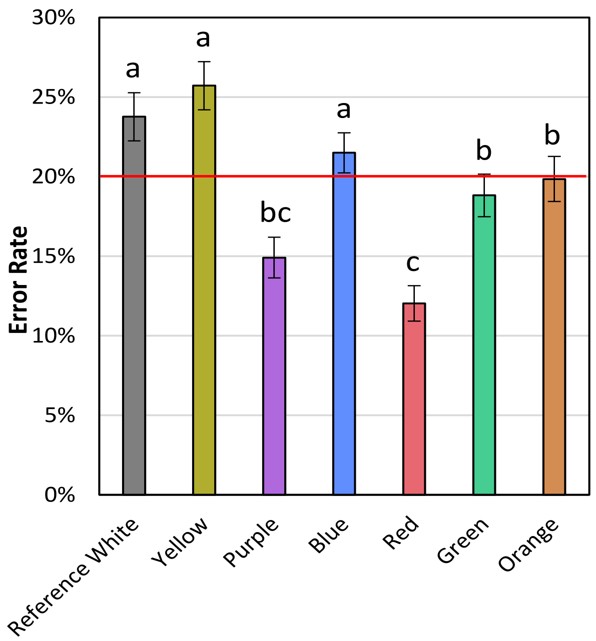


Figure 4.8 Error rate by background colour. The red line in figure represents the average line. Letters a-c refer to data sets shown to be significantly different to each other (at the P=0.05 level).

Figure 4.8 summarises the general trend of colour influence on participant's error rate. From the figure, it can be seen that yellow maintains the highest error rate which participants made 25% of mistakes on yellow background. Participants made only half proportion of errors on red background compared with yellow. From the statistical analysis, yellow and blue has the similar influence on people's error rate, participants all make more errors on these two colours than average. The errors make on orange, green and purple backgrounds are significantly decreasing compared with yellow and blue with all $P < 0.05$ for these colour pairs respectively. Participants performs not better but also not worth than average on green and orange backgrounds (with fewer errors). The performance on purple and red backgrounds are significantly the best. Participants' performance are all better than average, particularly the red, people make recognised fewer errors on red than yellow, blue, green and orange backgrounds with all $P < 0.05$. Participants make more errors in middle parts of spectrum as blue, green, yellow, and orange, whilst they make significantly fewer errors with two ends of spectrum as purple and red respectively.

4.4.2 Error Rate by Test Type

Hue influences on error rate with each psychometric test are also analysed and summarises in Figure 4.9. In the Logical Rule Test, yellow and blue owned the highest error rate than other colours, they are significantly differ with purple, red and green with all $P < 0.05$. The error rate for red and green are significantly smaller than other four colours as all $P < 0.05$. Yellow maintains the highest errors in the Mathematics Sequence Test, but it is not significantly differ with blue ($P = 0.28$). Participants made fewest mistakes on purple background in the Mathematics Sequence Test, however, this was not pointedly as $P = 0.60$. In the Rotation Test, the error rate of yellow, blue and green are similar. Orange has significantly lowest error rate among the six hues on the Rotation Test (all $P < 0.05$), and the error rate is far more lower than the highest (blue) with 3% and 34% respectively. Orange has the highest error rate on the Spatial Structure Test with a value of 39% which is significantly higher than other five colours with all $P < 0.05$. Yellow, blue, red and green maintained similar error rate on the Spatial Structure Test. Purple is the colour has significantly less errors than blue, red, green and orange with all $P < 0.05$. On the Odd One Out Test, yellow, purple and orange can be grouped in higher error rate group, blue, red and green can be grouped in lower error rate group. The difference between these two groups are significantly different with $P < 0.05$. The error rate for all colours in the Same Detail Test are small compare with other five tests. But the differences among the six colours are small as well. The lowest error rate is 4% and the highest error rate is 13%. The difference between the highest and lowest is significantly as $P < 0.05$. However the difference in between the highest and lowest are not significantly.

Apart from the Spatial Structure Test and the Same Detail Test, yellow is the colour participants make the most of errors on. The error rate for yellow on these four tests as the Logical Rule Test, the Mathematics Sequence Test, the Rotation Test and the Odd One Out Test are between 30% – 45%. Red and purple also not the colours participants make the fewest errors among the six test types. Participants made the fewest errors on red and green backgrounds with the Logical Rule Test; they performed the best (according to error rate) on purple and orange backgrounds with the Mathematics Sequence Test; orange and purple are the colours with lowest error rate for the Rotation Test and the Spatial Structure Test respectively; participants performed similarly on blue, red and green backgrounds with the lowest error rate for the Odd One Out Test; and hues may not have influences on error rate for the Same Detail Test. There is another trend of hue influence on error rate that the trend tends to be ladder-like for each psychometric test. Especially for the Mathematics Sequence Test and the Rotation Test. Yellow, blue and green are at the high error rate echelon; purple, red and orange are at the low error rate echelon.

From the discussion above, hue influence differently across six types of psychometric tests. The trend of hue influence on error rate for six psychometric test types are not entirely same as the colour general trend. Yellow is not the colour with highest error rate for the Spatial Structure Test and the Same Detail Test. Red is also not the colour with lowest error rate for all the psychometric tests. This shows that when discuss in detail with different psychometric test type, colour influence on error rate are more complicated.

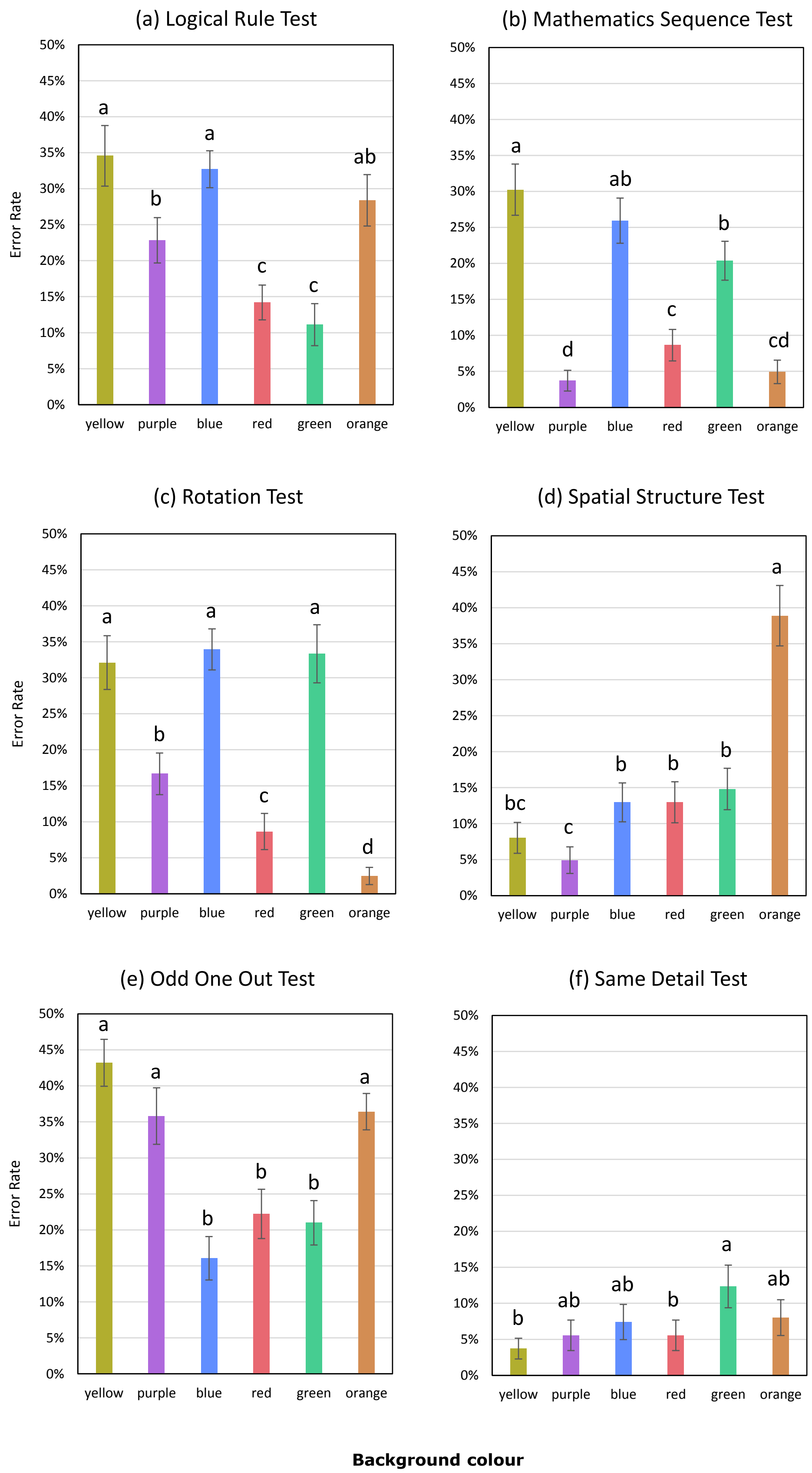


Figure 4.9 (a-f) Error rate by test. Letters a-d refer to data sets shown to be significantly different to each other (at the P=0.05 level).

4.4.3 Error Rate by Gender

Figure 4.10 summarises the hue influence on error rate between different genders. There is a potential that female participants make more errors than male participants, especially on purple and blue backgrounds. Female participants make more mistakes than male participants on green and orange backgrounds as well. While this trend is not significant as the error bars are overlapped for these two subjects on green and orange backgrounds. On yellow and red backgrounds, male and female participants make roughly similar errors at around 25% and 12% respectively.

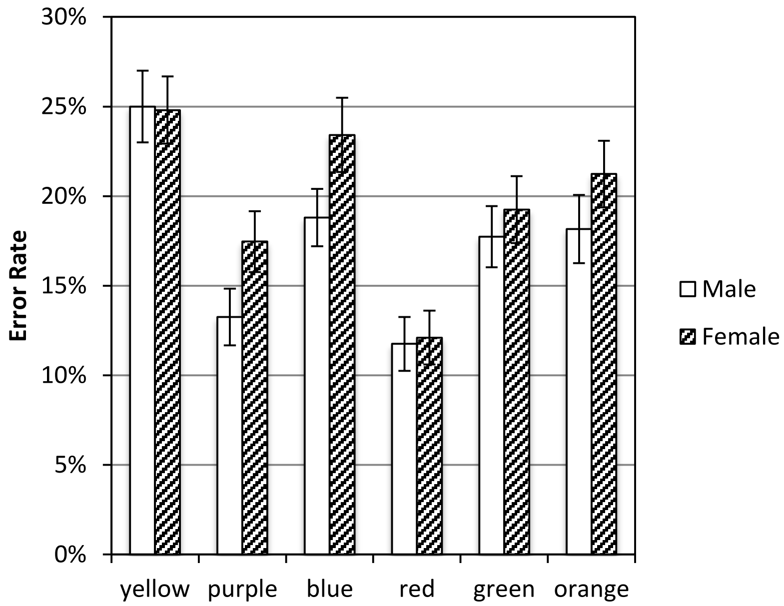


Figure 4.10 Error rate by gender.

4.4.4 Error Rate by Preference

Hue preferences influence on error rate are shown in Figure 4.11. From the figure, participants perform with lower error rate on colour they preferred than colour they do not preferred, such as yellow, purple and green. On the rest of colours as red, orange and blue, participants make more errors on colours they preferred than they do not. The difference of error rate for colour they preferred and not preferred is not big, the value of differences are between 5%. The influences of yellow and purple are similar. Participants who liked red and blue make significantly more errors than they do not like red and blue, as the error bars for three groups are very apart from each other. On the contrary, participants who like green make significantly fewer errors than they do not prefer green, as the error bars for green group are very apart from each other.

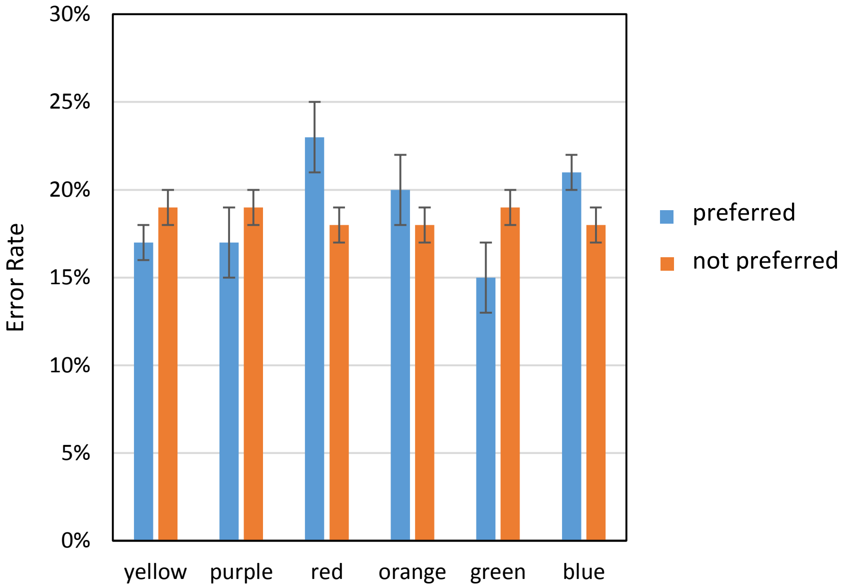


Figure 4.11 Response time by colour preference.

In conclusion, it is certainty that colour preference can influence on error rate distinctly. Colour preference can enhance the performance for yellow, purple, and green, and increase the error rate for red, orange and blue. however this trend cannot be drawn consistently.

4.5 The Influence on Impulsivity and Arousal

4.5.1 Colour General Trend

After discussed the hue influence on response time and error rate in detail, impulsivity and arousal are the next two terminologies been discussed in this chapter. Hue influences on impulsivity and arousal are judged by response time and error rate of participants performed according to different hue backgrounds. While looking at these two factors together (Figure 4.12), participants were slower to response but the error rate is fairly high with yellow and blue backgrounds. The influence of these two colours do not have a big difference. This indicates that participants are having a LA (low arousal) status when they performed on yellow and blue backgrounds. For purple, red and orange backgrounds, participants reacted significantly quicker than with yellow, blue and green backgrounds. In addition, they made fewer mistakes for purple, red and orange backgrounds. The difference is significant between yellow and blue with purple, red and orange. This suggests that participants found them highly aroused with HA (high arousal) status on purple and red backgrounds, and there is no significant difference between these two colours' influence on people's arousal. Orange is the only colour that touched the red line for both error rate and reaction time, which can be defined as a relatively impulsive colour that can influence participants to react moderately quickly but with fairly more mistakes. However, the difference of purple, red, green and orange influence on error rate is not significant. This shows that error rate do not differ significantly across the four hues. For a specific colour, the error bars of error rate are generally higher than that of the response time. This suggests that error rate is quite variable but is a greater reflection of impulsivity and response time is more reliable, on the other hand, it is a weaker reflection of impulsivity.

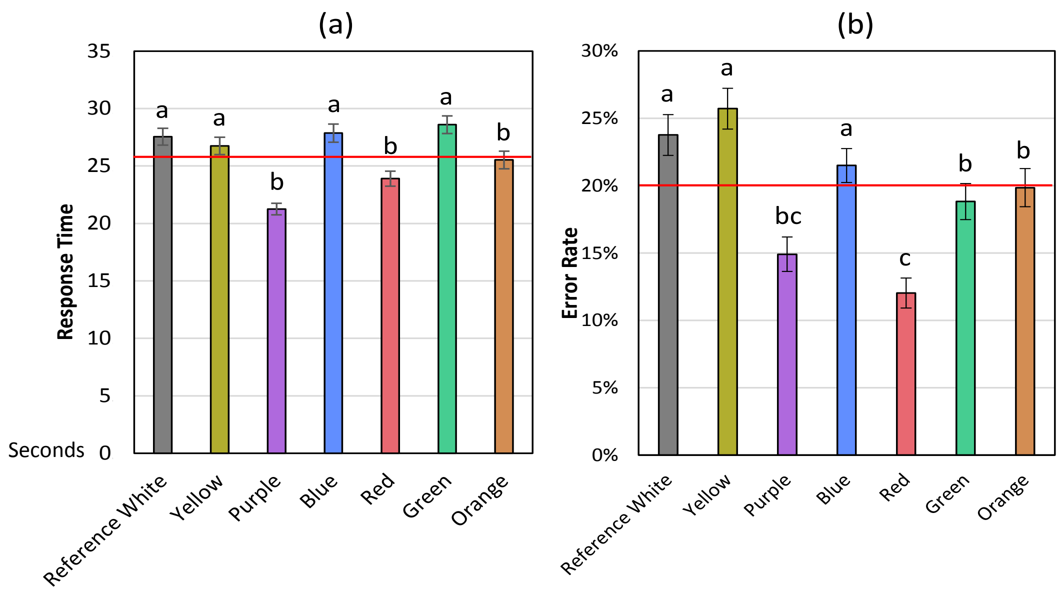


Figure 4.12 (a) Response time by background colour; (b) Error rate by background colour. The red lines in (a) and (b) represent the average line. The error bars are standard errors. Letters a-c refer to data sets shown to be significantly different to each other (at the P=0.05 level).

Meanwhile, it is worth putting the response time and error rate indicators in a single coordinate (Error/Speed space), in order to discuss the relationship between these two indicators in further. Therefore, statistical method of dimensionless has been involved in calculating the dimensionless quantities. The method used to dimensionless the data was extremum method:

$$x_i' = \frac{x_i}{\max x_i} \tag{4. 1}$$

where x_i' was the dimensionless data, $\max x_i$ was the maximum value of the whole data set of response time and error rate respectively.

The Error/Speed space of dimensionless values is shown in Figure 4.13.

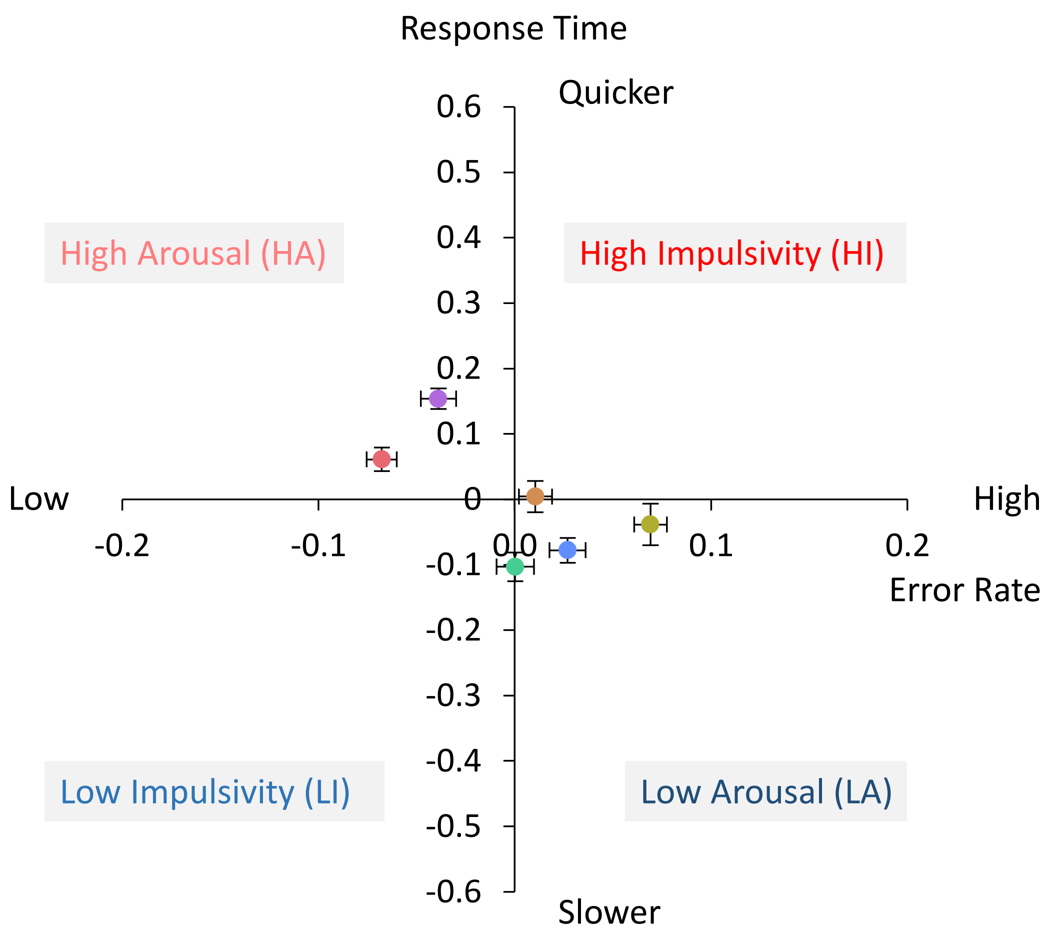


Figure 4.13 Six hues posited on the Error/Speed space.

Figure 4.13 summarises the six colour's position on Error/Speed space. The figure shows that impulsivity has an increase trend from left-bottom quadrant to top-right quadrant and arousal has an increase trend from right-bottom quadrant to top-left quadrant of the Error/Speed space. Most of the hues are located in HA and LA quadrants, which means hue influence more on arousal than impulsivity. Orange is the only colour that touched the boundary of HI quadrant, whilst it is not the colour with quickest response time nor have the highest error rate. Yellow is the colour has the variation touches the boundary of HI quadrant, meanwhile it is also the colour with the highest error rate. Therefore, orange and yellow can be considered as two relatively impulsive colours within the six hues show from the colour coordinate. Green is relatively the least impulsive colour as shows on the impulsivity coordinate; it touches the boundary of LI quadrant. Red and purple are two colours locate in HA quadrant that can arouse participants to perform with quicker response and fewer errors. Participants performed worse on blue and yellow backgrounds (they are locate in LA quadrant) as they required more time to think but made more mistakes on these two colours.

Nevertheless, from the impulsivity coordinate, it was still difficult to distinguish the order of these six colours according to their influence on people's impulsivity status. As error rate has a positive correlation with impulsivity, whilst response time has a negative correlation with impulsivity. The relationship between response time and error rate can be determined by the indicator: $\frac{E}{R}$ (where E was error rate and R was response time). The impulsivity status was increase with the value of this indicator increase. Error rate and response time all have negative correlations with arousal, therefore, the relationship between response time, error rate and arousal can be determined by the indicator: $1 - ER$. The arousal status was increase with the value of this indicator increase. The $\frac{E}{R}$ value and $1 - ER$ value of six colours are summarised in Table 4.3. Figure 4.15 shows the polar plots of colour influence on impulsivity and arousal in CIE L*a*b* diagram.

Table 4.3 The $\frac{E}{R}$ and $1 - ER$ value of six colours.

Indicators	red	purple	green	blue	orange	yellow
E/R	0.57	0.79	0.74	0.87	0.88	1.07
1-ER	0.60	0.56	0.26	0.17	0.30	0.06

Table shows the relative order of six colours' impulsivity and arousal status. From high impulsivity to low impulsivity, the six colours impulsivity and arousal order are summarised in Figure 4.14.

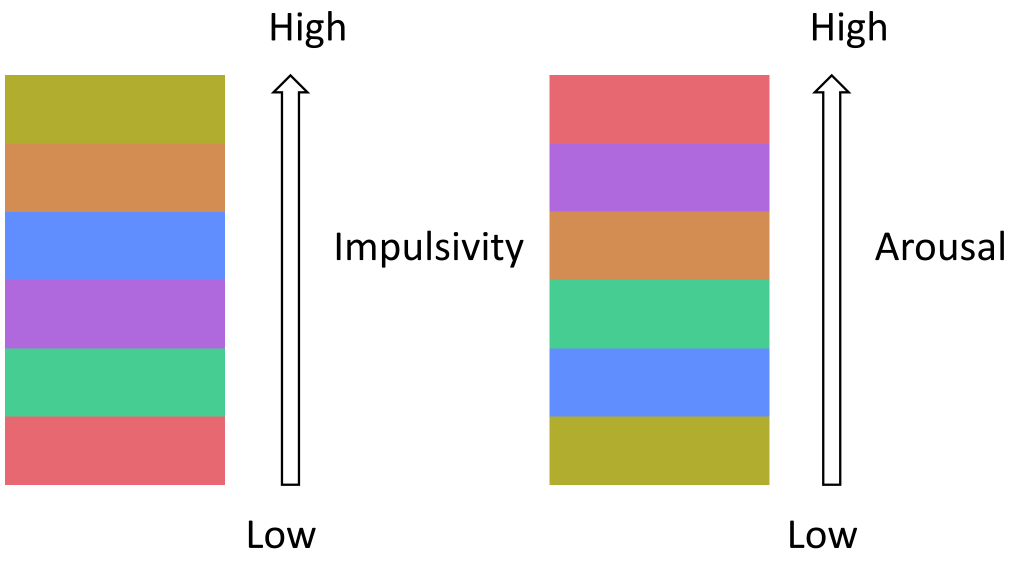


Figure 4.14 Colour influence on impulsivity and arousal in CIE L*a*b* diagram.

Figure 4.14 shows that yellow is the colour can influence people to be high impulsive. Red is the colour that influence people to be the least impulsive among the six. On the contrary, Red is the colour that highly arouse people's performance while yellow is the colour that influence people to be the least aroused. It is interesting to see that orange is the colour that can influence people in a both relatively impulsive and arousal status. Green is the colour that can influence people in a both relatively low impulsive and low arousal status among the six hues. To discuss the hue influence on impulsivity and arousal, six hues' impulsivity and arousal values are plotted on the hue diagram which shown in Figure 4.15. From Figure 4.15 it can be seen that colours with hue around 100 degree (yellowish colours) could influence people with the either highest impulsivity status or low arousal status, which means participants made quite a lot of errors with yellowish colours. The lowest impulsivity status posited at colours between 210° to 240° (greenish blue colours) and 0° to 30° (reddish colours). Moreover, the highest arousal status was pointed at around 300° to 330° (reddish and reddish purple colours). The reddish colour can influence people to be more arousal but less impulsive. Green colours at 180° have an equally influence on impulsivity and arousal. Greenish blue and bluish colours between 210° to 240° influence people to be both low in impulsive and arousal.

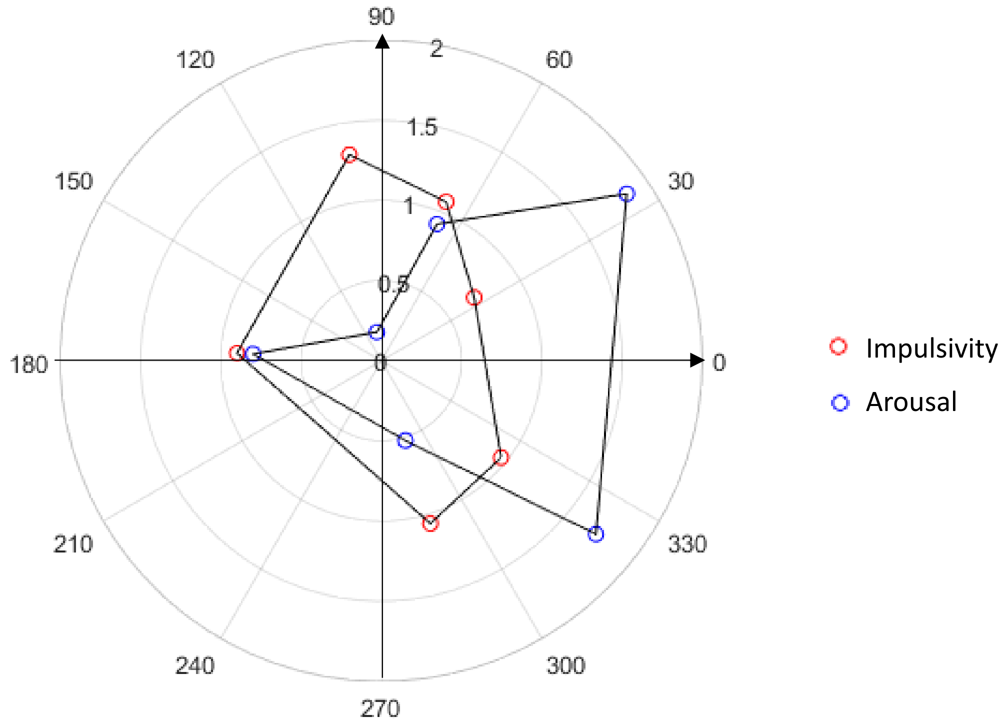


Figure 4.15 Colour influence on impulsivity and arousal in hue diagram.

4.5.2 Impulsivity and Arousal by Test Type

The six types of psychometric tests can be divided into three groups according to different test factors: (1) Logical ability (Logical Rule and Mathematics Sequence); (2) Spatial imagination ability (Spatial Structure and Rotation); (3) Detail ability (Odd One Out and Same Detail).

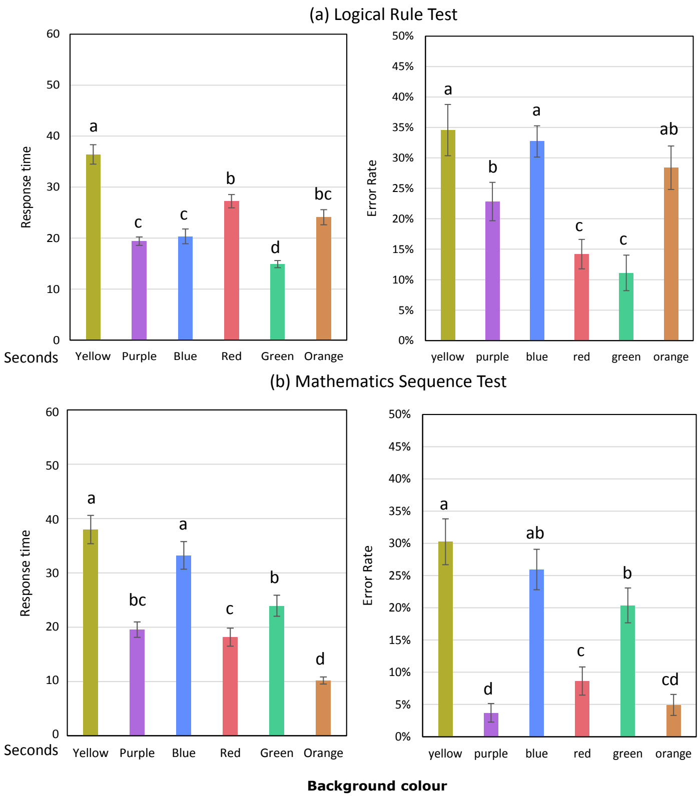


Figure 4.16 (a-b) Response time and error rate by test. Letters a-d refer to data sets shown to be significantly different to each other (at the P=0.05 level).

Figure 4.16 shows the response time and error rate of the Logical Rule Test and the Mathematics Sequence Test. From the figures showing the response time and error rate, generally, although participants found it less aroused to do the tests on yellow and blue backgrounds among the six, yellow and blue are not the worst colours for all types of psychometric tests. Yellow and blue backgrounds have big influences when participants solving the logical ability tests. The response time difference for yellow against the other five colours are significant in the Logical Rule Test; similarly, the response time difference for yellow against purple, red, green, orange; and blue against purple, red green, orange are all significant in the Mathematics Sequence Test respectively and there is no difference between yellow and blue influence on response time in the Mathematics Sequence Test. Yellow and blue influence on error rate in the Logical Rule Test are similarly, however these two colours against the rest of three colours as red, green, and purple are all have significant difference individually. The error rate is significant differ between blue against purple, red, green and orange in the Mathematics Sequence

Test. The difference between yellow and green on error rate in the Mathematics Sequence Test is not significant. However, yellow's influence is significantly differ from purple, red and orange. The difference of the influence of yellow and blue are non-significant.

The influence of purple and red backgrounds on the first group of tests are weak but can be seen. Participants performed relatively quicker with fewer errors when they solving the first group of tests. Although participants did not responded the quickest for red and purple in the Logical Rule Test (green was the significantly quickest) and the Mathematics Sequence Test (orange was the significantly quickest), they responded the second quickest on purple and red in both the Logical Rule Test and the Mathematics Sequence Test. Also for purple background, participants made the fewest mistakes in the Mathematics Sequence Test, which significantly differ from yellow, blue, red and green, but similarly with orange.

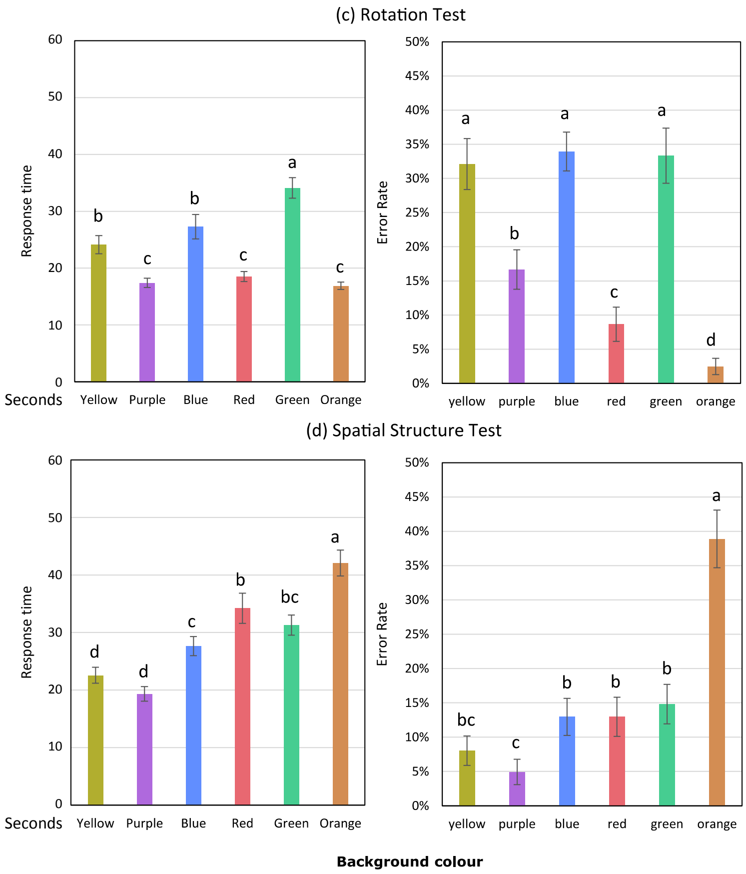


Figure 4.17 (c-d) Response time and error rate by test. Letters a-d refer to data sets shown to be significantly different to each other (at the P=0.05 level).

Figure 4.17 shows the response time and error rate of the Rotation Test and the Spatial Structure Test. Yellow and blue have some influence on the second group (spatial imagination ability tests) especially on the Spatial Structure Test. The influence of yellow and blue are significantly different from purple, red, green and orange on response time. The influence of these two colours are also significantly different from purple, red and orange on error rate, but yellow and blue have similar influence on error rate with green. The influence of red and purple on the second group of tests are much higher. Either on red or purple background, participants solved tests almost the quickest with a low error rate. Orange is the colour that participants responded quickest with the lowest error rate on the Rotation Test; while it is also the colour that participants responded the slowest with the highest error rate on the Spatial Structure Test.

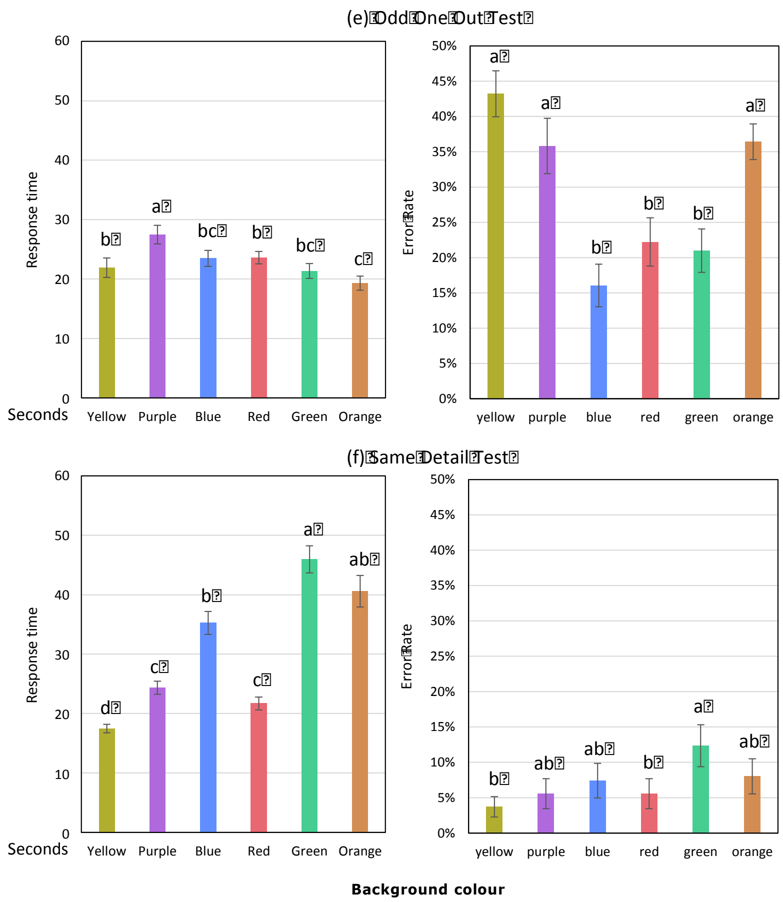


Figure 4.18 (e-f) Response time by test and error rate by test. Letters a-d refer to data sets shown to be significantly different to each other (at the P=0.05 level).

Figure 4.18 summarises the response time and error rate of the Odd One Out Test and the Same Detail Test. Yellow and blue backgrounds cannot influence on participants when they solving the third group of tests (detail ability tests), particularly less influence on the error rate. Participants performed even better on the yellow background, as the response time was quick and significantly differ with other colours while error rate was low towards the Same Detail Test. Again, there is no trend showing that red and purple can help participants to perform better on the third group of tests.

All the above discussions show that most of the findings agreed well with the general trend. However, colours may produce a much stronger influence when participants were solving logical ability tests and spatial imagination ability tests, but less influence on the detail ability tests. The variation of error rate is moderately higher among the tests. This suggests participants might made more guesses because of the specific time or the difficulty of the test. Thus the data for error rate is less reliable than response time.

Data of error rate and response time are dimensionless, the six hues plotted on the Error/Speed Space of each psychometric test are shown in Figure 4.19 – Figure 4.21. In the Logical Rule Test, green, purple are the colours plotted in the HA area, which can arouse people's emotion and enhance people's performance. Yellow and orange are located in the LA quadrant. Orange is the colour on the boundary of the HI and the LA area which supposed to be a colour with relatively higher impulsivity status than yellow. Participants performed worst (with long response time and high error rate) on orange and yellow backgrounds owing to the reason that participants were less aroused on these two colours than others. Blue is the colour influence participants to react in a high impulsive status, red is the colour influence participants to react in a low impulsive status.

In the Mathematics Sequence Test, none of the colours are highly influenced on impulsivity, while there is a very clear trend on hue influence on arousal. Orange, purple and red are colours highly arouse people to perform quick with fewer errors. Green, blue and yellow are influencing people to perform with less arousal status that they tend to react slow with more errors.

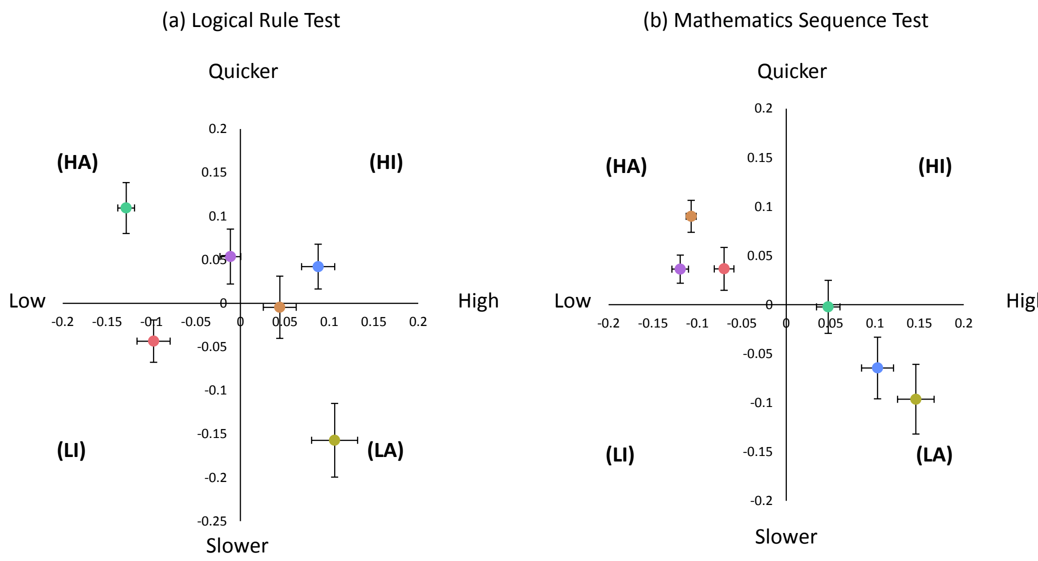


Figure 4.19 (a-b) Six hues posited on the Error/Speed space of the Logical Rule Test and the Mathematics Sequence Test.

The position of colours on Error/Speed space with the Rotation Test is similar as the Mathematics Sequence Test. Six hues are evenly plotted in the HA and the LA quadrants. Orange, red and purple can arouse people and help them to perform better in the Rotation Test, whilst yellow, blue and green influence participants to perform worse in the Rotation Test. Orange is the most arousal colour because with similar response time, participants made the fewest errors on orange. Green is the least arousal colour, because with the same error rate, participants responded slowest on green background.

In the Spatial Structure Test, all colours apart from orange have the error rate lower than the average, which means colours as purple, yellow, blue, green and red can impact participants to made fewer mistakes on the Spatial Structure Test. Purple and yellow can arouse participants more than blue, green and red. Red and green are plotted in the LI quadrant. Orange is plotted in the LA quadrant, that on orange background, participants responded slower with more errors.

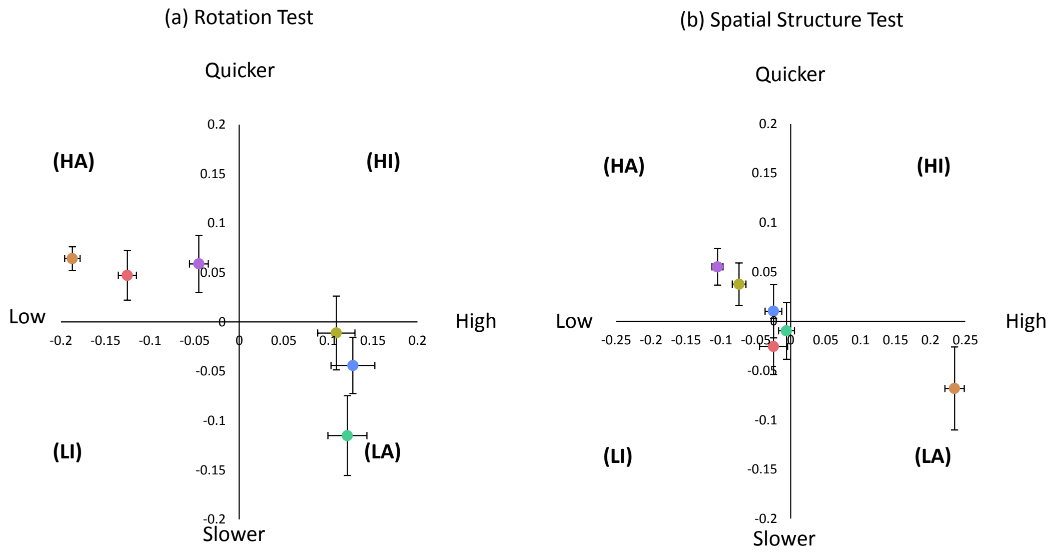
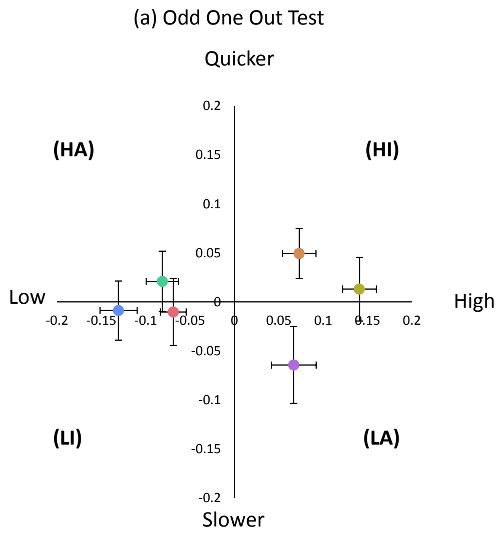


Figure 4.20 (a-b) Six hues position on the Error/Speed space of the Rotation Test and the Spatial Structure Test.

In the Odd One Out Test, orange and yellow are the colours with HI status. Purple is the colour located in the LA quadrant with higher error rate and slower response time. Green, blue and red are all hitting the boundary of the HA quadrant and the LI quadrant, while blue and red have the possible to be more in low impulsive status and green has the potential to arousing people more.

Hues do not influence much on impulsivity with the Same Detail Test. Yellow, red and purple are more arousing colours that influence people to perform better. Blue, orange and green are colours that less arousing and influence people to perform with long response time and high error rate. No colour has clear tendency to be high impulsive or low impulsive status.



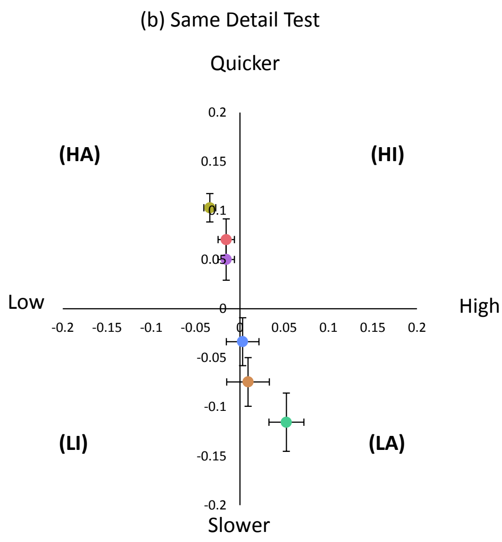


Figure 4.21 (a-b) Six hues posited on the Error/Speed space of the Odd One Out Test and the Same Detail Test.

From the above discussion of hue influence on impulsivity and arousal by psychometric tests. The influence of hue on impulsivity is very random and weak. Only in the Logical Rule Test and the Odd One Out Test, some hues can influence participants to be more impulsivity than others. The hues impact people to be more impulsive in the Logical Rule Test and the Odd One Out Test is blue for the Logical Rule Test, and yellow, orange for the Odd One Out Test. Purple is the colour almost in every type of psychometric test (apart from the Odd One Out Test) that arouse people to have a better performance. Hues can also influence people to be aroused are green, orange, red, yellow and blue, depend on different type of psychometric tests. Orange, yellow, green and blue are the hues influenced people to be less arousal and perform worse for half types of psychometric tests.

The hue influence on impulsivity order and on arousal order for each psychometric test types are analysed according to the two indicators as $\frac{E}{R}$.and $1-ER$. The $\frac{E}{R}$ and $1-ER$ values for six psychometric tests are summarised in Table 4.4 and shows in Figure 4.22 and Figure 4.23.

Table 4.4 The $\frac{E}{R}$ and $1 - ER$ value of six colours for six psychometric test types.

E/R	**Logical Rule**	Yellow	Purple	Blue	Red	Green	Orange
		0.91	1.12	1.54	0.50	0.71	1.12
	Mathematics Sequence	Yellow	Purple	Blue	Red	Green	Orange
		0.76	0.18	0.74	0.45	0.81	0.46
	Rotation	Yellow	Purple	Blue	Red	Green	Orange
		1.27	0.91	1.19	0.45	0.93	0.14
	Spatial Structure	Yellow	Purple	Blue	Red	Green	Orange
		0.34	0.24	0.45	0.36	0.45	0.88
	Odd One Out	Yellow	Purple	Blue	Red	Green	Orange
		1.88	1.24	0.65	0.90	0.94	1.80
	Same Detail	Yellow	Purple	Blue	Red	Green	Orange
		0.20	0.22	0.20	0.24	0.26	0.19
1-ER	**Logical Rule**	Yellow	Purple	Blue	Red	Green	Orange
		0.43	0.80	0.70	0.83	0.93	0.69
	Mathematics Sequence	Yellow	Purple	Blue	Red	Green	Orange
		0.48	0.97	0.59	0.93	0.78	0.98
	Rotation	Yellow	Purple	Blue	Red	Green	Orange
		0.65	0.87	0.58	0.93	0.49	0.98
	Spatial Structure	Yellow	Purple	Blue	Red	Green	Orange
		0.92	0.96	0.84	0.80	0.79	0.26
	Odd One Out	Yellow	Purple	Blue	Red	Green	Orange
		0.57	0.56	0.83	0.76	0.80	0.68
	Same Detail	Yellow	Purple	Blue	Red	Green	Orange
		0.97	0.94	0.88	0.95	0.74	0.85

Figure 4.22 summarised the order of colour influence on impulsivity for six types of psychometric tests. From the figure, it is difficult to point out which colour is the most and the least impulsive colour for all six types of psychometric tests. In general, green and yellow are two colours can influence people to be more impulsive for most of psychometric tests. Purple and Orange are two colours can influence people to be less impulsive for most of psychometric tests. The order of colour influence on impulsivity are not consistent among the six tests.

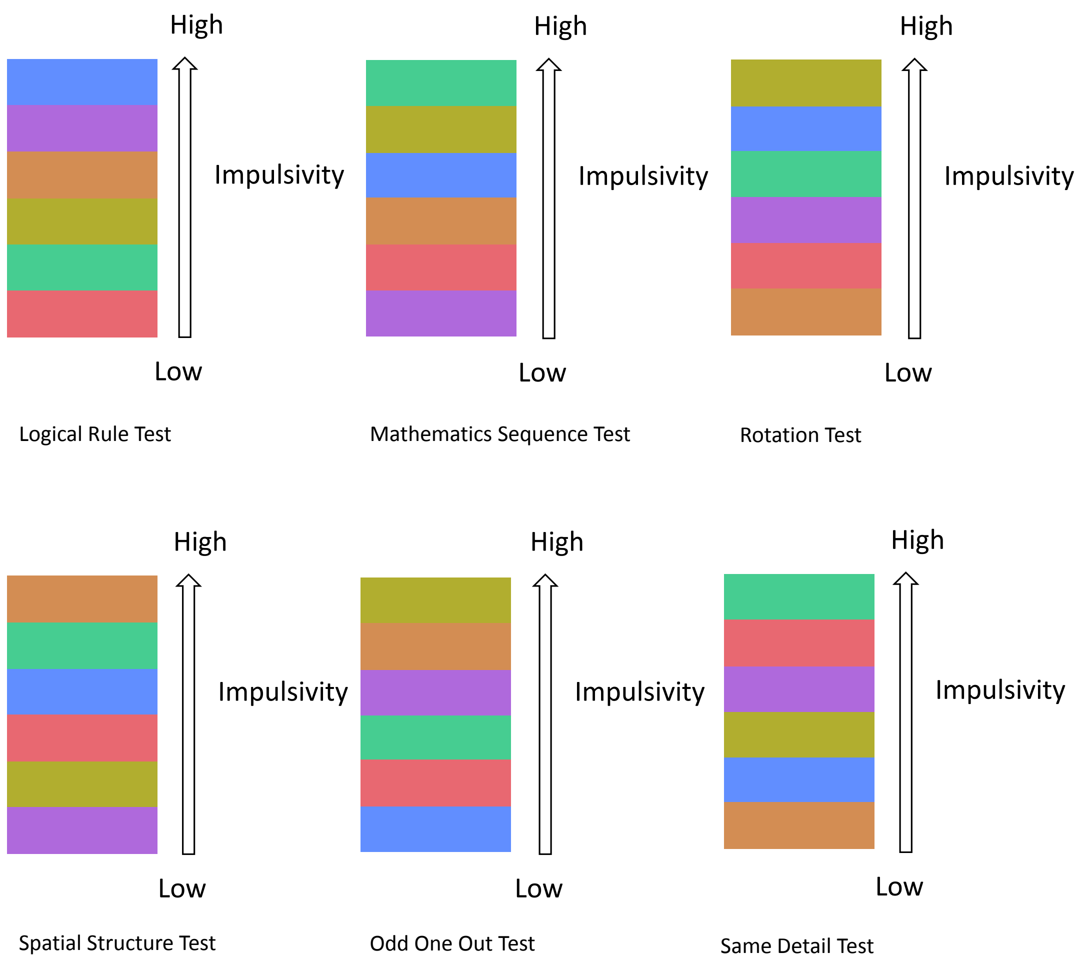


Figure 4.22 The order of colour influence on impulsivity for six types of psychometric tests.

Figure 4.23 summarised the order of hue impact on arousal for six types of psychometric test. From the figure it can be seen that the influence of hue on arousal are also not consistent for six types of psychometric tests. Although red and purple are not the colours influence people to be highly arousal for all types of test, they can generally influence people to be more arousal for most of tests. Orange is the colour influence people to be the most arousal for one third of tests. Consequently, it might can be concluded that reddish colours including yellowish red and bluish red can influence people to have a higher arousal status than other hues.

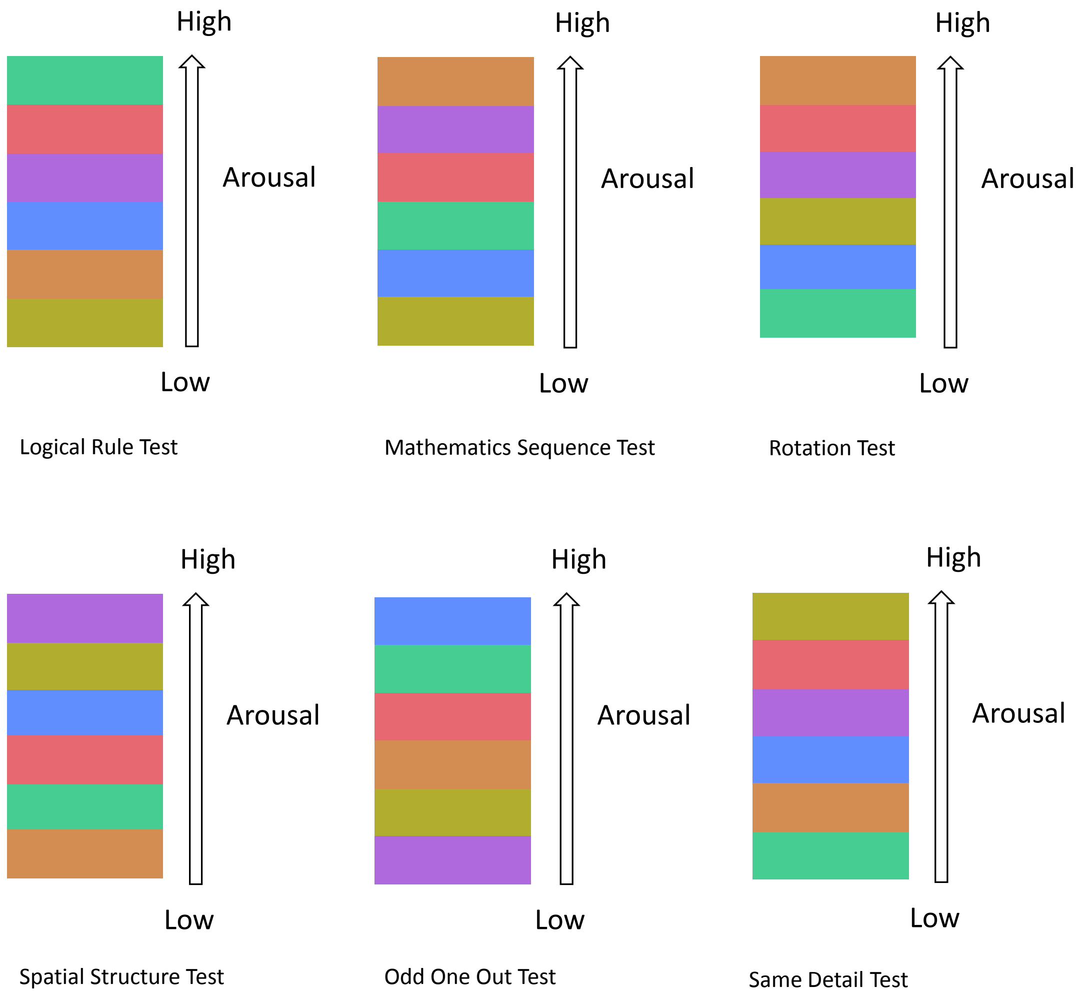


Figure 4.23 The order of colour influence on arousal for six types of psychometric tests.

The colour influence on impulsivity and arousal plotted in the hue diagram for six psychometric tests are shown in Figure 4.24.

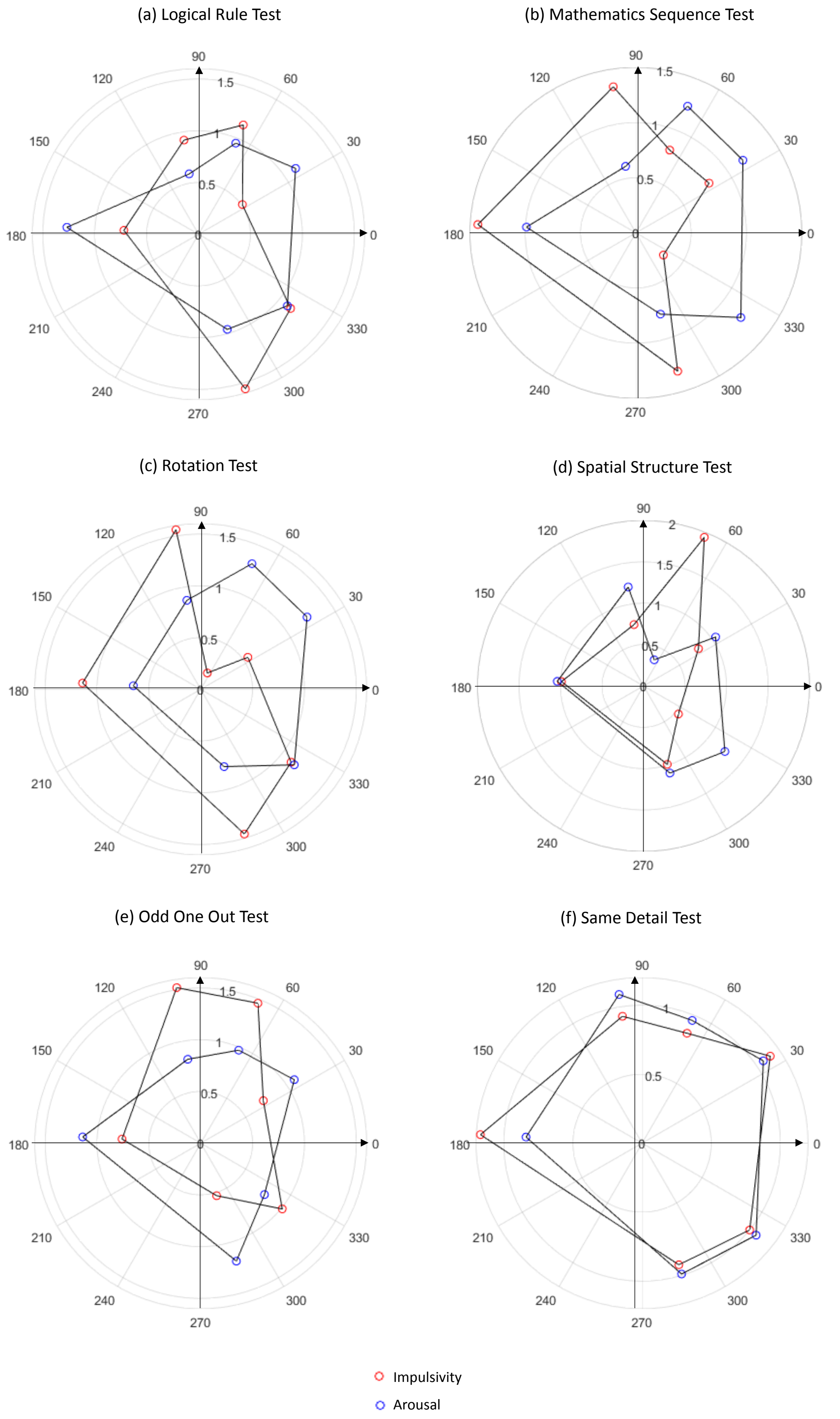


Figure 4.24 Colour influence on impulsivity and arousal in hue diagram for six psychometric test types.

Figure 4.24 summarises the hue influence on impulsivity and arousal in the hue diagram for six psychometric tests. Comparing the graph shows the general trend of colour influence on impulsivity (Figure 4.15) with Figure 4.24, the order was largely similar, however some differences can been seen as well. The similarities and differences can be summarised as follow.

A very different trend of hue influences on impulsivity and arousal for the Logical Rule Test can be found. The peak influence of colour on impulsivity is pointed at colours around 270º to 300º (bluish purple colours); colours around 210º to 240º (green to blue colours) influence people with low impulsivity status. The peak of arousal is located at 180º (greenish colours); while the lowest arousal located at 90º (yellowish colours).

The peak influence of hue on impulsivity for the Mathematics Sequence Test are pointed at nearly 180º (green colours), 100º (yellow colours) and 290º (bluish purple colours). Colours at 330º (reddish purple colours) and 65º (orange red colours) influence people to have a low impulsivity status. The highest arousal for the Mathematics Sequence Test are pointed at 0º to 50º, and 320º to 360º (orange red to purple red colours). The lowest arousal status also plots at around 90º (yellowish colours). Green colours influence people to be both very impulsive and aroused when doing the Mathematics Sequence Test, which means people responded very quick when solving the tests on green background.

The peak impulsivity status for the Rotation Test is plotted at 100º (yellow colours). The lowest impulsivity status for the Rotation Test is plotted at 60º (orange colours). The highest arousal for the Rotation Test is plotted at the orange red to purple red colours, and the lowest arousal status is yellowish colours. Yellow is the colour can both influence people to have a high impulsivity status and low arousal status.

For the Spatial Structure Test, the highest impulsive plotted at 70º (orange colours), and the lowest impulsive hue plotted at 330º to 360º (purplish red colours). The highest arousal for the Spatial Structure Test is located at 300 – 330º (purplish red colours) and the lowest arousal status for the Spatial Structure Test is at around 90º (yellowish colours). Orange is the colour that influence people to have a high impulsive status and low arousal status, which means people made more mistakes on the orange background. The colours at 180º (green colours) and 285º (blueish cholours) have similar influence on impulsivity and arousal.

For the Odd One Out Test, the high impulsivity pointed at 70º to 100º (orange to yellow colours); whereas the low impulsivity are posited at 290º (bluish purple colours) and 240º (greenish blue) individually. The highest arousal for the Odd One Out Test are pointed at 180º and 280º (green colours and bluish colours). The lowest arousal status is pointed at around 100º (yellowish colours). From the figure for the Odd One Out Test that, yellowish colours at around 100º influence people to have a high error rate, that lead to a high impulsive level and low arousal level.

The influence of hue on impulsivity and arousal are similar. The high impulsivity and arousal are all pointed at green colours at 180º.

Hue influence on impulsivity for the Logical Rule Test, the Rotation Test, and the Odd One Out Test are relatively strong, as the six colours' impulsivity status are very apart from each other in the hue diagram. Hue influence on the Mathematics Sequence Test and the Spatial Structure Test are relatively gradually as the impulsivity values for six colours are smaller than 1. There are little influence of colour on the Same Detail Test, as it can be seen from the figure, the impulsivity values are really small (no bigger than 0.3) for all six colours, which means colour influence on impulsivity for the Same Detail Test are similar. Apart from the Same Detail Test, which colour influence on arousal is unobvious, for the rest five types of psychometric tests, the low arousal status are normally plotted at 90º (yellowish colours) and the highest arousal is pointed from orange red to purple red in the first and fourth quadrants.

4.5.3 Impulsivity and Arousal by Gender

There is a tendency that female respond quicker yet made more mistakes through all colour backgrounds, which means female participants performed more impulsive than male participants in the experiment (shows in Figure 4.25). As most of the error bars are overlapped, shows that this trend is not significant for all colour backgrounds. Except blue may marginally increase the response time for male (30 seconds for male, 27 seconds for female) while decrease the error rate for male (19% for male, 24% for female) and the error bars for response time and error rate are not overlapped. This shows there is a gender specific influence over blue, which other colours do not seen. Arousal difference influenced by colour cannot be seen for different genders.

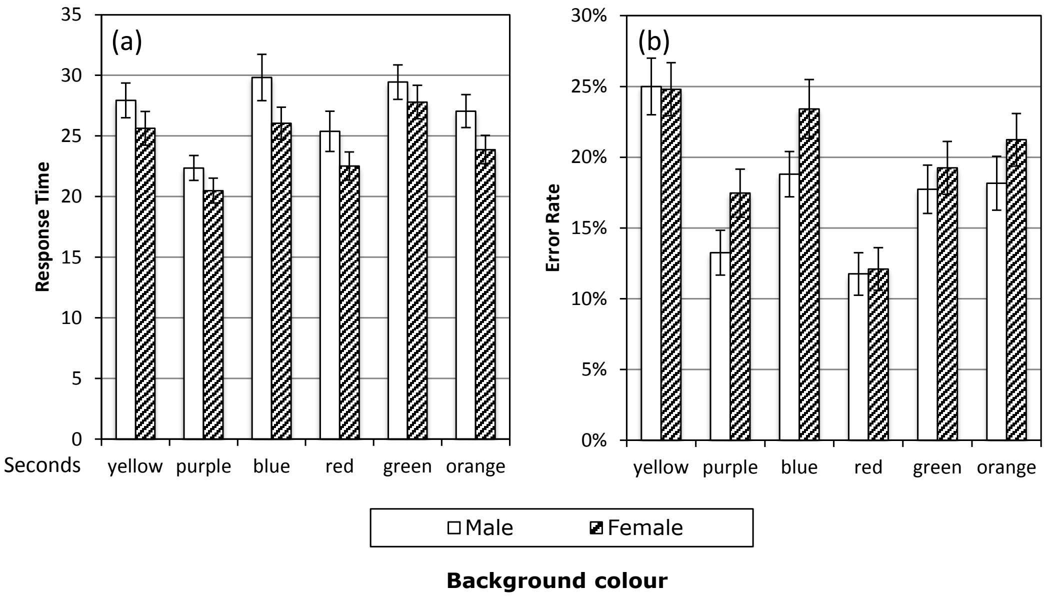


Figure 4.25 (a) Response time by gender; (b) Error rate by gender.

Table 4.5 and Figure 4.26 summarise the impulsivity and arousal values for male and female respectively. Figure shows that gender difference has little influence on the order of impulsivity and arousal. For impulsivity, the only difference between male and female are the sequence of orange/blue and purple/green. The highest impulsive colour for both genders is yellow, the least impulsive colour for both genders is red. The only difference for male and female on arousal order is that the highest arousal colour for male is purple, the second is red; and the highest arousal colour for female is red and the second is purple.

Table 4.5 The $\frac{E}{R}$ and $1 - ER$ value of six colours over genders.

Indicators	Gender	Yellow	Purple	Blue	Red	Green	Orange
E/R	Male	1.07	0.71	0.75	0.55	0.72	0.80
	Female	1.08	0.95	1.01	0.60	0.78	1.00
1-ER	Male	0.06	0.60	0.25	0.60	0.30	0.34
	Female	0.08	0.48	0.12	0.60	0.22	0.26

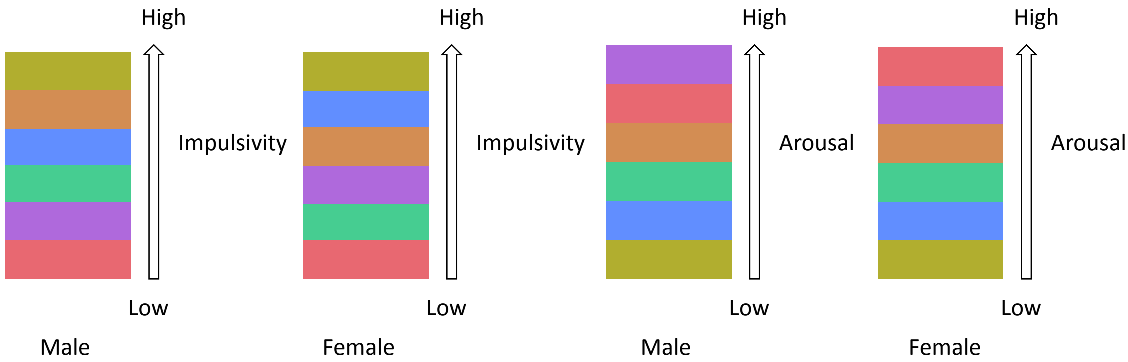


Figure 4.26 The order of hue impact on impulsivity and arousal by gender.

4.5.4 Impulsivity and Arousal by Preference

Figure 4.27 summarises the response time and error rate by colour preference. It was interesting to see that participants reacted less impulsively on the yellow background when they preferred yellow. They performed more impulsive on red and orange backgrounds when they preferred the red and orange. As yellow is the colour with medium impulsive status, participants performed better (less impulsive) when they like yellow. Red is the colour with high impulsivity status, however participants performed even worse (as more impulsive) when they like red. No one colour preference can make people more arousal than the other. However, blue can make people less aroused if they preferred blue.

It is still unavailable to draw a conclusion over the trend of hue preference influence. Nevertheless, it is clear to see that hue preference influence on impulsivity is more depended on hues.

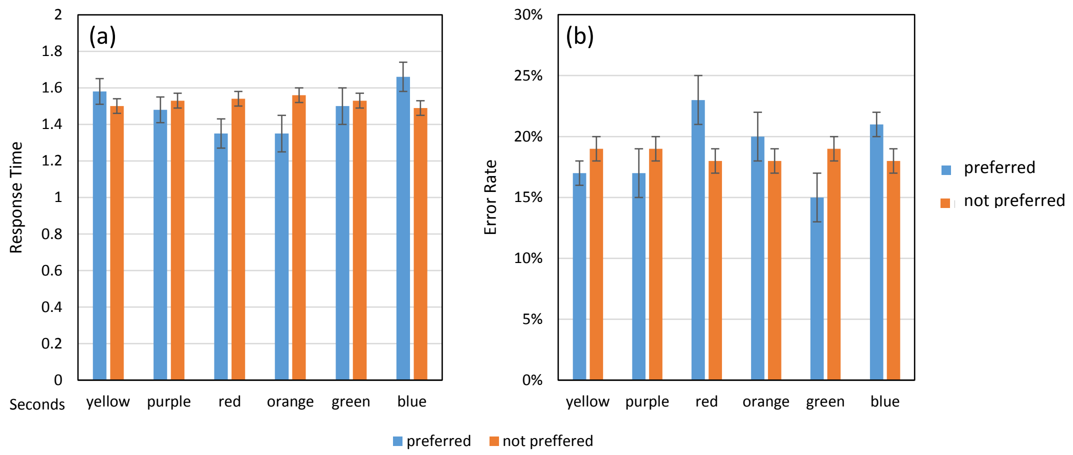


Figure 4.27 (a) Response time by colour preference; (b) Error rate by colour preference.

4.6 Discussion

In this chapter, hue influence on response time, error rate have been analysed individually, the influence of hue on impulsivity and arousal has been discussed. Discussion related to these three parts are summarised below.

4.6.1 The Influence on Response Time

Data collected from the hue experiment shows that:

- Yellow, blue and green are grouped into long response time group; while purple, red and orange can be grouped into short response time group. The differences between these two groups are significant.
- The response time trend for the Mathematics Sequence Test and the Rotation Test are following the general trend.
- Yellow and blue are the colours participants use the longest time to

solve the Logical Ability Tests (the Logical Rule Test and the Mathematics Sequence Test). Green and orange are the colours participants responded quickest when solving the Logical Ability Tests.

- The trend of hue influence on the Spatial Imagination Test are not consistent. Green is the colour with the longest response time; purple, red and orange are colours with the shortest response time for the Rotation Test. Orange is the colour with the longest response time; yellow and purple are the colours with shortest response time for the Spatial Structure Test.
- No large difference of hue influence can be seen for the Odd One Out Test. Green and orange are the colours participants responded the slowest on the Same Detail Test, while yellow is the colour participants responded quickest on the Same Detail Test.
- There is a tendency that female responded quicker than male participants did across all six colours.
- On most of hues (such as purple, red, orange and green), participants performed better when they like these colours.

AL-Ayash *et al.* (2015) found that long-wavelength colours are more arousing than short-wavelength colours. This finding also partly indicated in this experiment. For example, colours as red and orange influence participants to be more aroused and responded quicker in the experiment than yellow, blue and green. The finding in this experiment shows that reddish colours as purple (bluish red), orange (yellowish red) and red all have the function to arousing people and make them feel more active. This can be reflected from their low response time and low error rate. This finding also agreed well with Kwallek and Lewis (1990), and Blijlevens *et al.* (2012).

There are limited literature so far can be found related to this research area. Hue influence on response time is diverse across different psychometric tests. Some types of tests follow the similar trend as general trend such as the Mathematics Sequence Test and the Rotation Test. Some types as the Logical Rule Test, the Spatial Structure Test, and the Same Detail Test have different trends compare with the general trend. The influence of hue on the

Odd One Out Test is not significant. According to the discussion above, the pattern of hue influence on response time is not clear. However, a significant influence of hue on different psychometric test can be seen from the result. Colour influence on impulsivity by different psychometric test is an exciting area that has a huge potential to be explored in further.

Gender difference can be seen from the experiment data. Female solved tests quicker than male in all colours. Venkatesh *et al.* (2002) stated that females have longer reaction time than male either during stress-free condition and during the period of stress. The experiment result disagree with this finding. When solving the psychometric tests, female seems to be more arouse than male. This finding agree with the finding of Mekarski *et al.* (1996). They found from the Stroop task that women were consistently faster than the men on all tests. So far, the gender difference in reaction time are not consist in previous research, this experiment support that female solved tests quicker in all colour environment. From the data collected in hue experiment, the difference is not significant as error bars for most of the colours are over lapped.

4.6.2 The Influence on Error rate

From the results in section 4.3, major finding of hue influence on error rate can be summarises as:

- Yellow and blue are the colours participants made the most of errors on. Follow with orange and green, then purple and red with a decrease trend.
- Yellow and blue are the colours with the highest error rate for the Logical Rule Test, Mathematics Sequence Test, and Rotation Test. Yellow is the colour participants made the most of errors for the Odd One Out Test. Orange has a strong influence on the Spatial Structure Test that the errors they made on orange are significantly higher than other colours. Hue influence on error rate in the Same Detail Test is not significant.
- There is a trend that females made more errors than males on colour

backgrounds as purple, blue, green and orange.

- Participants made fewer errors on yellow, purple and green backgrounds when they liked these colours, whilst they made more errors on red, blue and orange backgrounds when they preferred these colours.

Hill *et al.* (2005) found that when athletes wearing red and blue football sportswear, it was consist and statistic significant that wearing red win more fights and made fewer mistakes than blue. The results in this experiment agreed well with their finding. It may be because colours as red, purple (bluish red) and orange (yellowish red) can arouse people’s attention. Help them to make quick decision and also be more concentrate. Therefore, participants can be more focused on the test and ignore the distraction items.

On 2/3 types of psychometric tests, yellow is always the colour that participants made the most of errors on. It may because people cannot very concentrate on solving tasks based on the hues in the middle part of the spetrum. Interestingly, orange have different influence on different types of psychometric tests. For example, participants performed worse on orange background when solving the Spatial Structure Test. They performed well on orange background when solving the Mathematics Sequence Test and the Rotation Test. A pattern may can be seen from the hue experiment result that yellow is the colour can reced people’s performance on logical thinking, spatial imagination and detail checking. Blue is not the preferable colour for people solving logical thinking test. Orange is the colour influence on people’s spatial imagination ability.

Feltman *et al*. (2011) suggested that chromatic colours as red and blue can influence on people viewing them. This influence was both on females and males. In this experiment, data pointed that colours as blue, purple, green and orange have influence differently across gender on making errors. However, gender difference were small on all colours, which proved the founding by Maccoby *et al*. in 1981.

4.6.3 The Influence on Impulsivity and Arousal

As error rate and response time are two indicators that can represent impulsivity and arousal at the same time. Hue influence on impulsivity and arousal will be discussed based on different combination of these two indicators. Based on hue experiment, some major findings are summarised as follow:

- According to the experiment result, hue influence significantly on arousal. Hue influence on impulsivity is not significant.
- Purple and Red are the colours that participants performed with the highest arousal status. Blue, yellow and green are the colours participants performed with the lowest arousal status among the six colours. Orange is the colour hit the boundary of high impulsivity quadrant, which is a relatively impulsive colour among the six hues.
- Purple and red are the colours that made people to be more aroused in most of the psychometric tests. Generally, orange, yellow, green, and blue are the colours influence people to be less aroused. Some hues can also influence people to be more impulsive and less impulsive in different tests. However, hue influence on impulsivity and arousal over different psychometric tests are complicated.
- There is a tendency that females are more impulsive than males across all six colours. However, as the error bars are mostly overlapped, this trend is not significant. No gender difference can be found to influence on arousal.
- Red is the colour with high impulsivity status, participants performed even more impulsive when they like red. People would be less aroused when they preferred blue.

Hill and Barton (2005) reported that wearing red sports attire has a positive impact on athlete’s scores in combat sports as tae kwon do and wrestling. Jacobs and Hustmyer (1974) also stated that red is the most arousing colour follow up with green, yellow and blue. Physical strength can be increased in a red office compare with a blue office because strong colours as red can put the brain into a more excited state (Küller, 2008). From the experimental data collected in hue experiment, it can be pointed out that red is the colour background that can influence people to be relatively more aroused in solving psychometric tests than most of other colours. From the Error/Speed space shown in 4.4.1, red is the colour participants performed with the lowest error rate and the second shortest response time. This can in some point prove the finding listed above and explain that red can influence people to be more aroused and performed well (with low error rate and short response time). This phenomenon was explained by Berlyne (1924) that colours as red and purple having the emotional meaning of danger, speed, blood, fire, and so forth. They can improve people’s blood pressure and heart rate, which also have the function of arousal. Colours as blue and green are the colours from nature, they also have the emotion of calm, peace and so on, which can influence people to be less aroused.

In some research such as Küller *et al.* (2008), Wang *et al.* (2008), AL-Ayash *et al.* (2015), colour influence on people's performance can be discussed with warm and cool colours. The general finding from these studies were warm colours can apply some extra arouse to people. Cool colours were calming while warm colours were more stimulating. Students more preferred a cool is also a cool colour but is one of the colour made people to be more aroused. This might can conclude that reddish colour (purple: bluish red) is an particular example which has significant influence on arousal.

When looking at results subdivided in different psychometric test, purple, blue and orange are three colours with representative influences. Participants were consisted on purple background with relatively high arousal status apart from the Odd One Out Test. This may can draft an conclusion that there is little different of purple influence on different types of psychometric tests, the difference only recognised on the Odd One Out Test. Although on blue background, participants were performed with high impulsive status with the Logical Ability Test and the Spatial Imagination Test, it has an inverse influence on the Detail Ability Test that the impulsivity of participants on blue background were low. Thus, blue background's influence on impulsivity is depend on test type. Orange can significantly influence participant to performed impulsively on the Detail Ability Test.

4.7 Summary

The present study investigated the influence of hues on response time, error rate, impulsivity and arousal. Effects of hue, psychophysics test type, gender and colour preference were discussed. **Some *novel findings* from this experiment are summarised as follows:**

1) Hue seems to influence on arousal more than impulsivity.
2) Reddish colours including yellowish red (orange) and blueish red (purple) can all influence people to a highly aroused status.
3) Yellow is the hue that produce the least arousal status. While it is also the colour that the most increase impulsivity.
4) Yellow, blue and green result in significant slower response time compare with purple, red and orange.
5) Yellow and blue are two colours under which participants made the most errors. Red and purple backgrounds resulted in participants making the fewest errors.
6) Differential hue influences on gender was not significant, but females tended to respond more quick with more mistakes (more impulsive) than males on all colour backgrounds.

This experiment has some limitations. Firstly, it is possible that participants may tire during the experimental period or even that their performance may improve as the task continued. For this reason, the order of the six coloured backgrounds was varied randomly for each participant. This was to avoid any bias. However, the reference white was always the first condition that participants encountered. It is therefore difficult to compare performance on a coloured background with performance on a white background because there could have been some temporal bias. The white background was, however, used first so that it acted as a training process. The nationality of participants in this study were all Chinese, and yellow was their most preferred hue background when they did the psychometric tests. Eysenck (1941), Hogg (1969) found that blue, purple are the colours people mostly preferred, while yellow are green are the least. Saito (1996) suggested the cultural difference has little effect on colour preference. However, in this study, the experimental result shows that colour preference may impact by culture difference. Meanwhile, the states of the person may influence on their preferred colour. Also, the age of participants were between 20 – 38, therefore, the finding might not be applicable for children and elderly. Additionally, only six hues were used in this experiment. It is difficult to use these six colours to predict the whole trend of hue influence on impulsivity, which could be further studied in the future.

Findings from this study could be used in various design areas, such as design marketing, information design and functional design. The next stage of this study will move to the influence of chroma on impulsivity. For instance, research showed that such as pink – a red colour with lower chroma – has a moderating effect on calming people (Schauss, 1979). In Schauss's "pink prison study", pink can physically relax people's muscles and reduce potential or actual aggression. This finding was examined in a prison in the US and received positive impact. Typical hues with different levels of chroma will be studied and the impact of chroma difference on impulsivity and arousal will then explored in the next experiment.

Chapter 5 The Influence of Chroma Levels

5.1 Introduction

In Chapter 4, experimental results of the effect of hue on impulsivity and arousal were analysed and discussed. From the result, yellow, red and orange are three typical colours been selected to further explore in this chapter, as participants performed with low arousal status (with high error rate and long response time) on the yellow background, high arousal status (low error rate and short response time) on the red background and orange was the colour that tended to result in high impulsivity.

As before, the two main factors used to measure impulsivity and arousal in this experiment are participants' response time and error rate for each colour background. The psychophysical experiment is designed to examine whether, in a particular colour environment, the response time and error rate are different. Participants are looking at backgrounds in three hues (red, yellow and orange) with different chroma levels on screen to complete a range of psychometric tests. During the experiment, participants were required to give their response to the psychometric test as quickly and accurately as possible. Figure 5.1 summarises the experimental method of the chroma experiment.

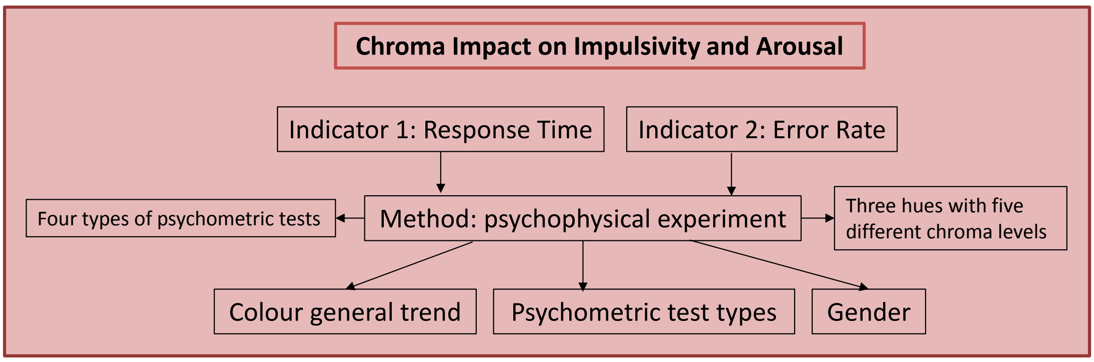


Figure 5.1 The flowchart of the experimental method of chroma experiment.

5.2 Observer Repeatability and Impulsivity Status

In the chroma experiment, 28 participants were took part in. In this section, participant's repeatability will be discussed according to their two times performance. Meanwhile how well individual performance agrees with majority decisions of the group will be also discussed. Similarly as in hue experiment, participant's performance are divided into four groups as LI (low impulsivity), HA (high arousal), LA (low arousal) and HI (high impulsivity). In Figure 5.2 the Error/Speed space shows that for both first time and repeat experiment, participants' performances are filled into four groups, more participants are plotted in the HI quadrant and the LI quadrant than the HA quadrant and the LA quadrant.

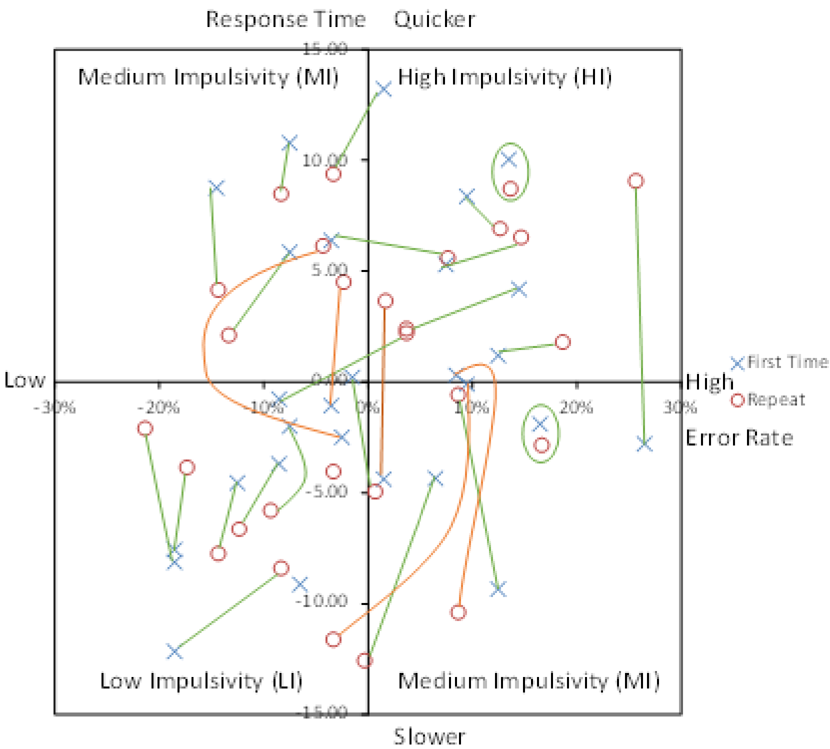


Figure 5.2 The Error/Speed space and participant's performance in chroma experiment.

Table 5.1 The repeatability of participants and their performance.

	Original			Repeat		
	Response time	**Error rate**		**Response time (R)**	**Error rate (R)**	
M1	41.27	13%	LI	31.7	10%	LI
M2	41.83	13%	LI	29.95	6%	LI
M3	34.48	23%	LI	24.19	29%	HI
M4	33.48	30%	HA	32.79	28%	LA
M5	28.42	39%	HI	20.94	40%	HI
M6	42.83	25%	LI	31.88	24%	LI
M7	33.81	41%	LA	39.45	24%	LI
M8	23.67	45%	HI	19.14	41%	HI
M9	25.33	41%	HI	21.33	42%	HI
M10	27.86	24%	HA	25.73	14%	HA
M11	34.78	28%	LI	23.35	25%	HA
M12	29.52	46%	HI	25.64	31%	HI
M13	36.2	29%	LI	21.72	23%	HA
M14	38.08	33%	LA	25.45	31%	HI
F1	22.94	24%	HA	19.37	19%	HA
F2	24.95	17%	HA	23.7	13%	HA
F3	20.52	33%	HI	18.48	24%	HA
F4	35.71	24%	LI	33.63	18%	LI
F5	33.4	40%	HI	38.23	36%	LA
F6	37.4	23%	LI	34.48	15%	LI
F7	38.25	19%	LI	35.59	13%	LI
F8	45.85	13%	LI	36.25	19%	LI
F9	36.5	58%	LA	18.78	53%	HI
F10	35.61	48%	LA	30.7	44%	LA
F11	32.5	44%	HI	26.04	46%	HI
F12	27.33	28%	HI	22.27	35%	HI
F13	43.04	44%	LA	28.43	36%	LA
F14	38.05	38%	LA	40.4	27%	LA

LI=low impulsivity, HI=high impulsivity, LA=low arousal, HA=high arousal.

Table 5.1 summarised the 28 observers' performances. From the table, there is no big jump in impulsivity status between the first time experiment and the repeat. A big jump means participant's impulsivity status changed from HI to LI, which means he or she performed worse with more guessing in the first time while he or she learned the method to solve the question and began to consider more in the repeat experiment. This means these observers do not need a long term training to complete the psychometric tests in this experiment. Only M3 was LI in the first experiment and HI in the repeat experiment, which means he was in a better condition in the first experiment than the repeat, that he thought longer and made fewer mistakes. Nevertheless, this did not meant M3 need a long-term training than other participants.

Participant’s repeatability has also been analysed by four impulsivity/arousal status categories, which summarises in Table 5.2. LI and HI are the biggest groups among the four groups, following with LA and HA. The response time for LI, LA, HI and HA are 37 ±1 seconds, 36 ±1 seconds, 25 ±1 seconds and 24 ±1 seconds individually. From the data it can be seen that the response time for LI group and LA group are similar, the response time for HI group and HA group are similar. The error rate for LI, LA, HI, and HA groups are 19% ±2, 39% ±3, 39% ±2 and 21% ±2 respectively. The error rate for LI and HA are similar, the error rate for LA and HI are similar.

Table 5.2 The mean response time and error rate for four impulsivity/arousal status.

Variables	Impulsivity Status	N	Mean± STD error
Response time (sec)	LI	18	37±1
	LA	11	36±1
	HI	17	25±1
	HA	10	24±1
Error rate (%)	LI	18	19±2
	LA	11	39±3
	HI	17	39±2
	HA	10	21±2

LI, Low Impulsivity; HI, High Impulsivity; LA, low arousal; HA, high arousal.

From the discussion above, data collected from the chroma experiment was repeatable and reliable. The four groups as LI, HI, LA and HA are distinguishable. Data collected can be used in the next stage of analysis.

5.3 The Influence on Response Time

5.3.1 Colour General Trend

The general trend of chroma influence on response time are summarised in Figure 5.3. From the figure it can be seen that participants performed significantly quicker for 0% and 25% chroma levels with response time of around 29 seconds, and slower for 50%, 75%, and 100% chroma levels with response time of around 32 seconds. Response time at 0% and 25% chroma levels are quicker than average, whilst at 50% – 100% chroma levels the response time are slower than average. Error bars are standard errors through the figures in the whole chapter.

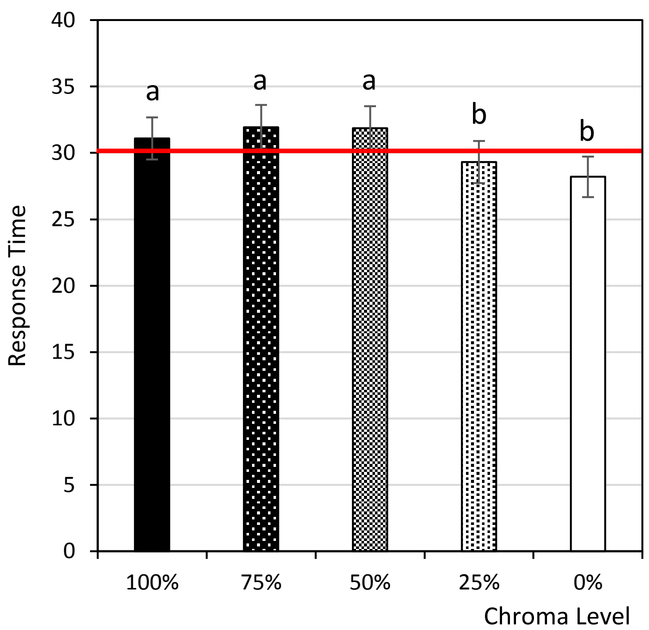


Figure 5.3 Response time by chroma levels. The red line in figure represents the average line. Letters a and b refer to data sets shown to be significantly different to each other (at the P=0.05 level).

Figure 5.4 represents the response time of red, orange and yellow at different chroma levels respectively. On different chroma levels of red backgrounds, participants performed significant slower at 50% than other four chroma levels, with the response time of 35 seconds. Although there are slightly differences among the response time at 0%, 25%, 75% and 100% chroma levels, the differences are not statistic significant. Compare with Figure 5.3 and Figure 5.4, the trend of chroma influence on red is similar with the general trend. The only difference is at 75% chroma level, the response time for 75% red is quicker than the total 75% chroma level of the three hues. The trend of orange influence on response time is similar as general trend as well, the difference between orange and total trend of the three colours is the gradation is enlarger on orange backgrounds than the total trend. Participants respond the slowest on 100%, 75% and 50% chroma levels, with response time of 33 seconds, 36 seconds and 35 seconds individually. The differences of 100%, 75% and 50% with other two chroma levels are statistic significant. Participants responded the slowest for 0% chroma level, with the response time of 28 seconds. The difference between the quickest (0% chroma level) and the slowest (75% chroma level) is 8 seconds. The trend of yellow backgrounds influence on response time is totally difference with the general trend. The response time for the general trend, the trend for red and orange are all the peak shape, while the response time trend for yellow chroma changes from 0% chroma level to 100% chroma level is the valley shape. Participants respond the quickest at 50% chroma levels with the response time of 25 seconds. The response time on other four chroma levels of yellow apart from 50% are similar, and there is no difference on response time for other four chroma levels.

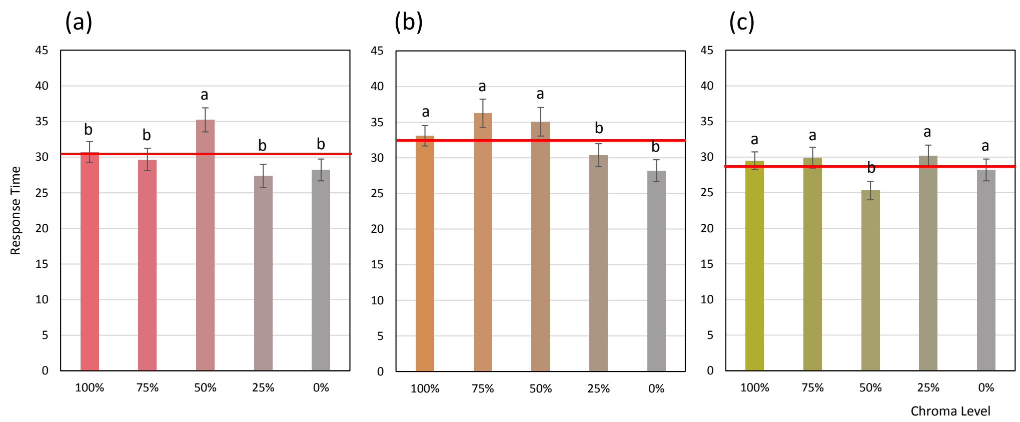


Figure 5.4 (a)-(c) represent the response time by chroma levels in red, orange and yellow. The red lines in (a)-(c) represent the average lines. Letters a and b refer to data sets shown to be significantly different to each other (at the P=0.05 level).

From the general trend and subdivided trend for red, orange and yellow backgrounds, 100%, 75% and 50% are the chroma levels that participants responded generally slow, while 25% and 0% chroma levels are the backgrounds that participants responded commonly quick. Trend of yellow chroma influence on response time is different with general trend, red and orange.

5.3.2 Response Time by Test Type

Chroma influence on response time will be discussed subdivided by four types of psychometric tests. They are the Logical Rule Test, the Mathematics Sequence Test, the Rotation Test and the Spatial Structure Test. Detail of the trend summarises in Figure 5.5. From the figure it can be seen that chroma influence on response time is very different across different types of psychometric test. Only the Logical Rule Test followed the similar trend as the general trend of chroma influence on response time. People responded generally quicker on the Rotation Test than other three types of tests. 50% and 75% are two chroma levels that participants performed the slowest on the Logical Rule Test with the response time of 38 seconds for both chroma levels. 100% and 25% chroma levels are the second slowest (the response time were 32 seconds for both chroma levels), 0% is the chroma level that participants performed the quickest among the five, the response time was 20 seconds.

The differences among the group of slowest (75% and 50%), the group of middle speed (100% and 25%) and the quickest (0%) are statistical significant. Participants responded the quickest for 100% chroma on the Mathematics Sequence Test, with the response time of 27 seconds. It is significantly slower than other four chroma levels. Response time for 75%, 50%, 25% and 0% chroma levels on the Mathematics Sequence Test are very similar, the values are around 32 seconds. Different from the Mathematics Sequence Test, participants performed the slowest for 100% chroma level on the Rotation Test. They reacted with similar speed on other four chroma levels at around 21 seconds. On the Spatial Structure Test, 0% chroma level is the one that participants performed with long response time. The response time value for the 100% chroma level is 38 seconds. The 100% chroma is the level that participants responded the quickest on the Spatial Structure Test, with the value of 31 seconds.

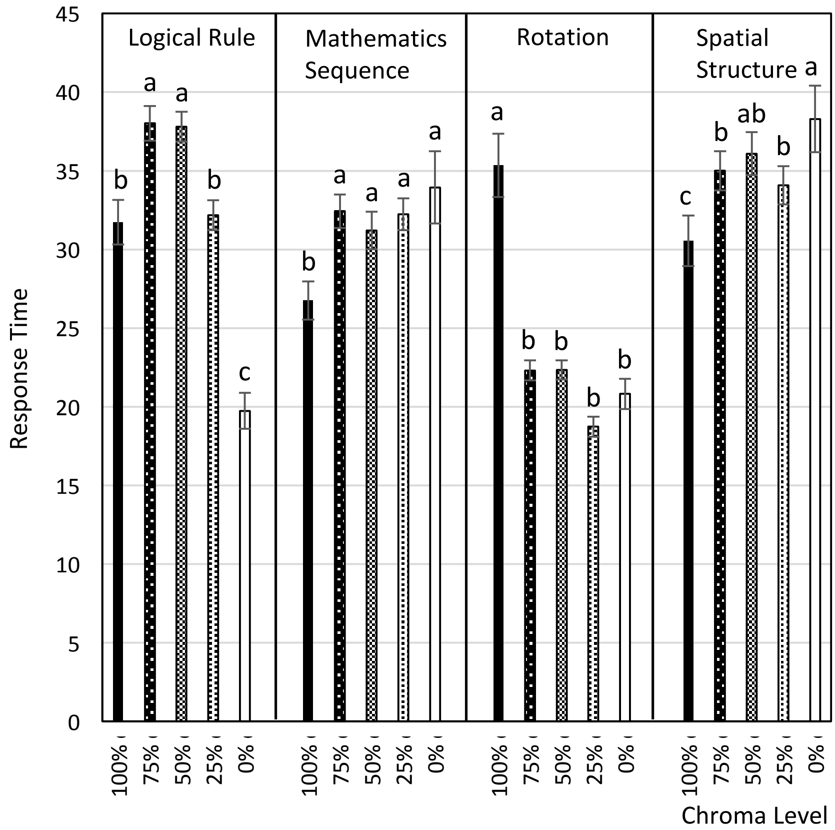


Figure 5.5 Response time by test. Letters a-c refer to data sets shown to be significantly different to each other (at the P=0.05 level).

An overall trend of chroma influence on response time has been discussed above. A more detailed discussion according to the influence of different chroma levels of each colour on response time will be discussed in the following section. Figure 5.6 – Figure 5.9 summarise the influence of different chroma levels of three hues on each type of psychometric test.

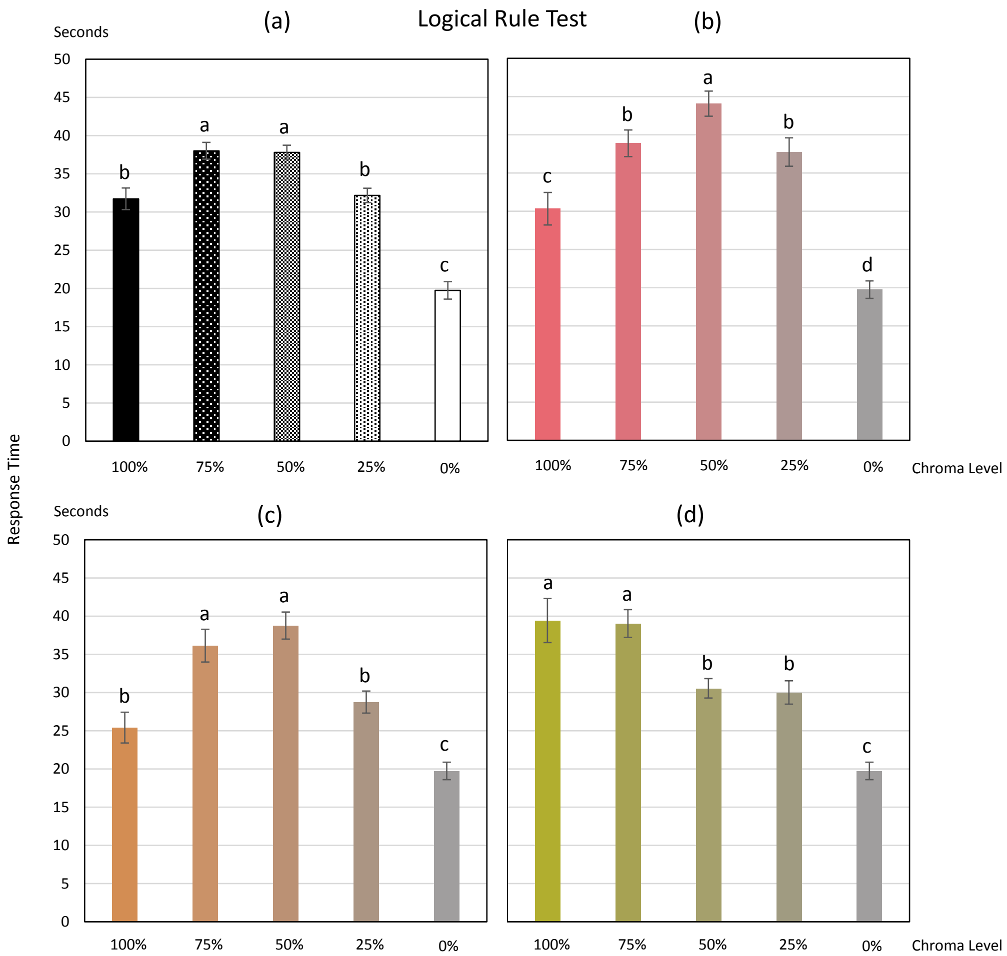


Figure 5.6 (a)-(d) Overall response time, response time of red, response time of orange, response time of yellow with the Logical Rule Test. Letters a-d refer to data sets shown to be significantly different to each other (at the P=0.05 level).

From Figure 5.6, influence of chroma on red and orange follow a similar trend with the overall trend. The 50% red and 50% orange are all having the slowest response time within the colour group and slower than the 50% of overall trend. The values for 50% red and 50% yellow are 44 seconds and 39 seconds respectively. The yellow trend is different with overall trend as the 100% and

75% yellow are the slowest among the five, with response time of 39 seconds for both chroma levels. The peak of response time with red and orange are all at 50% chroma level (the highest) and 0% chroma level (the lowest), while the peak of yellow was at 100% chroma level (the highest).

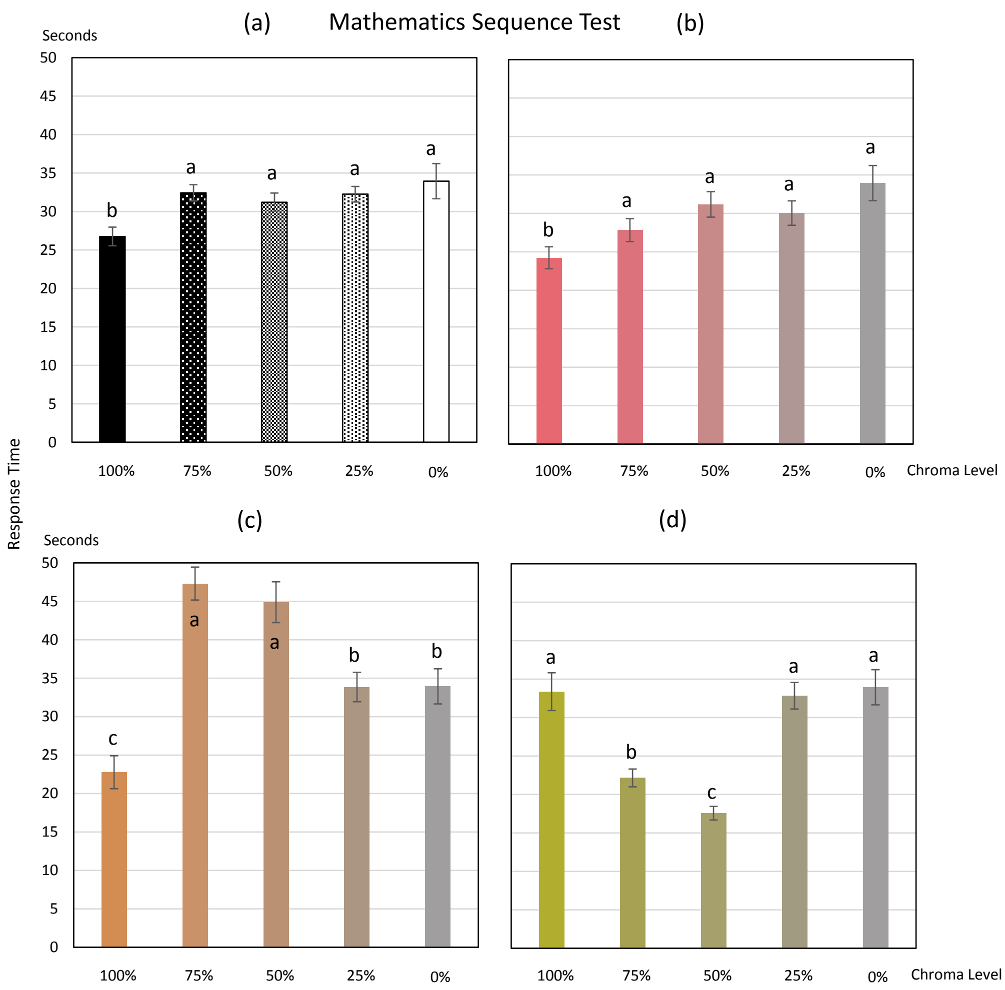


Figure 5.7 (a)-(d) Overall response time, response time of red, response time of orange, response time of yellow with the Mathematics Sequence Test. Letters a-d refer to data sets shown to be significantly different to each other (at the P=0.05 level).

In the Mathematics Sequence Test, only red follows the similar trend with the overall trend, the trend for orange and yellow are all very different. For 75% and 50% orange, participants responded extremely slower than on any other chroma levels across three colours. The values of response time on 75% and 50% orange are 36 seconds and 39 seconds respectively. 100% orange is the chroma level that participants responded the quickest among the five chroma levels within orange, with the value of 23 seconds. Yellow also has a different trend with the overall trend as on 50% yellow, participants reacted the quickest among all five chroma levels within yellow. The 100%, 25% and 0% yellow all having the similar response time at around 33 seconds. In addition, they are chroma levels that having the longest response time within the five chroma levels of yellow.

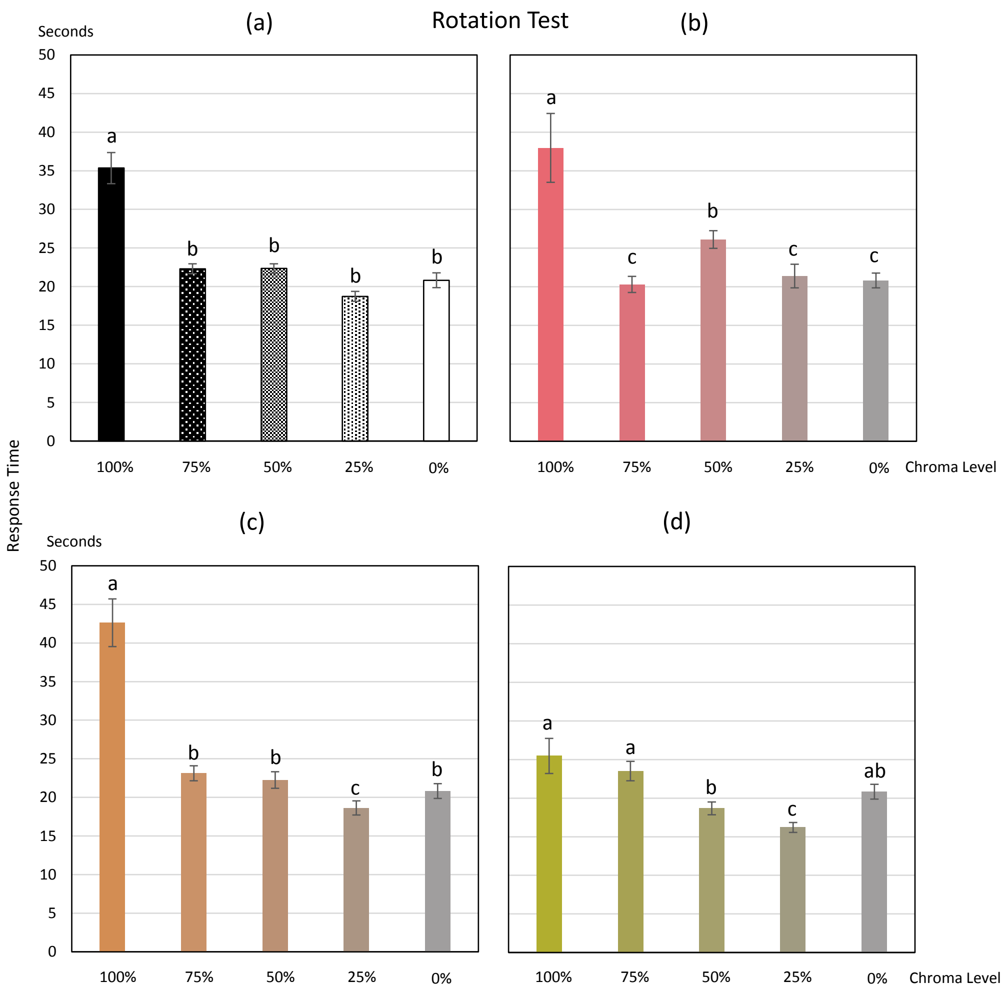


Figure 5.8 (a)-(d) Overall response time, response time of red, response time of orange, response time of yellow with the Rotation Test. Letters a-d refer to data sets shown to be significantly different to each other (at the P=0.05 level).

In the Rotation Test, trends of chroma influence with red, orange and yellow are more or less similar with the overall trend. Within the red group, 100% red is the chroma having the response time significantly slower than other four chroma levels, with the value of 38 seconds. The response time on 75% red, 25% red and 0% red are similarly quick, at around 21 seconds for three chroma levels. Similarly within the orange, the longest response time is also pointed at 100% orange, with the response time of 43 seconds. The quickest chroma level within orange is the 25% orange, the response time is 19 seconds. The slowest chroma level is more than two times slower than the quickest within orange. 100% is also the slowest chroma within the yellow, however, 75% yellow has the similar response time with 100% yellow, the response time of them are at arounds 25 seconds for both chroma levels. Still, participants performed the quickest at 25% yellow, and it is statistic significant quicker than other four chroma levels within yellow. The response time value for 25% yellow is 16 seconds.

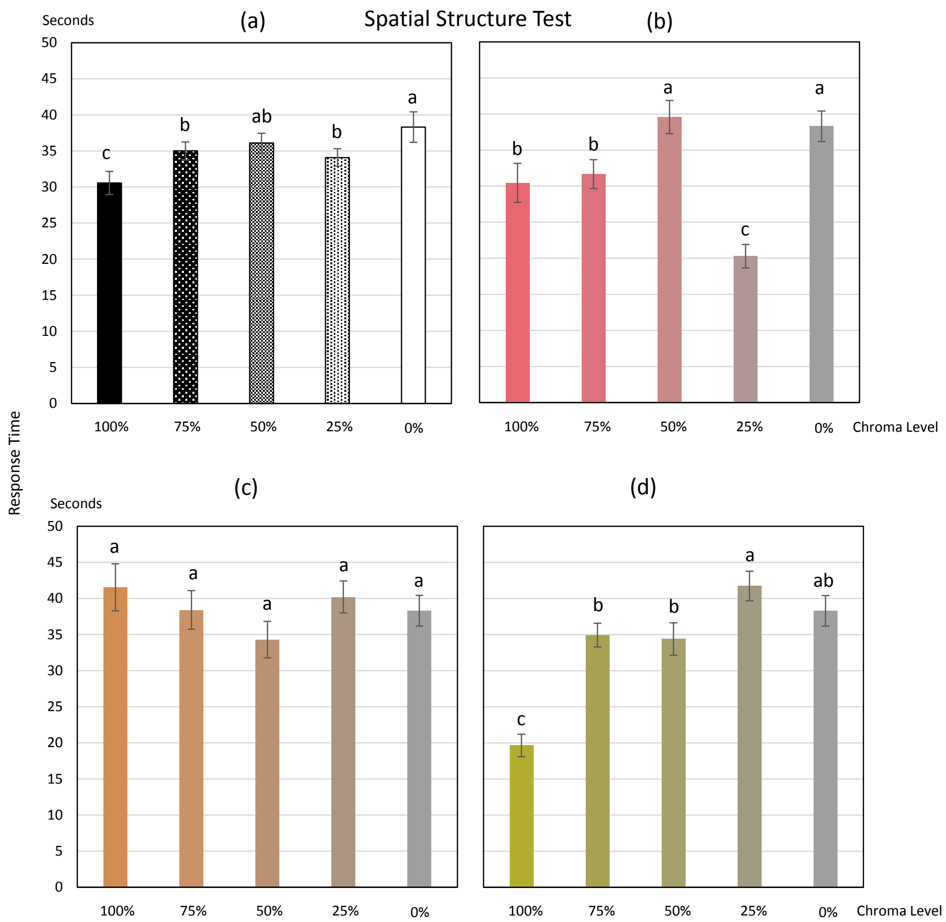


Figure 5.9 (a)-(d) Overall response time, response time of red, response time of orange, response time of yellow with the Spatial Structure Test. Letters a-d refer to data sets shown to be significantly different to each other (at the P=0.05 level).

In the Spatial Structure Test, there are some interesting results can be seen. From Figure 5.9: (c), no chroma influence can be seen within orange on the Spatial Structure Test. 25% red and 100% yellow are the chroma level that participants have the quickest response time among all three colours, with the response time of 20 seconds. 50% red and 25% yellow are the colours participants responded the slowest within red and yellow. The response time value for them are 40 seconds and 42 seconds individually. Only yellow follows a similar trend with the overall trend.

5.3.3 Response Time by Gender

Chroma influence on response time has been analysed by gender and summarises in Figure 5.10. From the figure it can be seen that apart from 100% chroma, female has a longer response time than male on all rest of chroma levels. Although, this trend is not significant as the error bars are overlapped between male and female across most of the chroma levels apart from 100% chroma level. On 100% chroma level, male responded significantly slower than female, with the response time of 34 seconds and 29 seconds respectively. Female participants responded the slowest on 50% chroma, while the quickest on 100% chroma, with the response time value of 33 seconds and 29 seconds individually. Male participants responded the slowest on 100% chroma level, and the quickest on 0% chroma level with the response time value of 34 seconds and 27 seconds respectively.

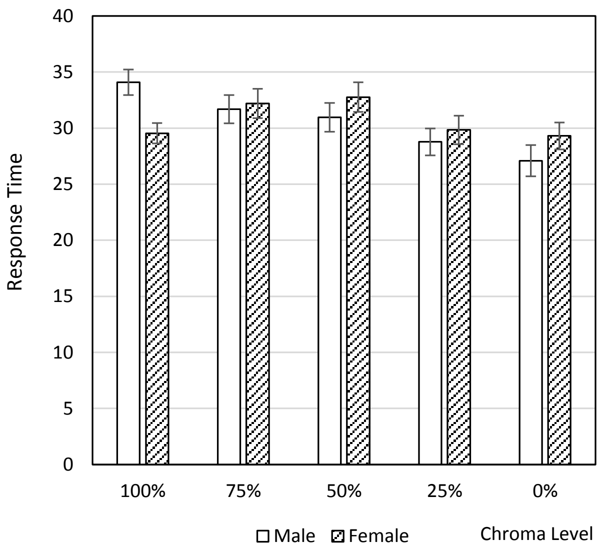


Figure 5.10 Response time by gender.

5.4 The Influence on Error Rate

5.4.1 Colour General Trend

Chroma influence on error rate is summarised in Figure 5.11. From the figure it can be seen that the 100% chroma level is the one that participants made the least of errors on, the value is 19%. The 25% chroma level has the second lowest error rate within the five chroma levels, with the value of 25%. The difference between 100% chroma level and 25% chroma level is not statistical significant. Participants made the most of errors on 75% chroma level and 0% chroma level, with the value of 35% and 32% respectively. The error rate on 75% and 0% are all bigger than average, however error rate on 100%, 50% and 25% are all smaller than average.

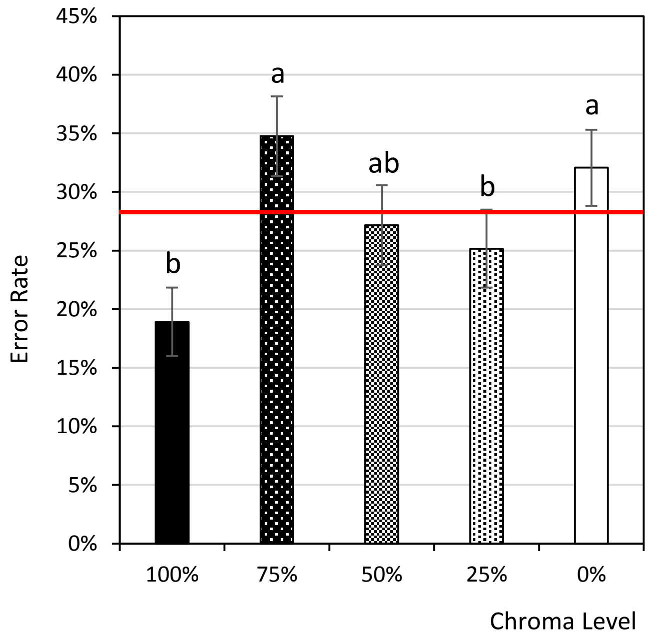


Figure 5.11 Error rate by chroma levels. The red line in figure represents the average line. Letters a and b refer to data sets shown to be significantly different to each other (at the P=0.05 level).

The chroma influence on error rate has also been analysed by subdivided into red, orange and yellow individually (shown in Figure 5.12). In the general trend, participants made the most of errors on 75% chroma level and 0% chroma level, orange and yellow have the similar trend with the general trend.

Whereas the trend of red is different, the peak of error rate at red backgrounds is at 50% and 0%. 100% chroma red is the colour participants make the fewest errors with (11%), they make the most of errors on 50% chroma level (33%) and 0% (32%) chroma level. The peak of error rate for orange backgrounds is at 75% chroma level, the errors made on 75% orange is significantly higher than other four chroma levels, with the error rate of 38%. The lowest error rate is performed with the 100% orange, with the error rate of 19%. Differently with red and orange, participants made the fewest mistakes on the 50% yellow, with the error rate of 17%. The peak of error rate of yellow backgrounds is at 75% chroma level, the error rate is 44%. Similar as the general trend, either for red, orange or yellow, error rate of 100% chroma level and 25% chroma level are all lower than average.

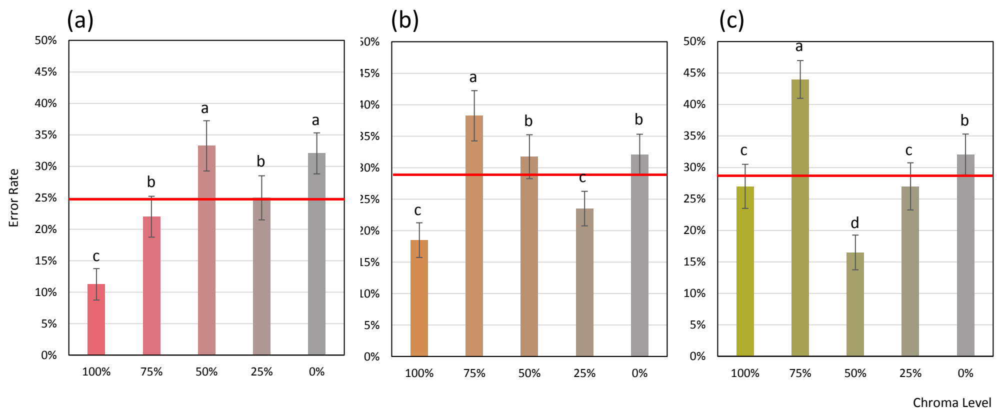


Figure 5.12 (a)-(c) represent the response time by chroma levels in red, orange and yellow. The red lines in (a) - (c) represent the average lines. Letters a to d refer to data sets shown to be significantly different to each other (at the P=0.05 level).

From the discussion above, 100% chroma levels are the backgrounds participants made the fewest mistakes on. Yellow is a different case that the lowest error rate is at 50% chroma level. 75% orange and yellow chroma levels are the backgrounds with the highest error rate, the peak error rate for red is at 50%.

5.4.2 Error Rate by Test Type

Chroma influence on error rate is also analysed by different psychometric tests. Figure 5.13 summarises the trend of chroma influence on error rate by different psychometric tests. From the figure it can be seen that 50% chroma is the chroma level that participants made the most of errors on the Logical Rule Test with the error rate of 37%. The lowest error rate on the Logical Rule Test points at 100% and 25% chroma levels with the error rate of 26% and 24% respectively. They are statistic significant with other three chroma levels. The 0% is the chroma level which participants made the most of errors on the Mathematics Sequence Test. The error rate is 40% and the difference between it with other four chroma levels are significant. Participants made considerably fewer errors on the 100% chroma level with the error rate of 15%. The difference between the highest and the lowest error is more than 2 times. 75% chroma is the level that participants performed with the highest error rate in the Rotation Test and the Spatial Structure Test. The error rates are 27% and 53% individually. Participants performed significant slower on the 75% chroma level than other four chroma levels in the Rotation Test, the other four chroma levels are containing similar error rate at 15%.The errors made at the 75% chroma level on the Spatial Structure Test is also significantly more than other four chroma levels. 0% chroma level is the second high error rate chroma level that has the error rate of 41%. Participants performed with significant high accuracy at 100% chroma level on the Spatial Structure Test, the value is 20%. The difference between the highest and the lowest is also more than two times.

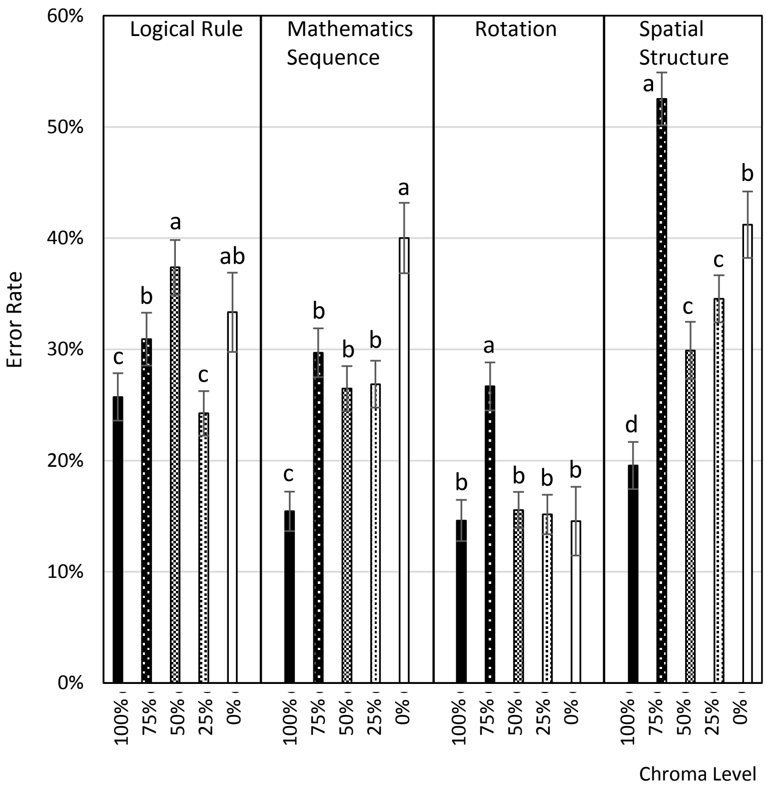


Figure 5.13 Error rate by test. Letters a-d refer to data sets shown to be significantly different to each other (at the P=0.05 level).

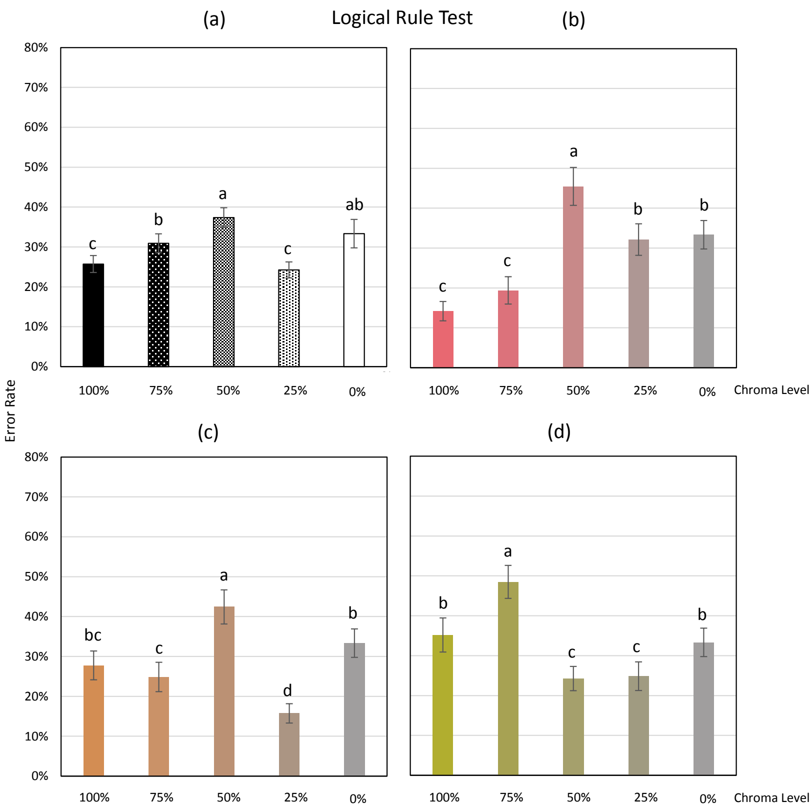


Figure 5.14 (a)-(d) Overall error rate, error rate of red, error rate of orange, error rate of yellow on the Logical Rule Test. Letters a-d refer to data sets shown to be significantly different to each other (at the P=0.05 level).

Figure 5.14 summarises the error rate on the Logical Rule Test and the results are split up in red, orange and yellow. Similar as the general trend, 50% red and 50% orange are the chroma levels that maintains the highest error rate within their groups, with the values of 45% and 42% respectively. The 100% red is the chroma level that with the lowest error rate within the red group, the error rate is 14%. The lowest error rate is pointed at 25% orange within the orange group. The error rate of 25% orange is 16%. The highest error rate in yellow group is happened at 75% chroma level, the error rate is 48%. The 75% yellow is the chroma level that participants made the most of mistakes across all the chroma levels in red, orange and yellow. Participants made similarly fewer errors on the 50% yellow and 25% yellow, with the error rate of 24% and 25% respectively. Error rate within the three chroma groups can be divided into three levels, the high error rate, the medium error rate and the low error rate levels. 50% red, 50% orange and 75% yellow can be grouped into high error rate levels; 25% red, 0% red, 100% orange, 75% orange, 0% orange, 100% yellow, and 0% yellow are all medium error rate chroma levels; 100% red, 75% red, 25% orange, 50% yellow and 25% yellow are all low error rate chroma levels. The peak error rate are all located at the middle chroma levels, such as 75% and 50%, which has the similar trend with the overall trend. Apart from the red, which has the lowest error rate at 100% chroma, the valley value for orange and yellow are all pointed at 25% chroma level that similar with the overall trend.

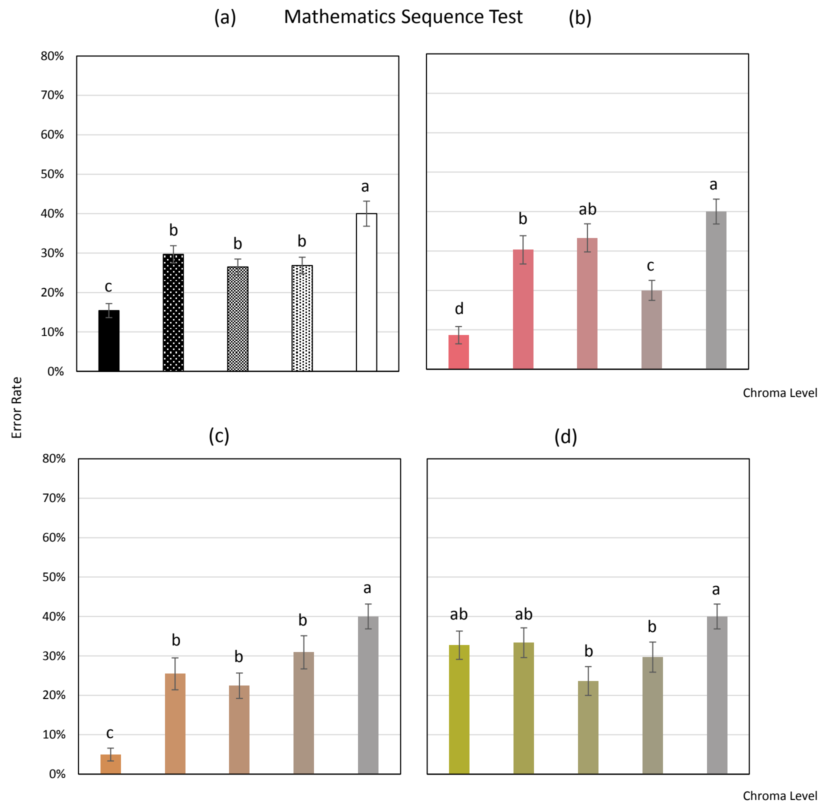


Figure 5.15 (a)-(d) Overall error rate, error rate of red, error rate of orange, error rate of yellow on the Mathematics Sequence Test. Letters a-d refer to data sets shown to be significantly different to each other (at the P=0.05 level).

For the Mathematics Sequence Test shows in Figure 5.15, the peak value of error rate are all at 0% chroma level for red, orange and yellow, with the error rate of 40%. The lowest error rate for red is 9%, pointed at 100% red. The lowest error rate for orange is 5%, pointed at 100% orange. The difference between the highest and the lowest error rate in red and orange chroma groups are all very big. They are 4 times and 8 times for red and orange individually. The lowest error rate for yellow is 24% that pointed at 50% yellow. However the difference between 50% yellow with 100% yellow, 75% yellow and 25% yellow are not statistical significant. Therefore, the different levels of yellow may have little influence on participant’s error rate.

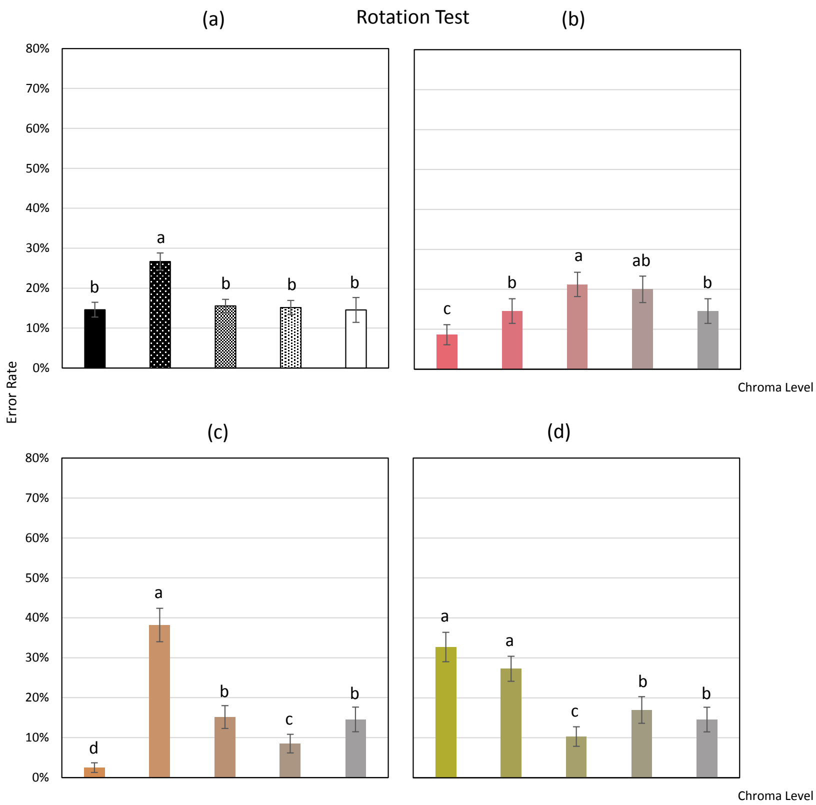


Figure 5.16 (a)-(d) Overall error rate, error rate of red, error rate of orange, error rate of yellow on the Rotation Test. Letters a-d refer to data sets shown to be significantly different to each other (at the P=0.05 level).

The errors participants made on the Rotation Test (Figure 5.16) were all relatively less than other three psychometric tests. The highest error rate across all the chroma levels within the three colour groups can be seen at 75% orange with the value of 38%. The highest error rate for red is located at 50% red, with the value of 21%. Moreover, participants made the most of errors at 100% yellow, with the value of 33%. The lowest error rate across all the chroma levels within the three colour groups is also seeing in orange, which is the 100% orange, participants only made 2% errors on this chroma level. There is a big error rate difference across orange, the difference between the highest (75% orange) and the lowest (100% orange) is 19 times. Participants performed relatively smoothly on red. The lowest error rate is at 100% red with the error rate of 9%. Difference between the highest error rate and the lowest error rate in red is roughly 2 times. Participants made 10% of errors on 50% yellow, which is the chroma level in yellow with the lowest error rate. Difference between the highest error rate and the lowest error rate in yellow is approximately three times.

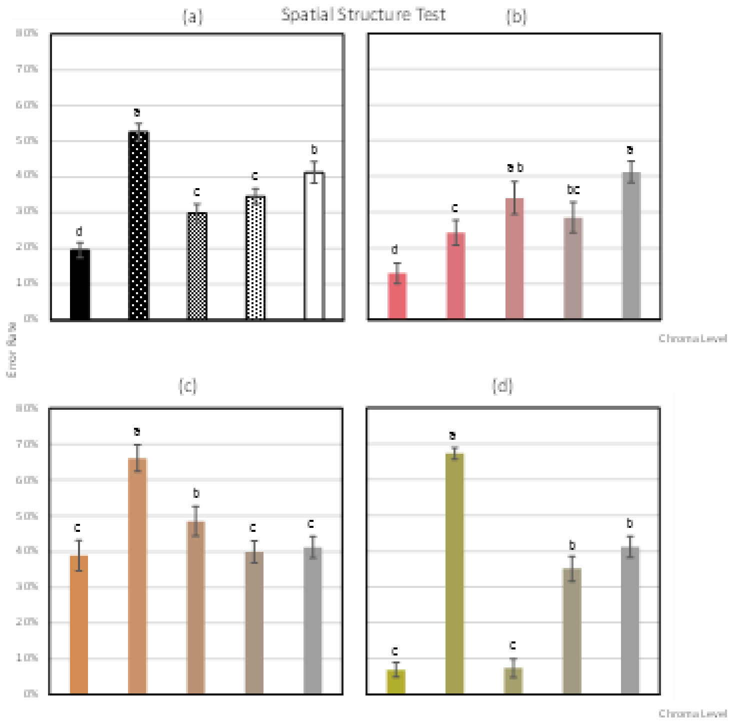


Figure 5.17 (a)-(d) Overall error rate, error rate of red, error rate of orange, error rate of yellow on the Spatial Structure Test. Letters a-d refer to data sets shown to be significantly different to each other (at the P=0.05 level).

From Figure 5.17 it can be seen that, on the Spatial Structure Test, yellow is the colour that participants made the dramatic different errors across five chroma levels. The lowest error rate are pointed at the 100% yellow and 50% yellow with the error rate of 7% for both of them. The highest error rate is pointed at the 75% yellow, the error rate value is 67%. This dramatic difference may be caused by chroma difference, also perhaps there are some uncertain variations in when solving the Spatial Structure Test, such as some particular tests are more difficult or easy for participants to solve. Both the highest and the lowest error rate in yellow are the highest and the lowest across all chroma levels. The highest error rate for red is the 0% red, with the value of 41%. The lowest error rate in red is 100% red, with the error rate of 13%. The difference between them are nearly 3 times. The error rate difference for orange is smaller than the other two chroma groups. The highest error rate is 66%, posited at the 75% orange; the lowest error rate is roughly 40%, posited at the

100% orange, the 25% orange and the 0% orange. The difference between the highest and lowest for orange is less than 2 times. Therefore, the chroma influence on error rate may be less in orange than other two chroma groups.

5.4.3 Error Rate by Gender

Figure 5.18 summarised the chroma influence on error rate over different genders. From the figure it can be seen that female tend to have a not lower error rate than male. However, this trend is not significant as all the error bars are overlapped for all the chroma levels. There are no gender difference on the 25% chroma level and the 0% chroma level as male and female participants are all having a 25% and 32% error rates on the 25% and 0% chroma levels individually. A relatively bigger difference can be seen on 75% and 50% chroma levels. On these two chroma levels, female all tend to have a bigger error rate than male participants. Female participants have the lowest error rate on the 100% chroma level with the value of 19%, and the highest error rate on 75% chroma level with the value of 37%. Male participants have the lowest error rate on the 100% chroma level with the value of 18%, and the highest error rate on the 75% chroma level with the value of 33%.

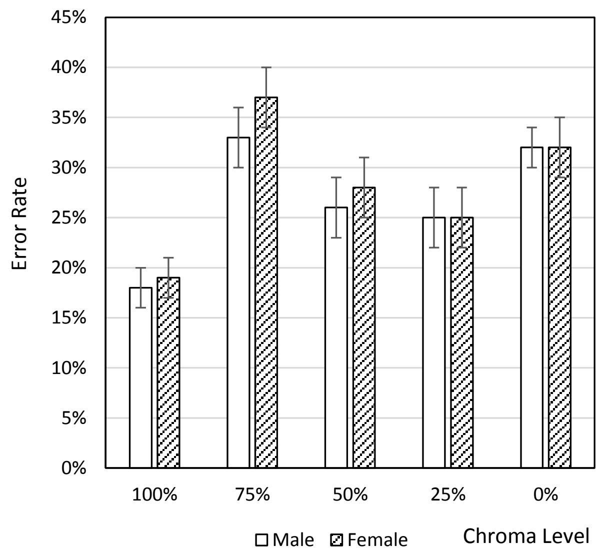


Figure 5.18 Error rate by gender.

5.5 The Influence on Impulsivity and Arousal

5.5.1 Colour General Trend

In the chroma experiment, similar as in the hue experiment, impulsivity and arousal are also determined by response time and error rate. From Figure 5.19 it can be seen that participants performed best (most aroused) on the 100% chroma level with the shortest response time and the lowest error rate at 26 seconds and 19% errors respectively. The 75% chroma level is the chroma level that participants performed the worst (the least aroused), with the longest response time of 32 seconds and the highest error rate of 35% errors. The 0% chroma level is the one that showing the tendency of high impulsivity, which the response time is shorter than the average at 28 seconds and error rate is larger than the average at 32%. The 50% chroma level is the one that participants performed with low impulsivity, with response time of 32 seconds and error rate of 25%. The 25% chroma level has the response time hit the average line and lower error rate than average.

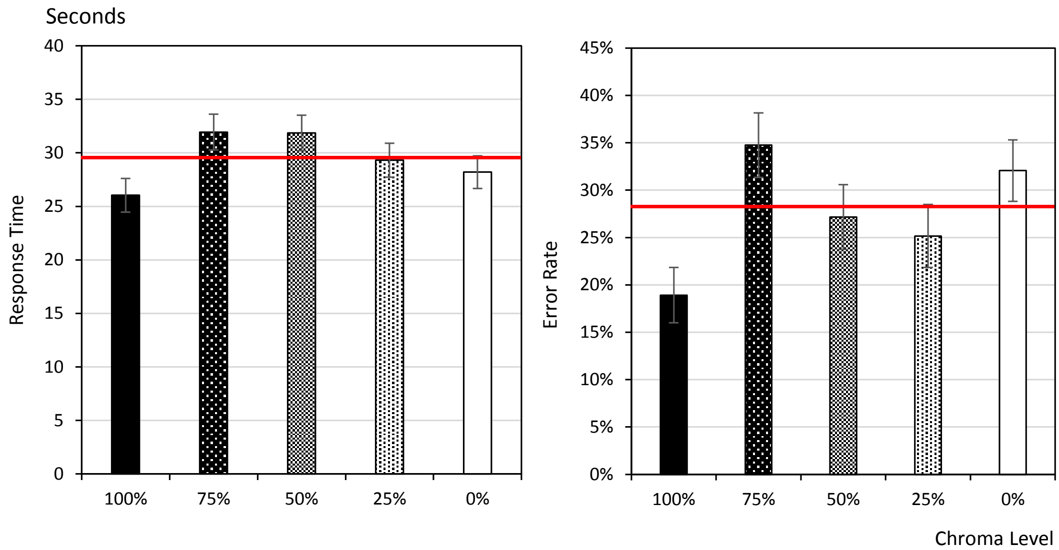


Figure 5.19 Response time and error rate by chroma levels. The red lines in figure represent the average line.

For red, orange and yellow individually (shows in Figure 5.20), the 100% red and 100% orange are the chroma levels that participants performed with high arousal status (with shortest response time and lowest error rate). Whereas they performed with high arousal status on 50% yellow as well. The 50% red, 75% orange and 75% yellow are the chroma levels with the low arousal status within each colour (these chroma levels are all having the longest response time and the highest error rate within the chroma group). The 0% red, 0% orange and 0% yellow learn to be the colours with high impulsive within each chroma group as they have shorter response time than average (red is similar with average) but higher error rate than average.

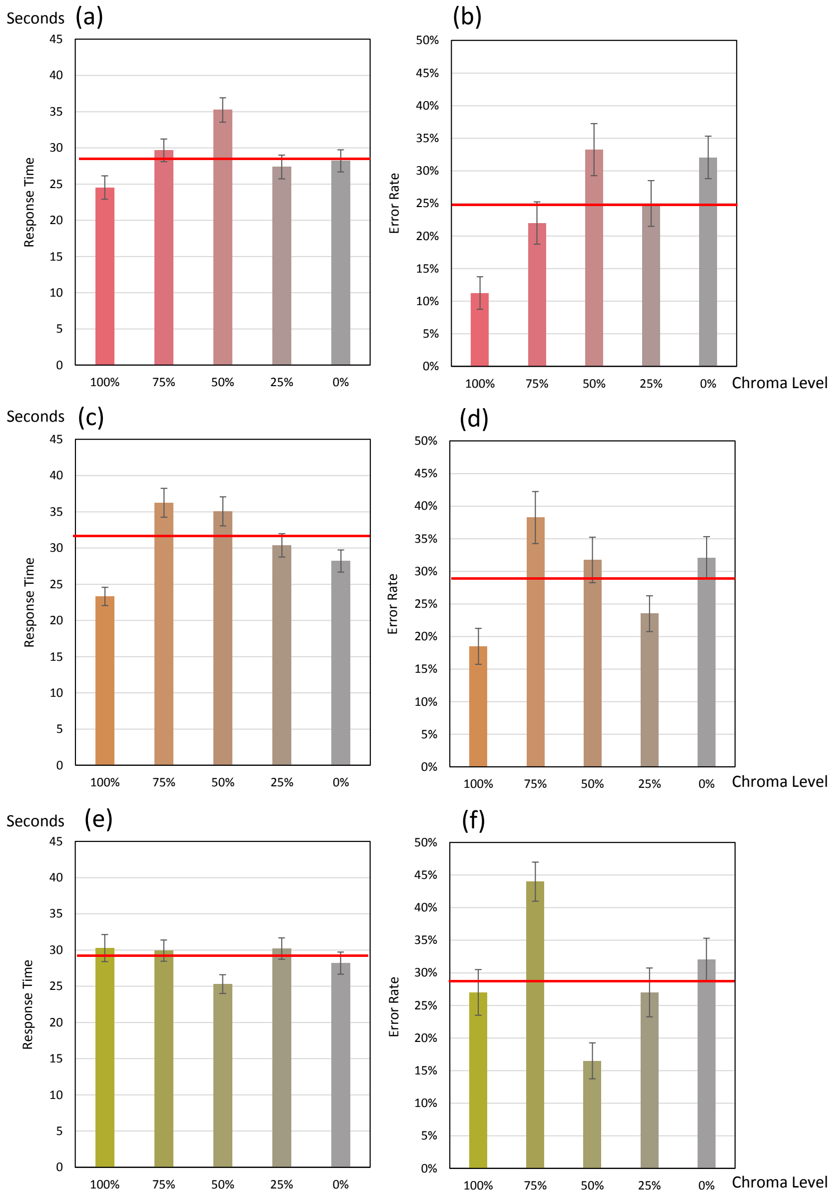


Figure 5.20 (a)-(f) represent the response time and error rate by chroma levels in red, orange and yellow. The red lines in (a) - (f) represent the average lines.

Experiment data collected from chroma experiment are also dimensionless using the same statistical method in order to position the two factors as response time and error rate in a single coordinate to discuss impulsivity and arousal. The dimensionless method been used is extremum method that using the actual value divide the maximum value of the whole data set of response time and error rate individually. The Error/Speed space of dimensionless values shows in Figure 5.21.

Figure 5.21 Thirteen colours (with reference white) plotted in the Error/Speed space.

From the figure it can be seen that the reference white and 75% yellow are the colours that participants performed with high impulsivity status. Colours in the 25% chroma level are all plotted in the HA quadrant or on the boundary of HA quadrant and HI quadrant, which means participants responded quicker than average on the 25% chroma level. The 50% orange and 50% red are all in LA quadrant, while the 50% yellow is in the HA quadrant. The 50% orange and 50% red can influence people to be less aroused and perform slow with high error rate, whilst the 50% yellow arouse people to perform quick with low error rate. Three hues in 75% chroma levels are very apart from each other in the Error/Speed space. The 75% yellow is an impulsive colour that plotted in the HI quadrant. The 75% red is a colour plotted in the HA quadrant that can arouse people to respond quickly with fewer errors. The 75% orange is in the LA quadrant that influence participant to respond slowly with more errors. Colours in the 100% chroma level are roughly plotted in the HA quadrant and the LI quadrant. The 100% yellow hits the boundary of the HA quadrant and the HI quadrant, the 100% red posits the boundary of the HA quadrant and the LI quadrant. The 100% orange is in the LI quadrant. People generally made fewer errors on 100% chroma level than the average.

The order of chroma influence on impulsivity has also been calculated by indicator: $\frac{E}{R}$ (where E was error rate, R was response time), and chroma influence on arousal has also been calculated by indicator: $1 - ER$, as same as in the hue experiment. The $\frac{E}{R}$ value and $1 - ER$ value are summarised in Table 5.3. According to the $\frac{E}{R}$ value and $1 - ER$ value, the correlation between C* values and impulsivity values are summarised in Figure 5.22. The correlation between C* value for red, orange and yellow and impulsivity values are summarised in Figure 5.23. The correlation between C* values and arousal are summarised in Figure 5.24, and the correlation between C* value for red, orange and yellow and arousal values are summarised in Figure 5.25.

Table 5.3 The $\frac{E}{R}$ and $1 - ER$ values of thirteen colours.

Colour	E/R	1-ER	Colour	E/R	1-ER
100% yellow	0.75	0.51	25% orange	0.64	0.55
75% yellow	1.21	0.17	100% red	0.39	0.72
50% yellow	0.54	0.74	75% red	0.61	0.59
25% yellow	0.73	0.49	50% red	0.78	0.27
100% orange	0.37	0.69	25% red	0.74	0.58
75% orange	0.87	0.13	reference white	0.93	0.43
50% orange	0.75	0.30			

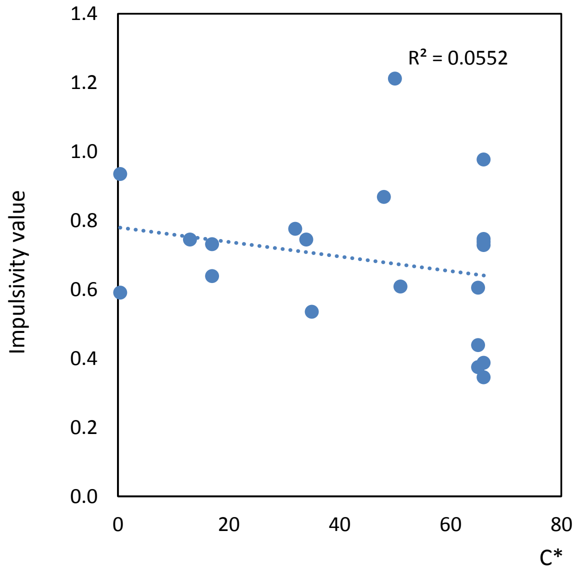


Figure 5.22 The regression between C* values and impulsivity values.

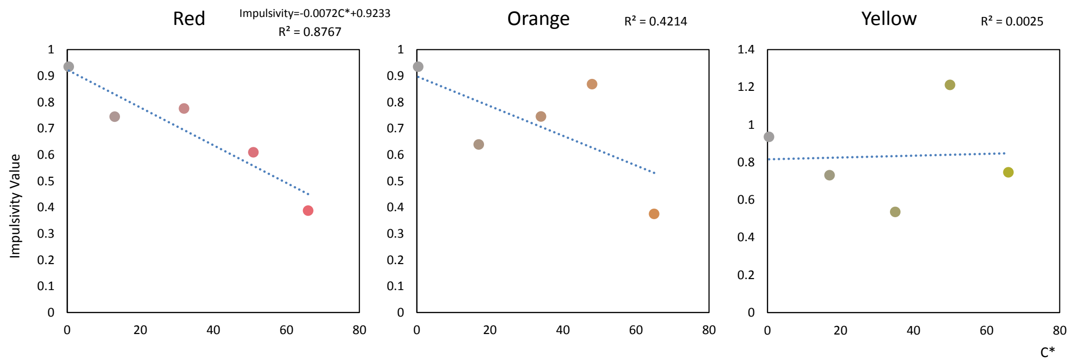


Figure 5.23 The regression between C* value for red, orange and yellow and impulsivity values.

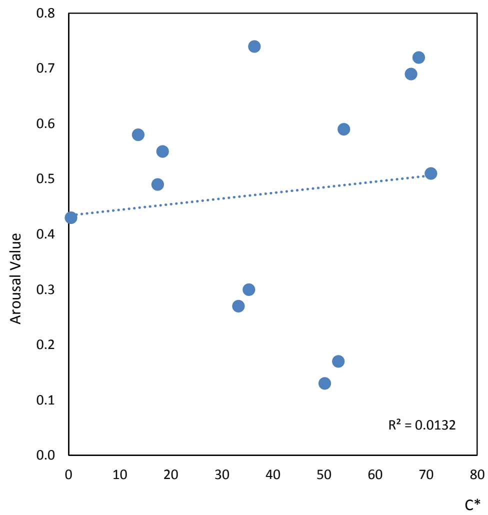


Figure 5.24 The regression between C* values and arousal values.

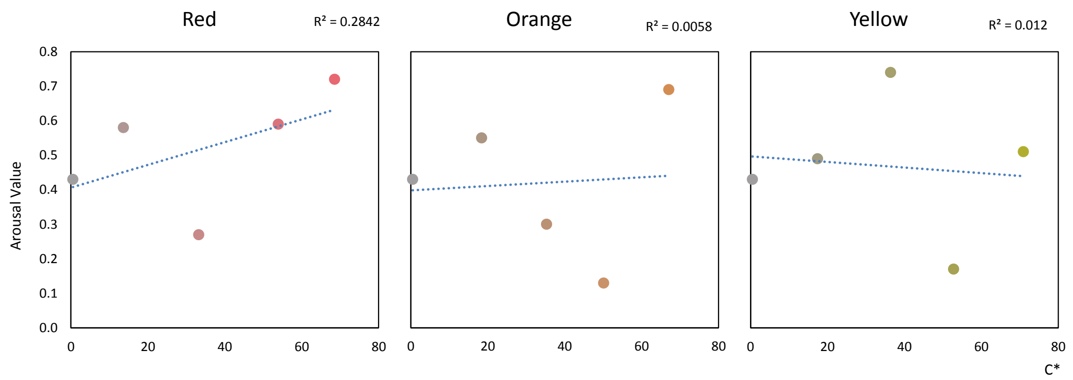


Figure 5.25 The regression between C* value for red, orange and yellow and arousal values.

From Figure 5.22 and Figure 5.23 it can be seen that, although there is no relation of chroma change influence on impulsivity in total, as the R squared value is too small (R^2 = 0.06), when discuss across different hues, some regression can be founded. For red, there is a high influence of chroma change on impulsivity. When chroma increase, the impulsivity status decrease. The R squared value for red chroma change and impulsivity is 0.88. The chroma changes in orange is obvious but not as significant as in red. There is also a decrease trend for chroma increase in orange, and the R squared value is 0.42 for orange. No trend can be found for chroma change on impulsivity across yellow.

Although there are some colours plotted in the HA and LA quadrants, from Figure 5.25 and Figure 5.26 it can be seen that the regression between chroma change and arousal is not significant as the R^2 = 0.01. When looking at detail of red, orange and yellow chroma changes, the regression between chroma changes in red, orange and yellow are all not significant (R^2 = 0.28, 0.00 and 0.02 for red, orange and yellow respectively). Therefore, it can be summarised that chroma change has no influence on arousal.

5.5.2 Impulsivity and Arousal by Test Type

In this section, chroma influence on impulsivity and arousal are analysed and discussed subdivided into four types of psychometric tests. The absolute values of response time and error rate of these four types of psychometric tests are summarised in Figure 5.26 and Figure 5.27.

From Figure 5.26 it can be seen that participants performed the worst on the 50% chroma level with the Logical Rule Test, as they responded the longest with the highest error rate among the five chroma levels, which means 50% chroma level influence participants to be less aroused. They performed the best on the 100% chroma level with low response time and the lowest error rate (the most arousal chroma level). The 0% chroma level is the chroma level that participants performed relatively with high impulsivity status as they responded with the shortest time but the error rate is higher than the average. On the other hand, participants performed worse with less aroused on the 0% chroma level with the Mathematics Sequence Test. The response time and error rate on this chroma level are all higher than the average. 100% chroma level is also the chroma level that participants performed the best for the Mathematics Sequence Test, as the error rate and response time are all the lowest among the five chroma levels (the most aroused chroma level). It is difficult to say which chroma level is the relatively impulsive chroma for the Mathematics Sequence Test, as no chroma match the condition of higher response time than average and lower error rate than average. Therefore, it is suggested that for the Logical Ability Tests (the group of the Logical Rule Test and the Mathematics Sequence Test) participants are the most aroused and performed the best on the 100% chroma. They performed worse with less arousal or more impulsivity on the 50% and 0% chroma levels.

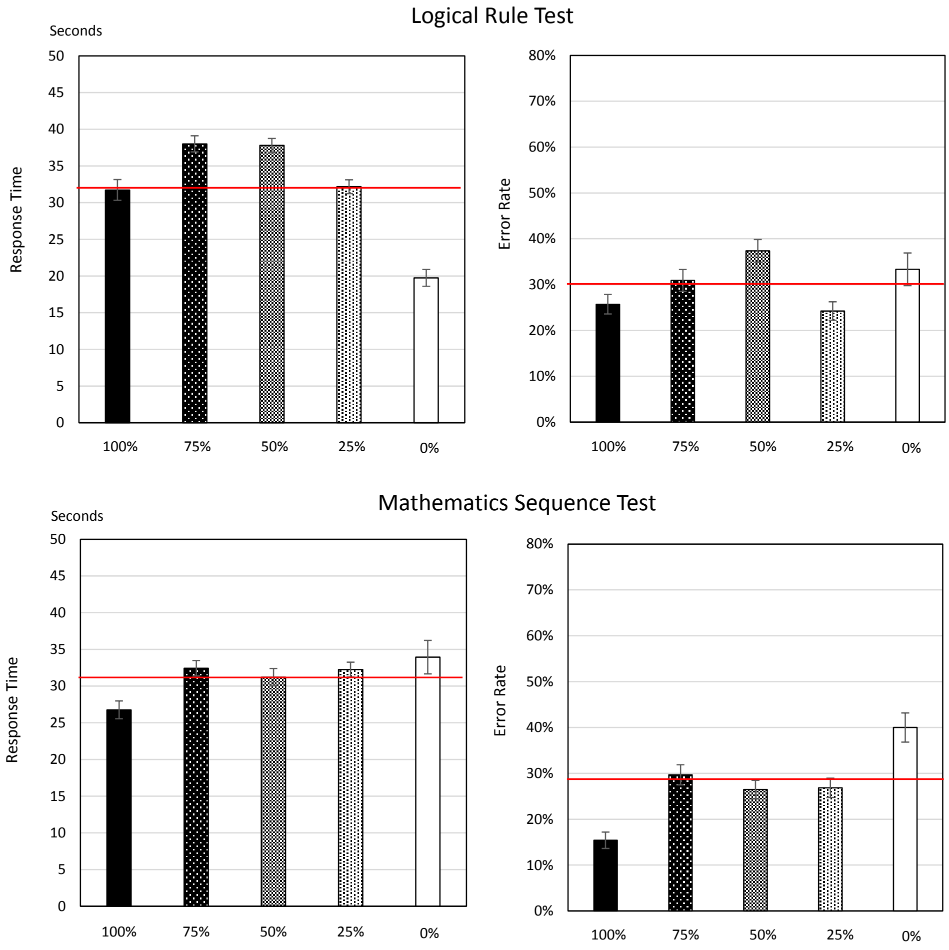


Figure 5.26 Response time and error rate by test. The red lines represent the average value.

From Figure 5.27, for the Rotation Test, there is no chroma can be seen that participants performed the worst with less arousal status, however, they performed relatively impulsive on the 75% chroma level. The 50%, 25% and 0% are chroma levels that participants performed well with high arousal status, with the response time lower than average and error rate lower than average as well. For the Spatial Structure Test, participants performed better with high arousal status on the 100% and 25% chroma levels, with all the response time and error rate lower than average. They performed the worst with low arousal status on 0% chroma level, because the response time and error rate are all higher than the average. The 75% chroma level is the one that they performed relatively impulsive, with the response time slightly slower than average and error rate much higher than average. Thus for the Spatial Imagination Tests (including the Rotation Test and the Spatial Structure Test), a commonly result can be found that normally participants performed good and highly aroused on the middle chroma level as 25% chroma level, less aroused or more impulsive on 75% chroma level.

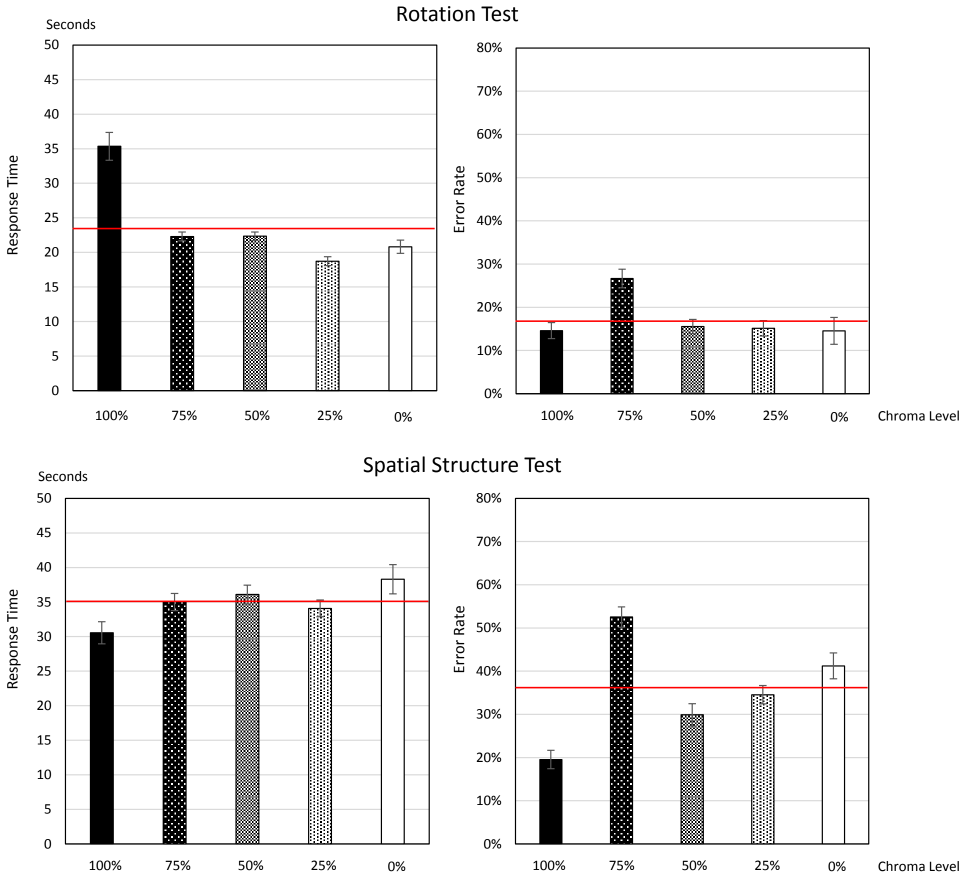


Figure 5.27 Response time and error rate by test. The red lines represent the average value.

Therefore it can be summarised that chroma influence differently on each type of psychometric test. Different chroma levels have their own influence on participant's logical and spatial imagination abilities. For example, they performed good and highly aroused at the high chroma colours when they solve the Logical Ability Tests, with the chroma decrease, their performance on the Logical Ability Tests become worse and less aroused. Nevertheless, participants performed commonly better at middle range of chroma levels when solving the Spatial Imagination Test. With the high chroma colours or the low chroma colours, their performance (either the response time or the error rate) became worse and they were less aroused.

Data of chroma influence on error rate and response time by psychometric test are dimensionless using the same method as in hue experiment. The trends of chroma influence on impulsivity and arousal on different psychometric test are summarised in Figure 5.28.

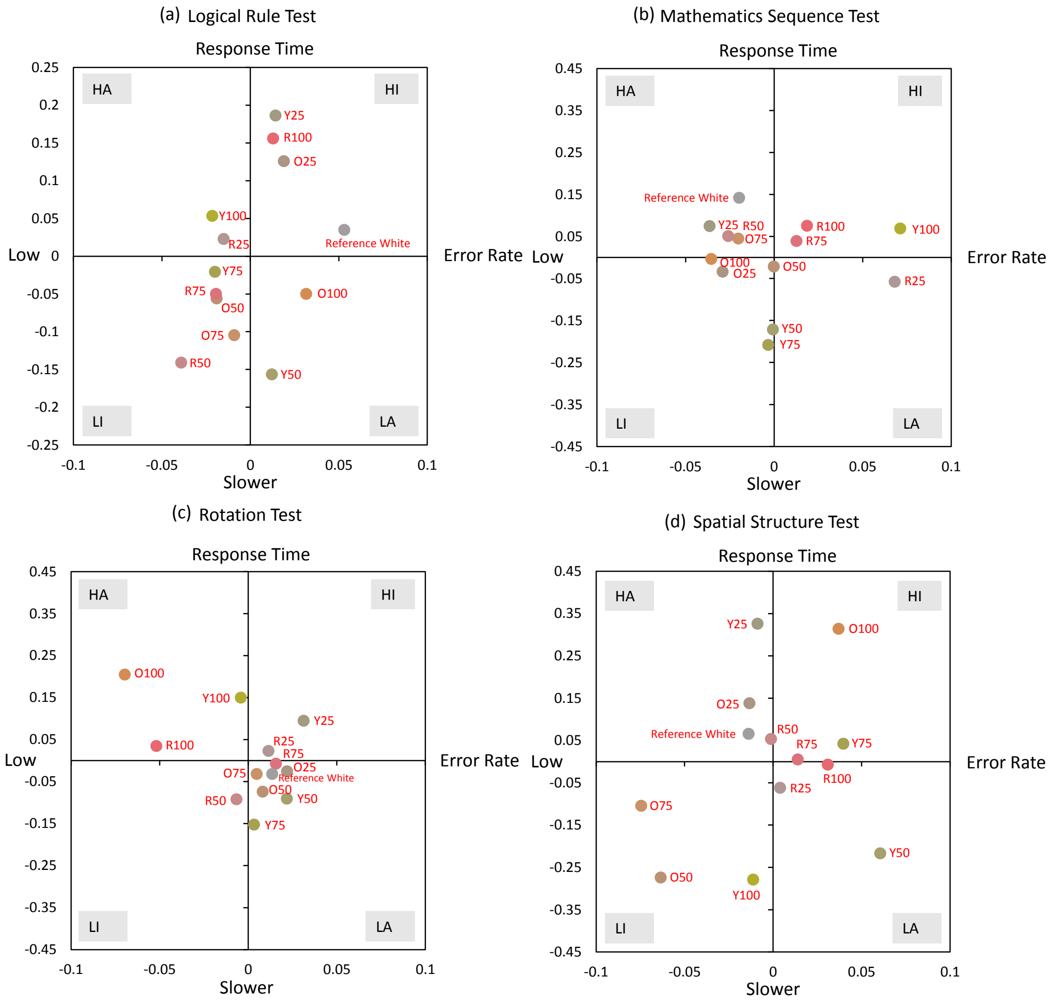


Figure 5.28 (a-d) Thirteen colour chroma levels plotted on the Error/Speed space for each psychometric test.

From (a) in Figure 5.28 it can be seen that chroma levels as 50% and 75% are mostly plotted in the LI quadrant that can influence the performance of participants to be slower and with lower error rate on the Logical Rule Test. The 50% yellow is plotted in the LA quadrant that influence participants to be less aroused, made more mistakes and responded longer. Most of participants performed quicker at the 25% chroma level when solving the Logical Rule Test. 25% yellow, 100% red, 25% orange and reference white are the colours that participants were reacted with high impulsivity on the Logical Rule Test. Participants performed with LI status on all hues in the 75% chroma level, 50% orange and 50% red on the Logical Rule Test.

From figure (b) in Figure 5.28, participants performed with high impulsivity status on the 100% red, 75% red and 100% yellow on the Mathematics Sequence Test. Almost all hues with high chroma levels as 100% and 75% could influence participants to respond quicker. Apart from the 75% yellow which influence participants to respond slow. However, the reference white, 25% yellow and 50% red can also influence participants to respond quicker than the average. The 25% orange and 75% yellow are located in the LI quadrant that participants responded slowly with low error rate. The 25% red is the less aroused colour for participants to respond slowly with more errors. The influence of chroma on the Mathematics Sequence Test is lower than the influence on the Logical Rule Test as compare with (a) and (b), colours are more dispersed distributed on the Error/Speed space for the Logical Rule Test than for the Mathematics Sequence Test.

According to (c) in Figure 5.28, participants generally performed with high error rate on the Rotation Test, however, all hues with 100% chroma level and the 50% red can influence them to make fewer errors on this test. The 100% chroma level also located in the HA quadrant that can highly aroused people with a good performance on the Rotation Test. The 75% orange and 50% red are located in the LI quadrant that participants performed slowly with low error rate on them.

From figure (d) in Figure 5.28, chroma influence is generally wide spread for the Spatial Structure Test. The 100% orange and 75% yellow influences participants with a high impulsivity status; the 50% red and 75% red plot at the boundary of HA/HI and HI/LA that can all influence participants to have a quicker response. The 25% yellow, 25% orange and reference white are located in the HA quadrant that aroused people to have a good performance. On the 75% orange, 50% orange and 100% yellow participants all have a low impulsive status. The 100% red, 25% red and 50% yellow are in the LA quadrant that people feel less arousal and performed worse on these colours.

Chroma influence on impulsivity and arousal are also ranked for each type of psychometric test. The order of it is calculated based on the indicators: $\frac{E}{R}$ and $1 - ER$ for impulsivity and arousal respectively (where E is error rate, R is response time). Table 5.4 summarises the $\frac{E}{R}$ value and $1 - ER$ value. Table 5.5 summarises the correlation of chroma change influence on impulsivity and arousal for yellow, orange and red.

Table 5.4 The $\frac{E}{R}$ and $1 - ER$ value for thirteen colours.

	Colour	E/R	1-ER	Colour	E/R	1-ER
Logical Ability Test	100% yellow	0.63	0.56	25% orange	0.39	0.86
	75% yellow	0.87	0.41	100% red	0.64	0.74
	50% yellow	0.56	0.77	75% red	0.35	0.76
	25% yellow	0.58	0.77	50% red	0.73	0.37
	100% orange	0.39	0.89	25% red	1.14	0.80
	75% orange	0.48	0.72	reference white	1.19	0.79
	50% orange	0.77	0.48			
Mathematics Sequence Test	100% yellow	1.17	0.80	25% orange	0.53	0.62
	75% yellow	0.67	0.63	100% red	0.20	0.92
	50% yellow	0.49	0.74	75% red	0.68	0.70
	25% yellow	0.51	0.60	50% red	0.58	0.59
	100% orange	0.08	0.94	25% red	0.69	0.87
	75% orange	0.47	0.69	reference white	0.72	0.53
	50% orange	0.46	0.76			
Rotation Test	100% yellow	0.90	0.74	25% orange	0.31	0.95
	75% yellow	0.84	0.79	100% red	0.16	0.90
	50% yellow	0.40	0.94	75% red	0.50	0.09
	25% yellow	0.78	0.91	50% red	0.58	0.18
	100% orange	0.04	0.97	25% red	0.65	0.13
	75% orange	1.14	0.73	reference white	0.50	0.90
	50% orange	0.49	0.89			
Spatial Structure Test	100% yellow	0.14	0.93	25% orange	0.83	0.58
	75% yellow	2.13	0.53	100% red	0.38	0.90
	50% yellow	0.29	0.96	75% red	0.60	0.79
	25% yellow	0.74	0.64	50% red	0.77	0.67
	100% orange	1.20	0.72	25% red	0.66	0.74
	75% orange	0.97	0.03	reference white	0.85	0.56
	50% orange	0.75	0.33			

Table 5.5 The correlation of chroma change influence with impulsivity and arousal for yellow, orange and red.

Test	**Colour**	**R^2 (Impulsivity)**	**Trend**	**R^2 (Arousal)**	**Trend**
Logical Rule	Yellow	0.24	no	0.57	decrease
	Orange	0.49	no	0.00	no
	Red	0.75	decrease (sig)	0.01	no
Mathematics Sequence	Yellow	0.37	no	0.71	increase (sig)
	Orange	0.84	decrease (sig)	0.84	increase (sig)
	Red	0.57	decrease	0.26	no
Rotation	Yellow	0.37	no	0.66	decrease (sig)
	Orange	0.00	no	0.02	no
	Red	0.51	decrease	0.03	no
Spatial Structure	Yellow	0.00	no	0.24	no
	Orange	0.55	increase	0.02	no
	Red	0.73	decrease (sig)	0.79	increase (sig)

In Table 5.5, if $R^2 > 0.5$ shows a trend of chroma change on impulsivity and arousal can be seen. If $R^2 > 0.6$, the chroma change on impulsivity and arousal is considered more significant. From Table 5.5 it can be seen that chroma changes for red, yellow and orange can somehow influence participant's impulsivity and arousal status.

For the Logical Rule Test, the increase of chroma can significantly influence on impulsivity as $R^2 = 0.75$. The trend of red chroma change on impulsivity when solving the Logical Rule Test is that when chroma increase, the impulsivity status of participants decrease. The only chroma change influence on arousal is happed on yellow, as $R^2 = 0.57$. With chroma of yellow increase, there is a decreased trend on people's arousal status.

For the Mathematics Sequence Test, orange and red chroma changes can all influence on people's impulsivity status, as R^2 = 0.84 and 0.57 for orange and red respectively. The trend of chroma increase influence on impulsivity for orange and red are similar. A decrease trend of impulsivity status along with orange and red chroma increase. The chroma changes influence on people's arousal for the Mathematics Sequence Test are happened with yellow and orange, as R^2 = 0.71 and 0.84 individually. The arousal status increase when chroma of yellow and orange increase.

For the Rotation Test, the only influence of chroma change on impulsivity can be seen on red, as R^2 = 0.51. When chroma of red increase, people's impulsivity status decrease. The only significant influence of chroma change on arousal happened on yellow, with the R^2 = 0.66. With the increase of chroma for yellow, arousal status for participants decrease.

For the Spatial Structure Test, the change of chroma with orange and red colours can both influence on people's impulsivity status, as R^2 = 0.55 and 0.73 individually. When chroma of orange increase, the impulsivity of participants increase. While, when chroma of red decrease, the impulsivity status of participants decrease. Red is also the colour could influence on arousal when its chroma changes, as R^2 = 0.79. When chroma of red increase, the arousal status of participants increase accordingly.

From the above discussion, red is the colour that can influence on participants impulsivity status with all the tests when its chroma changes. When chroma of red increase, the impulsivity status decreased. Orange can also influence on people's impulsivity with parts of psychometric tests. There is no one colour can influence on people's arousal status with all types of psychometric tests. Yellow is the only colour can influence on people's arousal status with most of psychometric test. Moreover, the trend of yellow chroma change on arousal are various across different psychometric tests.

5.5.3 Impulsivity and Arousal by Gender

Figure 5.29 summarises the chroma influence on impulsivity with different genders. On the 100% chroma, male participants respond slower with lower error rate than female observers. On the 75% – 0% chroma levels, male participants respond quicker with no higher error rate than female participants. Therefore, for female participants, 100% chroma level is the chroma influence them to be more impulsive. No chroma level is found can influence male to be more impulsive. However, this trend is not significant as the error bars are mostly overlapped.

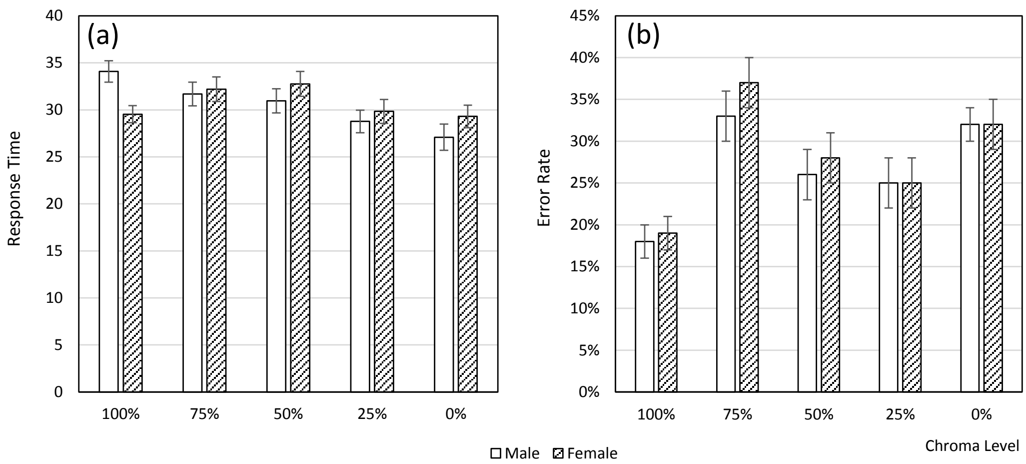


Figure 5.29 (a) Response time by gender; (b) Error rate by gender.

5.6 Discussion

In this chapter, chroma influence on response time, error rate, impulsivity and arousal are analysed and discussed respectively. Some discussions related to these three parts are summarised in this section.

5.6.1 The Influence on Response Time

Data collected from section 5.2 shows that:

- Participants performed the quickest on the 0% chroma level while the slowest on the 75% and 50% chroma levels.

- Response time on the 50% red is significantly longer than other chroma levels of red. Orange has a similar trend of response time with general trend that the quickest on 0% chroma level while the slowest on the 75% and 50% orange. Participants performed significantly quicker on the 50% yellow than other chroma levels in yellow.
- The 0% chroma level is the chroma level that participants performed the quickest on the Logical Rule Test across all three hues. The 50% chroma level is the chroma level for general trend, red and orange that participants performed the slowest on the Logical Rule Test. Participants responded the slowest on the 100% yellow across all chroma levels in yellow.
- The 100% chroma level is the one that participants performed the quickest with general trend, red and orange on the Mathematics Sequence Test. The 50% yellow is the chroma level across the yellow that participants performed with the shortest response time on the Mathematics Sequence Test. Participants performed the slowest on the 0% yellow, 0% red and 75% orange on the Mathematics Sequence Test.
- The 100% chroma is the level that participants performed the slowest across all three hues on the Rotation Test. They performed the quickest with the 25% chroma level for the most of hues as orange and yellow on the Rotation Test. 75% red is the chroma that participants performed the quickest on the Rotation Test.
- The 50% red, 100% orange and 25% yellow are the colours that participants performed the slowest on the Spatial Structure Test. The quickest for red on the Spatial Structure Test is 25% red, for orange is 50% orange, for yellow is 100% yellow.
- Male participants performed quicker than female on the most of chroma levels as 75%, 50%, 25% and 0%. However, male participants responded significantly slower on 100% chroma level than female.

5.6.2 The Influence on Error Rate

Data collected from section 5.3 shows that:

- Participants made the fewest errors on the 100% chroma level while they made the most of errors on the 75% chroma level.
- For red and orange, 100% chroma level are still the chroma that participants performed with the lowest error rate. The lowest error rate for yellow points at 50% yellow. The 75% is the chroma level for orange and yellow that participants made the most of errors on, while they made the most of errors on the 50% red.
- The 75% red and 75% orange are the chroma levels that participants made the most of errors on the Logical Rule Test, whilst the peak of error rate on red plots at 50% chroma level. The chroma level that participants made the fewest errors on the Logical Rule Test for red, orange and yellow are different. They plots at 100% red, 25% orange and 50% yellow respectively.
- The lowest error rate for red and orange posits at 100% chroma level, for yellow is posited at the 50% chroma level on the Rotation Test. 0% is the chroma level that participants performed with the highest error rate within all three hues on the Rotation Test.
- The 75% orange, 75% yellow and 0% red are the chroma levels that participants performed with the most of errors on the Spatial Structure Test. The 100% chroma level is the one that participants performed with the lowest error rate across all three hues on the Spatial Structure Test.
- There is a trend that female participants made more errors than male participants did in general.

5.6.3 The Influence on Impulsivity and Arousal

Data collected from section 5.4 are summarised as follow:

- There is a significant influence of red chroma changes on impulsivity. When chroma of red decrease, the impulsivity status increase.
- The influence of orange chroma changes on impulsivity also can be

seen but not as significant as red. Similar as red, when chroma of orange decrease, the impulsivity status increase.

- The 75% yellow and 0% chroma level are plotted in the HI quadrant. The 100% orange is plotted in the LI quadrant. Most of the middle chroma levels as 75% orange, 50% red, and 50% orange are posited in the LA quadrant. Colours as 75% red, 50% yellow,25% orange, 75% orange, 25% red and 100% red are plotted in the HA quadrant. The 100% yellow, 25% yellow, and 100% red are posited on the coordinate axis.
- The 100% red is the colour with the lowest impulsivity status, 75% yellow is the colour with the highest impulsivity status among all test colours in this experiment. The 75% orange is the least arousal colour while the 50% yellow is the most colour among all test colours.
- The 25% yellow, 100% red, 25% orange and 0% chroma level are the colours plotted in the HI quadrant for the Logical Rule Test. Most of the colours in the middle chroma levels as 75% yellow, 75% red, 50% orange, 75% orange and 50% red are plotted in the LI quadrant for the Logical Rule Test. 100% yellow, and 25% red are plotted in the HA quadrant, 100% orange and 50% yellow are posited in the LA quadrant for the Logical Rule Test.
- The red in 100% and 75% chroma levels and yellow in 100% chroma level are colours participants performed with high impulsivity status for the Mathematics Sequence Test. The 25% orange and 75% yellow are colours participants performed with low impulsivity status for the Mathematics Sequence Test. The 0% chroma, 25% yellow, 50% red, and 75% orange are the colours participants performed with high arousal, 25% red is the colour that participants performed with low arousal for the Mathematics Sequence Test.
- Most of colours are in the HI and LA quadrants with high error rate for the Rotation Test. The 50% red are in the LI quadrant for the Rotation Test. The 100% chroma levels with three hues are in the HA quadrants that participants performed with short response time and low error rate.
- The 100% orange, 75% yellow are the colours participants performed with high impulsivity status for the Spatial Structure Test. The 75%

orange, 50% orange and 100% yellow are the colours participants performed with low impulsivity. The 25% yellow, 25% orange and 0% chroma are plotted in the HA quadrant. The 25% red and 50% yellow are in the LA quadrant for the Spatial Structure Test.

- The 100% chroma level are the chroma level could influence female participants to perform with a higher impulsivity status than male.

Gorn and colleagues (1997) found that when designing web pages, chroma is an important factor for relaxation. Lower level of chroma associated with a higher level of relaxation. In Gorn's experiment (2004), he found when people feels more relaxing; they will quicker perceive web downloads. In this study, 0% is the chroma that participants performed the quickest among the five chroma levels, which agreed with the findings from Gorn *et al*. The 25% chroma is also relatively quick for participants to respond. However, in this study, participants responded slower on middle chroma levels as 50% and 75%.

Ayash *et al*. (2015) found that whiteness has significant influence on reading comprehension. Pale colours like pale blue and pale yellow have a more positive impact on intellectual activity and spatial properties. Schauss (1979) found pink, a red colour with lower chroma, has effect on calming people. From section 5.2 and 5.3 in this study, some findings can agreed with Ayash's research. For the Logical Ability Tests as the Logical Rule Test and the Mathematics Sequence Test, 50% yellow is the colour always have low error rate. The 0% chroma level is the colour that participants made the fewest errors for the general trend. Therefore, it can be summarised that the low to middle chroma levels can influence people to be more calming and have a positive impact on people's physical expression.

A big feature can be found from this experiment is that colours in the middle chroma levels influence people to think twice and improve their answers for almost all types of psychometric tests. This partly agree with the major findings from Schauss (1979), Gorn (1997 and 2004) and Ayash (2015). However, in this study, chroma influence on impulsivity and arousal is more complexed than what previous research found. Some vivid colours can also made a positive impact on people's performance. For example, the general trend shows that people perform with low impulsivity on the 100% chroma level. Especially the 100% orange and 100% red. When chroma decrease does not mean the performance is keep improving. For colours like red and orange, chroma decrease can raise the level of impulsivity.

5.6.4 The Influence of Colour on Impulsivity and Arousal

In the chroma and hue experiment, as participants were roughly spent 15 minutes on each colour, the influence of colour on participants is more short time to mid time terms. Figure 5.30 and Figure 5.31indicate the degree of impulsivity and arousal in the Hue/Chroma polar contour space.

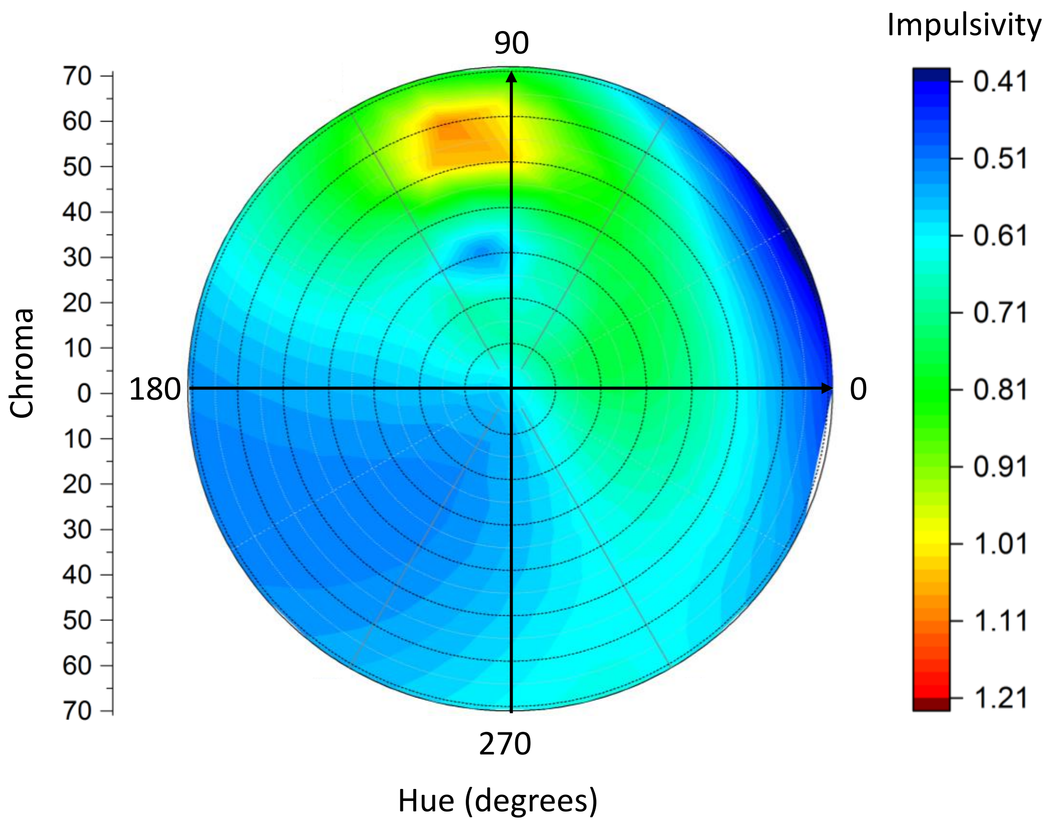


Figure 5.30 Impulsivity contour map.

From Figure 5.30, it can be seen that the high impulsivity locates at

- Middle to high chroma yellow and orange (hues around 75° to 125°, with the chroma level of 75% – 100%).

The low impulsivity plots at

- High chroma red (hue of nearly 45°, and 100% chroma level),
- Middle chroma yellowish green (hue of around 100°, and 50% chroma level),
- High chroma greenish blue (hue of around 180° – 240°, and 100% chroma level).

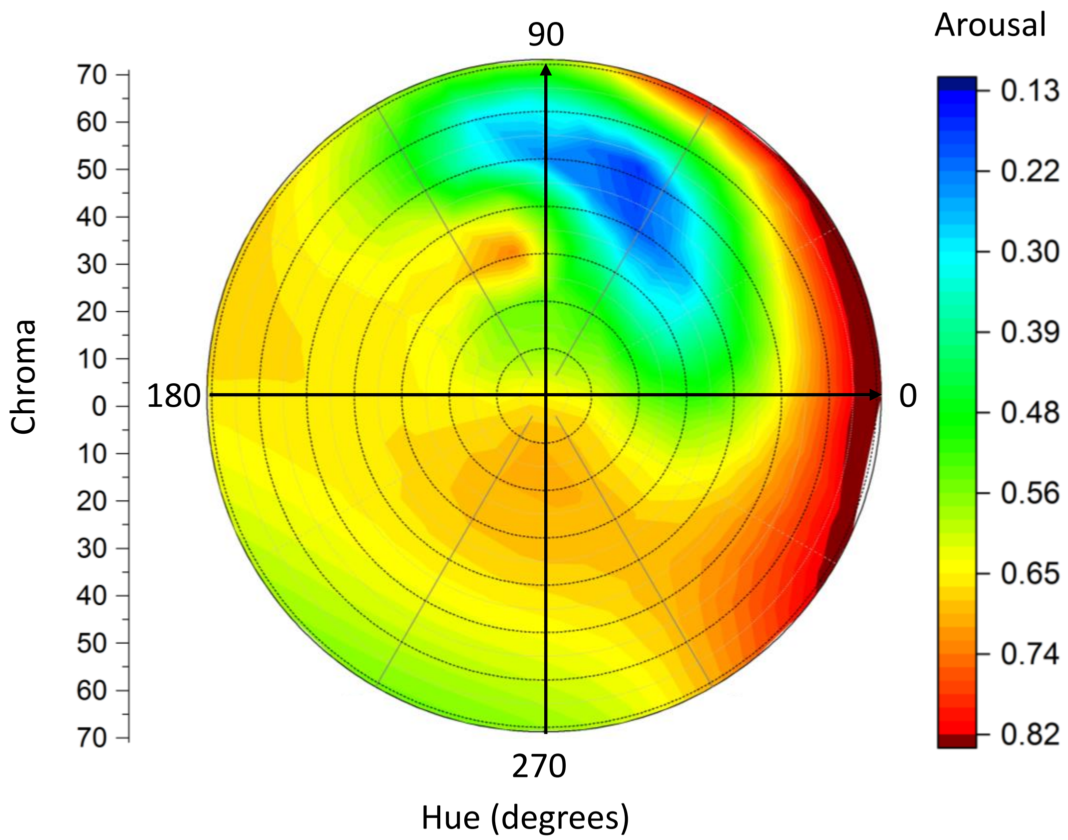


Figure 5.31 Arousal Contour Map.

From Figure 5.31, the high arousal colours locate at

- High chroma reddish colours (hue of 330° – 45°, and 100% chroma level),
- Middle chroma yellowish green (hue of 100°, and 25% – 50% chroma levels).

The low arousal colours locate at

- Middle chroma orange (hue of 50° to 75°, and 50% – 75% chroma levels),
- High chroma yellow (hue of 90° to 100°, and 75% chroma levels).

5.7 Summary

In this chapter, the influence of chroma on response time, error rate, impulsivity and arousal are explored. The discussion is by chroma, by psychometric test type, and by gender respectively. **Some *novel findings* can be summarised:**

1) The effect of chroma on impulsivity and arousal is complicated. Chroma influences impulsivity more than arousal, as a clear decrease trend of impulsivity can be seen along with the increase of chroma for red and yellow. There was no clear effect of chroma on arousal.
2) Generally, middle chroma levels (50% and 75%) result in slower response time than low and high chroma levels. Colours in 100% chroma results in the fewest errors. Although people think longer on middle chroma levels, this does not mean that they make fewer errors on middle chroma levels. On the contrary, they normally make more errors on middle chroma levels than on 100% chroma.
3) Chroma influences on response time, error rate and impulsivity are significantly different across the four types of psychometric tests.
4) Gender difference was not significant. However, there was a trend for

females to respond slower than males and with more errors.

Findings from this chapter along with findings from the last chapter can be used together in solving different design issues. However, there are some limitations can be found in this experiment. As the colour preference data collected from this experiment focused on several particular colours, it is limited to compare the colour preference across all test colours. It is suggested that in later research, more participants need to be involved if colour or chroma preference influence on impulsivity is the target research question need to be solve. Similar as in the hue experiment, participants in this experiment were all Chinese, aged between 20 and 38. The results in this experiment are limited in that it did not cover a broad culture and age group. It is difficult to use these selected colours to predict the trend of chroma influence in the whole colour space, which can be also studied in the future.

Chapter 6 Colour Influence on Impulsivity, Arousal and Emotion

6.1 Introduction

In order to posit the colour influence on impulsivity and arousal in a broader concept of emotion, colour influence on impulsivity and arousal will be also compared with colour emotion. This is to explore if the influence of colour on impulsivity and arousal has some similar rules with the influence on emotion. An experiment of colour influence on emotion was designed to verify Ou's (2004) colour emotion models for single colours. The comparison of colour influence on impulsivity, arousal and emotion will be explored later on. Firstly, participants undertook the experiment twice and the repeat responses were compared with the first responses in order to quantify the reliability of the data and to assess intra-observer and inter-observer accuracy. Secondly, all the reliable data were transformed into scale values using the categorical judgement method, and the scale values were tend to explore textile impact on colour emotion. Thirdly, principal component analysis was used for classifying the components. Fourthly, Ou's colour emotion model for single colour was evaluated based on the data collected. Finally, emotions for the test colours used in the hue and chroma experiments were calculated based on Ou's colour emotion model for single colours. The comparison of colour influence on emotion and colour impact on impulsivity and arousal is discussed in this chapter. Figure 6.1 summarises the experimental method of the emotion experiment.

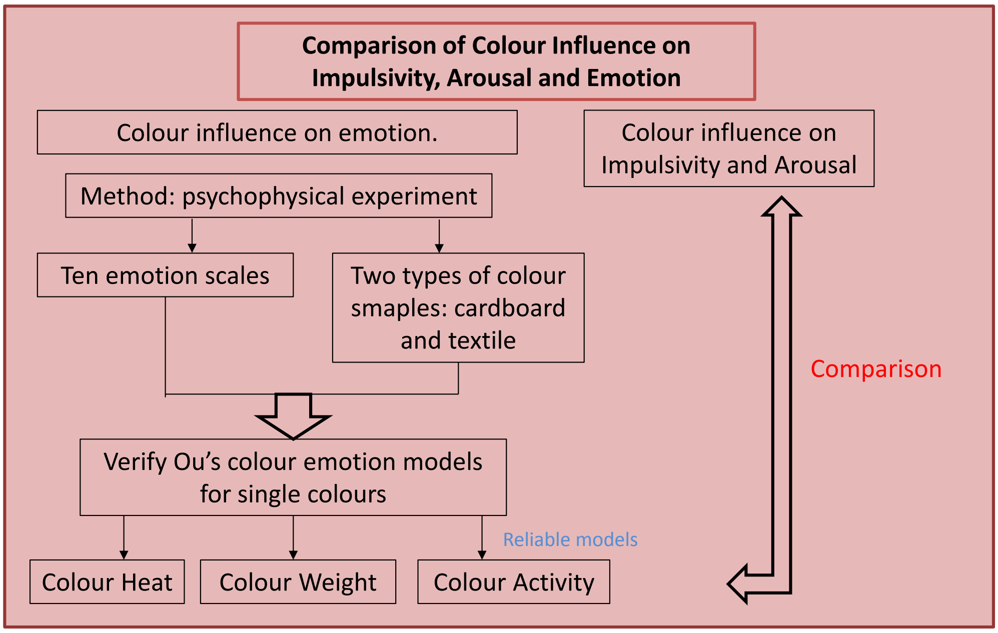


Figure 6.1 The flowchart of the experimental method of emotion experiment.

6.2 The Reliability of the Data

The reliability of the data are examined by two factors, the repeatability of data and the observer consensus. In this experiment, data has been analysed in both parts.

6.2.1 Repeatability

Repeatability for each observer

The repeatability indicates to each observer, how well an experimental data set agrees with a replicated data set. It can be shown as the probability of these two data sets agreed with each other. From the data shown in Table 6.1 and Figure 6.2, in average observers are all self-consistent in their result with both paper samples and textile samples (mean value for the two experiment are 0.81 against 0.79). Furthermore, the observers all had good repeatabilities as all of them have a high repeatability which above 0.70. The fact indicates that data collected from these 12 observers are repeatable.

Table 6.1 The total repeatability for each observer in emotion experiment.

Emotion Experiment with Paper Samples				Emotion Experiment with Textile Samples			
Observer1	0.93	**Observer7**	0.80	**Observer1**	0.89	**Observer7**	0.76
Observer2	0.83	**Observer8**	0.79	**Observer2**	0.78	**Observer8**	0.79
Observer3	0.77	**Observer9**	0.86	**Observer3**	0.83	**Observer9**	0.84
Observer4	0.72	**Observer10**	0.78	**Observer4**	0.76	**Observer10**	0.71
Observer5	0.87	**Observer11**	0.74	**Observer5**	0.78	**Observer11**	0.75
Observer6	0.88	**Observer12**	0.79	**Observer6**	0.80	**Observer12**	0.78
Mean			0.81	**Mean**			0.79

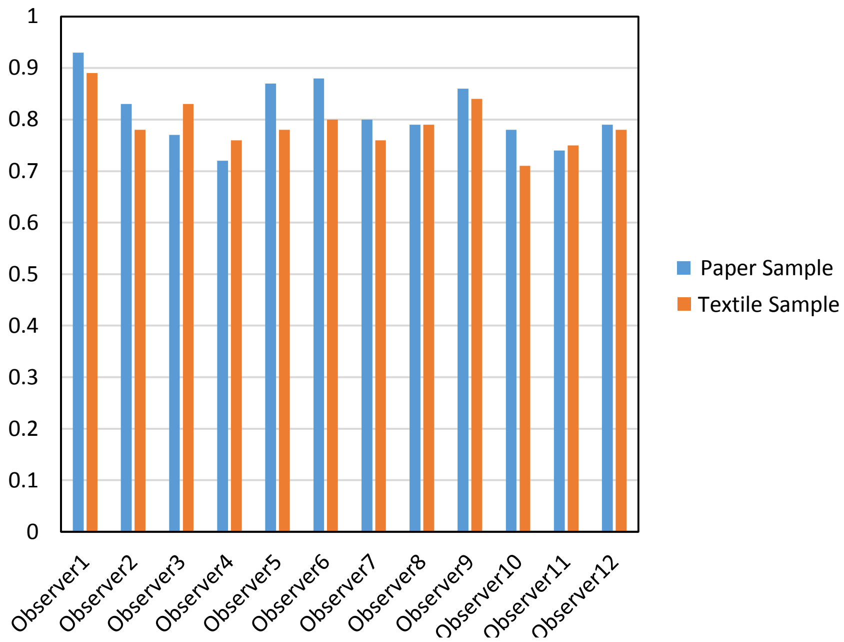


Figure 6.2 The total repeatability for each observer in experiment with paper samples and with textile samples.

Repeatability for each colour

Table 6.2 and Figure 6.3 show the repeatability for each colour in emotion experiment with paper samples and textile samples. Error bars are standard errors through the figures in the whole chapter.

Table 6.2 The repeatability for each colour in emotion experiments.

Emotion Experiment with Paper Samples				Emotion Experiment with Textile Samples			
Colour1	0.88	Colour11	0.78	Colour1	0.88	Colour11	0.69
Colour2	0.87	Colour12	0.81	Colour2	0.78	Colour12	0.82
Colour3	0.88	Colour13	0.81	Colour3	0.84	Colour13	0.73
Colour4	0.78	Colour14	0.93	Colour4	0.72	Colour14	0.84
Colour5	0.80	Colour15	0.88	Colour5	0.79	Colour15	0.86
Colour6	0.82	Colour16	0.81	Colour6	0.88	Colour16	0.83
Colour7	0.71	Colour17	0.70	Colour7	0.66	Colour17	0.72
Colour8	0.84	Colour18	0.78	Colour8	0.83	Colour18	0.78
Colour9	0.68	Colour19	0.86	Colour9	0.73	Colour19	0.88
Colour10	0.79	Colour20	0.90	Colour10	0.73	Colour20	0.88
Mean			0.81	**Mean**			0.79

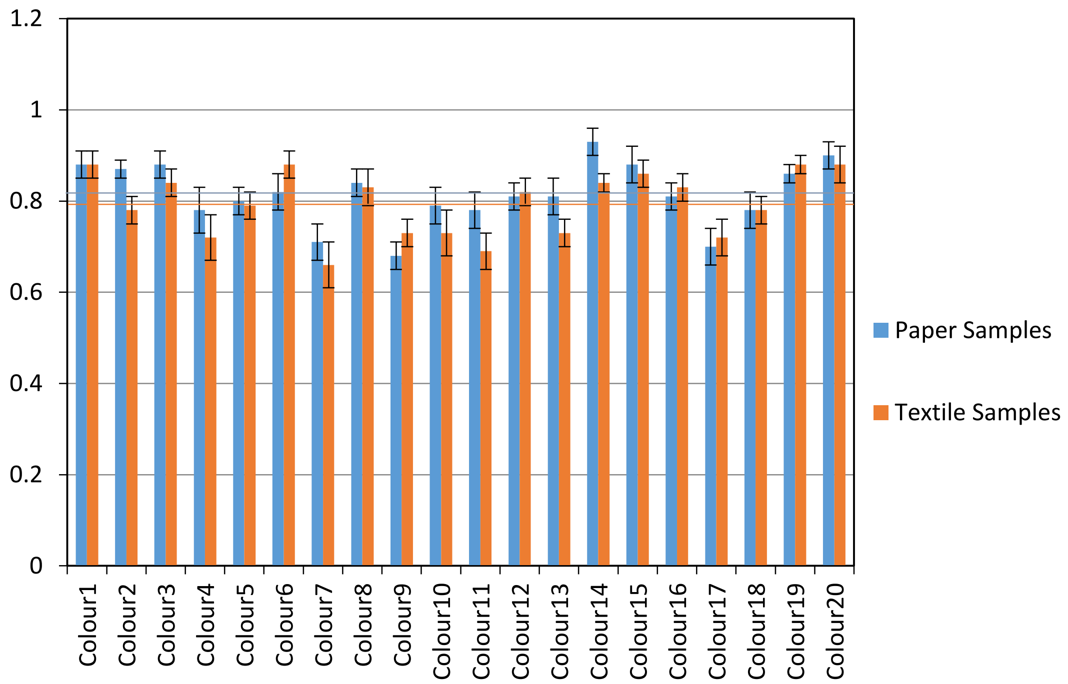


Figure 6.3 The repeatability for each colour in emotion experiment with paper samples and with textile samples.

From the data in table and figure, it can be seen that in general there is no clear pattern to show material could influence the repeatability of colour emotion. However when looking in detail some patterns can be found:

- With paper sample, colour with same hue tend to have similar repeatability (such as colour 2 – 5; colour 10 – 13), however with textile sample this appearance is weak.
- Only three colours with paper sample (colour 7, 9, and 17) have the repeatability below the average, but seven colours with textile sample

(colour4, 7, 9, 10, 11, 13 and 17) have the repeatability below the average.

Thus, texture might cause more variation in the experiment, which could influence on repeatability. In general, observers are more confidence in judging nature colours with low chroma. For example:

Colour1 of paper sample		Colour1 of textile sample	
Colour14 of paper sample		Colour14 of textile sample	
Colour20 of paper sample		Colour20 of textile sample	

Participants are less confidence in judging some boundary colours, which are difficult to name them. For example:

Colour7 of paper sample		Colour7 of textile sample	
Colour9 of paper sample		Colour9 of textile sample	
Colour11 of paper sample		Colour11 of textile sample	
Colour17 of paper sample		Colour17 of textile sample	

When looking at the correlation coefficient between repeatability of paper samples and the L*, C*, h value of 20 colours (shown in Table 6.3), L* and h has no correlation with the repeatability. The same for the repeatability of textile samples and the L*, C*, h value of 20 colours. The only factor which might correlated with the repeatability is the C* value of the colours. Furthermore there is a weak negative correlation between the repeatability and the C* value of the colour.

Table 6.3 The correlation Coefficient between repeatability of paper samples and the L*, C*, h value of 20 colours, and between repeatability of textile samples and the L*, C*, h value of 20 colours.

Correlation Coefficient	L*	C*	*h*
Between repeatability of paper sample	0.03	-0.43	0.23
Between repeatability of textile sample	0.14	-0.44	-0.02

In emotion experiment with paper samples, colour 9 has the lowest repeatability amount the 20 colours. In emotion experiment with textile samples, colour 7 has the lowest repeatability amount the 20 colours. Within the twelve observers who have done repeat experiments, there were ten female observers and two male observers; five experts and seven naïve; eleven Chinese and one Iranian. Therefore, a detail discussion between experts and naïve can be conducted owing to a relatively equivalent observer number. Table 6.4 shows each observer's repeatability of colour 9 with paper sample and each observer's repeatability of colour 7 with textile sample. There is no clear pattern to show that the expert group can perform better than the naïve group. Therefore, a trend could be drawn; the education background might has no influence on observer's repeatability.

Table 6.4 Each observer's repeatability of colour 9 with paper sample and colour 7 with textile sample.

Colour9 (with paper sample): shows each observer's repeatability								**Mean**
Expert	0.6	0.9	0.9	0.6	0.4			0.7
Naive	0.7	0.7	0.6	0.7	0.8	0.8	0.5	0.7
Colour7 (with textile sample): shows each observer's repeatability								**Mean**
Expert	1	0.4	1	0.6	0.7			0.7
Naive	0.4	0.6	0.7	0.8	0.7	0.4	0.5	0.6

Repeatability for each scale

Table 6.5 and Figure 6.4 show the repeatability for each scale in emotion experiment with paper samples and textile samples. From the table it can be notice that texture could influence observer's repeatability on some certain scales. For example, for Heavy-Light scale and Hard-Soft scale, observers were harder to give the same answer twice, which might owing to the texture influence. However, for Active-Passive scale and Tense-Relaxed scale, texture has no influence on observers' repeatability. Warm-Cool scale always has the highest repeatability for both paper and textile samples, on the contrary Modern-Classical scale has the lowest repeatability. Nevertheless, Figure 6.4 show that by adding the error bars, texture makes less significance error on repeat between scales. The relatively lower repeatability of Modern-Classical scale may because there is no universal meaning on understanding the terminology of this pair.

Table 6.5 The repeatability for each scale.

Emotion Experiment with Paper Samples				**Emotion Experiment with Textile Samples**			
CD	0.82	FM	0.86	CD	0.78	FM	0.81
FS	0.78	WC	0.90	FS	0.78	WC	0.86
LD	0.75	MC	0.73	LD	0.81	MC	0.74
HL	0.84	AP	0.80	HL	0.78	AP	0.80
HS	0.85	TR	0.78	HS	0.76	TR	0.78
Mean			0.81	Mean			0.79

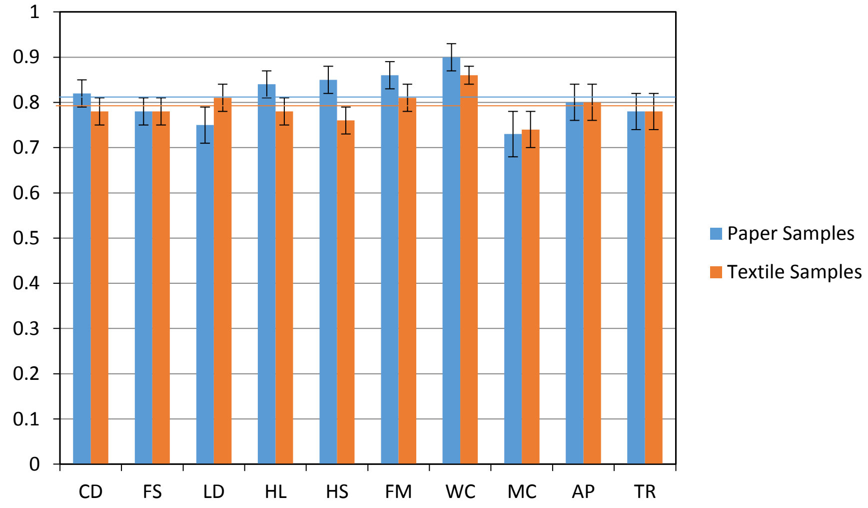


Figure 6.4 The repeatability for each scale in experiment with paper samples and with textile samples.

In conclusion, all observers, colours and scales have a relatively high repeatability. Owing to the limited repeat, it is not clear that texture could have a big influence on repeating colours' emotion. However, the data do show that texture cause more variations in observation.

6.2.2 Observer Consensus

Observer Consensus shows how well each observer agreed with majority decisions of the group. It is determined by the equation:

$$\boldsymbol{Consensus} = \frac{\sum_i(\mathbf{1}-\boldsymbol{w_i})}{\boldsymbol{N}} \qquad (7.\ 1)$$

where w_i is the percentage of incorrect decisions within an observer group concerned with the colour sample i,. An incorrect decision is the number of observers whose decision on colour emotion word is different from the majority of the group (majority is defined as the mean value), and N is the number of colour samples.

Consensus for each observer

Table 6.6 and Figure 6.5 show the consensus for each observer. From the table and figure, all observers have good agreement as the observer consensus values are all higher than 0.7. In general, the observer consensus of Emotion Experiment with Textile samples is lower than Emotion Experiment with Paper samples. This might indicates texture could involve more variations.

Table 6.6 Consensus for each observer.

Emotion Experiment with Paper Samples				**Emotion Experiment with Textile Samples**			
Observer1	0.77	Observer12	0.75	Observer1	0.72	Observer12	0.74
Observer2	0.85	Observer13	0.79	Observer2	0.79	Observer13	0.76
Observer3	0.76	Observer14	0.74	Observer3	0.84	Observer14	0.81
Observer4	0.72	Observer15	0.78	Observer4	0.71	Observer15	0.78
Observer5	0.84	Observer16	0.77	Observer5	0.74	Observer16	0.86
Observer6	0.81	Observer17	0.78	Observer6	0.86	Observer17	0.71
Observer7	0.80	Observer18	0.78	Observer7	0.79	Observer18	0.71
Observer8	0.86	Observer19	0.76	Observer8	0.71	Observer19	0.78
Observer9	0.70	Observer20	0.80	Observer9	0.80	Observer20	0.70
Observer10	0.79	Observer21	0.80	Observer10	0.82	Observer21	0.80
Observer11	0.74	**Mean**	**0.78**	Observer11	0.81	**Mean**	**0.77**

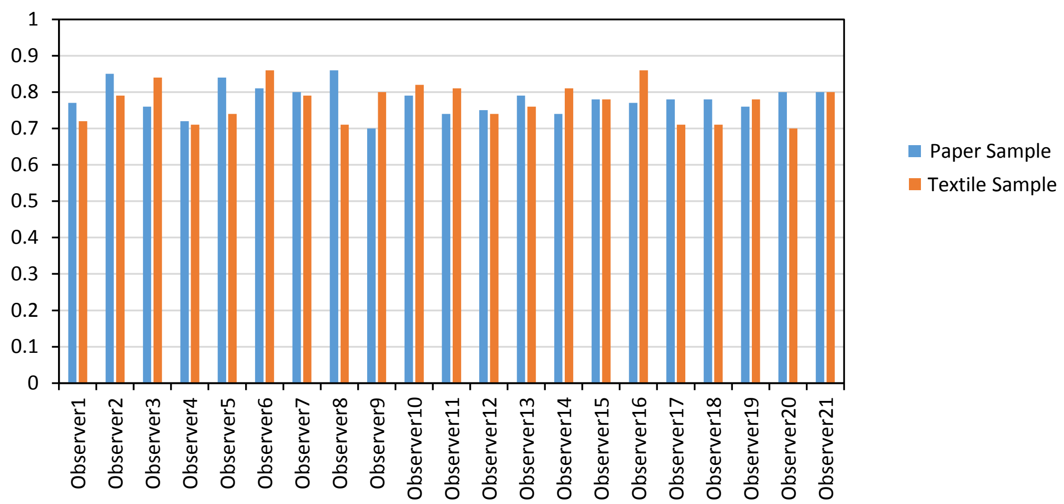


Figure 6.5 Consensus for each observer.

Observer consensus for each colour

Table 6.7 and Figure 6.6 show the observer consensus for each colour in the emotion experiment.

Table 6.7 Observer consensus for each colour.

Emotion Experiment with Paper Samples				**Emotion Experiment with Textile Samples**			
Colour1	0.76	Colour11	0.69	Colour1	0.90	Colour11	0.62
Colour2	0.91	Colour12	0.78	Colour2	0.81	Colour12	0.75
Colour3	0.85	Colour13	0.76	Colour3	0.85	Colour13	0.68
Colour4	0.68	Colour14	0.80	Colour4	0.70	Colour14	0.79
Colour5	0.78	Colour15	0.86	Colour5	0.76	Colour15	0.83
Colour6	0.83	Colour16	0.79	Colour6	0.81	Colour16	0.83
Colour7	0.72	Colour17	0.68	Colour7	0.77	Colour17	0.68
Colour8	0.77	Colour18	0.78	Colour8	0.77	Colour18	0.73
Colour9	0.74	Colour19	0.81	Colour9	0.73	Colour19	0.80
Colour10	0.77	Colour20	0.87	Colour10	0.83	Colour20	0.79
Mean			0.78	Mean			0.77

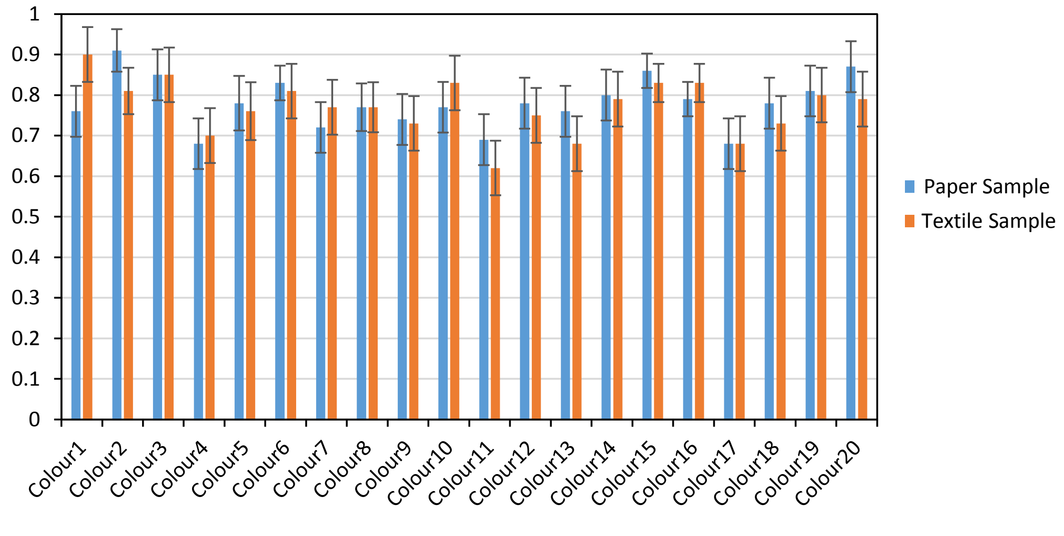
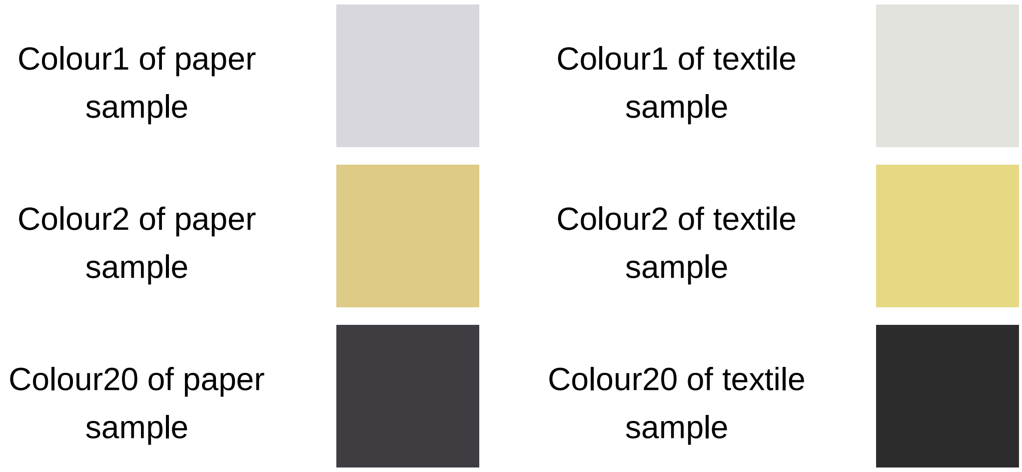


Figure 6.6 Observer Consensus for each colour.

From the table and figure, no strong pattern on how texture influence the observer consensus on each colour can be found. However, a trend can be recognised that texture involves in more variants, also it might influence on colours that have high and low in lightness. For example, Colour 1, Colour2 and Colour 20, their observer consensus change a lot between the experiment with paper sample and textile sample.



Again, participants are less confidence in judging boundary colour's emotion, such as Colour4, 11 and 17.

Furthermore, the Pearson Correlation between observer consensus of paper samples and the L*, C*, and h value of 20 colours; the Pearson Correlation between observer consensus of textile samples and the L*, C*, and h value of 20 colours are shown in Table 6.8. It can be seen that lightness influences more on correlation between observer consensuses of textile samples than paper samples. This can explain the fact that texture arouses the lightness difference, which influence more on observer consensus.

Table 6.8 The Pearson Correlation between observer consensus of paper samples and the L*, C*, h value of 20 colours, and between observer consensus of textile samples and the L*, C*, h value of 20 colours.

	L*	C*	H
Observer consensus of paper sample	0.24	-0.23	-0.21
Observer consensus of textile sample	0.50	-0.20	-0.27

Observer consensus for each scale

Table 6.9 and Figure 6.7 show the observer consensus for each scale in the two experiments using paper samples and textile samples.

Table 6.9 Observer Consensus for each scale.

Emotion Experiment with Paper Samples				**Emotion Experiment with Textile Samples**			
CD	0.80	FM	0.85	CD	0.80	FM	0.80
FS	0.78	CW	0.85	FS	0.80	CW	0.81
LD	0.75	CM	0.66	LD	0.71	CM	0.69
HL	0.84	AP	0.75	HL	0.84	AP	0.72
HS	0.80	TR	0.74	HS	0.81	TR	0.73
Mean			0.8	Mean			0.8

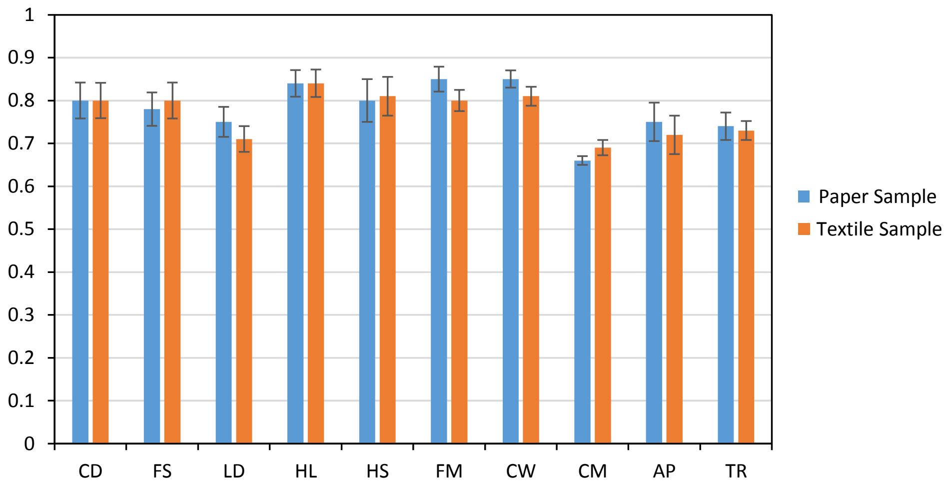


Figure 6.7 Observer Consensus for each scale.

Corresponding with repeatability for each scale, Modern-Classical scale still has the lowest consensus; Warm-Cool scale has relatively high observer consensus. However, there is no pattern indicating that texture can affect observer consensus for each scale.

In conclusion, observer consensus for each observer, each colour and each scale are all relatively high (as all above 0.7). This indicates the data collected from the experiments are accurate. Although results indicate that texture can cause more fluctuation, there is no strong pattern to show texture could influence on all the observers, colours and scales. The high repeatability and observer consensus of the data shows the data collected are reliable and repeatable.

6.3 Evaluation of Colour Emotion Model for Single Colour

The four models built by Ou are:

Warm - Cool

$$\boldsymbol{WC = -0.5 + 0.02(C^*)^{1.07}\cos(h - 50°)} \quad \boldsymbol{R^2 = 0.74} \qquad (7.\ 2)$$

Heavy - Light

$$\boldsymbol{HL = -2.1 + 0.05(100 - L^*)} \quad \boldsymbol{R^2 = 0.76} \qquad (7.\ 3)$$

Active - Passive

$$\boldsymbol{AP = -1.1 + 0.03[(C^*)^2 + (L^* - 50)^2]^{\frac{1}{2}}} \quad \boldsymbol{R^2 = 0.75} \qquad (7.\ 4)$$

Hard - Soft

$$\boldsymbol{HS = 11.1 + 0.03(100 - L^*) - 11.4(C^*)^{0.02}} \quad \boldsymbol{R^2 = 0.73} \qquad (7.\ 5)$$

The different R^2 here are coefficient determinations, which indicate a fairly high fitting exists in each model.

The experimental data are then transferred into probability values of 0 or 1. For instance, for each word pair: Warm:0 and Cool:1; heavy:0 and light:1;

active:0 and passive:1; hard:0 and soft:1. Subsequently, all the probability values are calculated as z-scores by using the Torgerson's Law of Categorical Judgement (Condition D):

$$\boldsymbol{z_{ij}} = \sqrt{(\boldsymbol{n}-\mathbf{1})\boldsymbol{N}}\left(\boldsymbol{B_i} - \boldsymbol{x_j}\right) \tag{7. 6}$$

where n is the number of stimuli and N is the number of observations (Ou, 2004). The z score values for the four word pairs with paper samples: Warm-Cool, Heavy-Light, Active-Passive, and Hard-Soft (called "experimental value" in the later section) are summarised in Table 6.10. The scale value calculated from Ou's WC, HL AP and HS equations with paper samples (called "model value" in later section) are summarised in Table 6.11. The experimental value with textile samples are summarised in Table 6.12, the model value with textile samples are summarised in Table 6.13.

Table 6.10 The z - score for the four emotion scales, calculated from experimental data (experimental value-paper sample).

Colour	***WC***	***HL***	***AP***	***HS***
Colour 1	-1.07	-1.31	0.06	-0.43
Colour 2	0.88	-2.41	0.88	-1.67
Colour 3	1.67	-1.67	0.88	-2.41
Colour 4	1.67	-0.57	0.30	-0.88
Colour 5	0.71	0.57	-2.41	0.06
Colour 6	0.88	-2.41	0.30	-2.41
Colour 7	1.07	-0.71	0.57	-1.67
Colour 8	1.67	0.88	1.07	0.71
Colour 9	1.67	0.71	2.42	0.30
Colour 10	-0.88	-1.07	0.30	-0.06
Colour 11	-1.67	0.43	-0.43	0.43
Colour 12	-1.31	0.88	-0.57	1.31
Colour 13	-1.31	1.07	-0.43	1.07
Colour 14	-0.88	1.67	-1.07	1.07
Colour 15	-1.31	-2.41	0.18	-1.67
Colour 16	-1.07	-1.07	0.43	-0.71
Colour 17	-1.31	0.06	0.18	0.30
Colour 18	-1.07	1.31	-0.57	0.88
Colour 19	-0.18	1.07	-1.67	0.71
Colour 20	-0.57	2.41	-1.67	2.41

Table 6.11 The scale value from Ou's models (model value-paper sample).

Colour	*WC*	*HL*	*AP*	*HS*
Colour 1	*-0.53*	*-1.38*	*1.47*	*-0.12*
Colour 2	0.22	-1.19	1.59	-0.61
Colour 3	0.56	-0.90	1.57	-0.49
Colour 4	0.49	-0.47	1.25	-0.20
Colour 5	0.13	0.23	0.67	0.34
Colour 6	-0.01	-0.82	1.23	-0.25
Colour 7	0.29	0.00	0.91	0.13
Colour 8	0.88	0.71	1.01	0.44
Colour 9	0.47	0.72	0.72	0.50
Colour 10	-1.28	0.41	0.66	0.40
Colour 11	-0.94	0.74	0.40	0.64
Colour 12	-1.17	0.87	0.48	0.65
Colour 13	-1.03	1.01	0.35	0.76
Colour 14	-0.71	1.45	-0.14	1.23
Colour 15	-0.53	-0.58	-1.07	-0.10
Colour 16	-0.90	-0.13	1.00	0.04
Colour 17	-1.09	0.38	0.65	0.39
Colour 18	-0.58	1.13	0.11	0.94
Colour 19	-0.21	0.58	0.39	0.63
Colour 20	-0.47	1.59	-0.31	1.65

Table 6.12 The z score value for the ten emotion scales, calculated from experimental data (experimental value-textile sample).

Colour	*WC*	*HL*	*AP*	*HS*
Colour 1	-2.41	-2.40	-0.30	-1.31
Colour 2	0.43	-2.40	0.57	-1.31
Colour 3	0.88	-1.67	0.71	-1.31
Colour 4	0.88	-0.88	0.30	-1.67
Colour 5	1.07	0.30	-1.31	0.30
Colour 6	0.57	-2.40	0.30	-2.40
Colour 7	1.31	-1.31	0.18	-1.67
Colour 8	1.07	0.57	1.67	0.88
Colour 9	1.67	0.71	1.07	0.57
Colour 10	-1.07	-0.57	0.71	0.06
Colour 11	-0.88	0.06	-0.30	0.18
Colour 12	-1.31	0.43	0.18	1.07
Colour 13	-0.71	0.88	-0.18	0.43
Colour 14	-0.88	1.67	-1.31	1.31
Colour 15	-1.07	-1.67	0.30	-1.67
Colour 16	-1.31	-1.67	0.88	-0.88
Colour 17	-1.07	-0.06	0.06	0.43
Colour 18	-0.43	2.41	-0.57	1.07
Colour 19	-0.18	1.31	-1.67	0.88
Colour 20	-0.43	1.67	-0.88	1.31

Table 6.13 The scale value from Ou's models (model value-textile sample).

Colour	*WC*	*HL*	*AP*	*HS*
Colour 1	-0.50	-1.58	0.09	-0.27
Colour 2	0.62	-1.40	0.59	-0.77
Colour 3	-1.04	-1.03	0.68	-0.59
Colour 4	-0.24	-0.53	0.37	-0.26
Colour 5	0.22	0.24	-0.22	0.31
Colour 6	-0.32	-0.95	-0.01	-0.36
Colour 7	0.38	-0.06	0.06	0.07
Colour 8	-2.03	0.58	0.68	0.34
Colour 9	-0.33	0.68	0.31	0.46
Colour 10	-1.09	0.52	-0.10	0.45
Colour 11	-0.41	0.91	-0.20	0.72
Colour 12	-1.00	1.09	0.07	0.76
Colour 13	-1.35	1.33	0.04	0.93
Colour 14	-0.31	1.83	-0.14	1.43
Colour 15	-0.37	-0.57	-0.14	-0.14
Colour 16	0.36	-0.07	0.18	0.04
Colour 17	-1.30	0.48	-0.05	0.41
Colour 18	-0.02	1.32	-0.25	1.03
Colour 19	-0.29	0.69	-0.39	0.64
Colour 20	-0.51	2.02	-0.13	2.05

Table 6.14 shows the correlation for each experimental value with paper and with textile. From the table it can be seen that the experimental value for both paper samples and textile samples are correlated well (WC, HL, HS models are all above 0.9). AP (Active-Passive) model correlated poorer than other three models shows the Active-Passive model might be influenced with the texture.

Table 6.14 The correlation between experimental value for both paper sample and textile sample.

Model	**HL**	**HS**	**WC**	**AP**
Correlations	0.88	0.86	0.81	0.77

Table 6.15 shows the coefficient determination (R^2 value) of experimental value and model value collected from the emotion experiment with paper sample. From the R^2 value it can be seen that WC, HL, and HS models are all

having higher correlations than Ou's (0.81 against 0.81; 0.88 against 0.83; 0.86 against 0.83) which means the data from the experiment are more suitable to use these three models than Ou's original data. However, AP model has a very small correlation indicates that Ou's AP model has its limitations, the colours used in this experiment cannot use Ou's AP model to describe.

Table 6.15 The correlation of experimental value and model value collected from the emotion experiment (with paper sample).

Model	**HL**	**HS**	**WC**	**AP**
Correlations	0.83	0.83	0.88	0.18

Table 6.16 shows the correlation of experimental data and model data from the emotion experiment with textile samples. Again, the WC, HL and HS model are all proved the repeatability of Ou's models (0.90 against 0.72; 0.94 against 0.85; 93 against 0.71), AP model still has a low correlation that further shows Ou's AP model has a poorer adaption for the colour used in this experiment.

Table 6.16 The coefficient determination of experimental value and model value collected from the emotion experiment (with textile sample).

Model	**HL**	**HS**	**WC**	**AP**
Correlations	0.85	0.71	0.72	0.58

In conclusion, three out of four colour emotion models have been tested to have a good function. They are WC (Warm-Cool), HL (Heavy-Light) and HS (Hard-Soft) models. AP (Active-Passive) model can be improved to fit a wider range of colours. In addition, texture might have influence on AP (Active-Passive) model as experimental value and model value correlated better with textile samples than paper samples.

6.4 Factor Analysis

Ou's colour principal component matrix for single-colour emotion is shown as:

Component 1: Active-Passive, Fresh-Stale, Clean-Dirty, Modern Classical;

Component 2: Hard-Soft, Masculine-Feminine, Heavy-Light;

Component 3: Warm-Cool

6.4.1 Factor Analysis for Paper Samples

The components have been extracted from the experimental data for paper samples for 89% of the total variance. They are summarised as component 1, 2, and 3 shown in Table 6.17. Figure 6.8 summarises the three-dimensional colour emotion spaces for paper sample (for component 1 and 2; component 1 and 3). The two figures clearly explain that Component 1 is determined by lightness of the colour (the boundary could be L^*=50); Component 2 is broadly influenced by the hue angle of the colour (grouped by roughly "0° – 99°" and "100° – 360°"); and Component 3 is determined by the combine of lightness, chroma and hue angle. Compared with Ou's components, there is a similar grouping between Ou's components and the components extracted from this experiment with paper samples.

Table 6.17 Factor matrix of colour emotions for paper samples.

	Component		
	1	2	3
Tense-Relaxed	0.96	-0.14	0.18
Heavy-Light	0.82	-0.39	-0.38
Hard-Soft	0.71	-0.25	-0.63
Masculine-Feminine	0.40	-0.41	-0.78
Active-Passive	0.02	0.88	0.42
Fresh-Stale	-0.34	0.87	0.06
Clean-Dirty	-0.61	0.75	0.04
Modern-Classical	-0.47	0.67	0.26
Like-Dislike	-0.62	0.50	0.00
Warm-Cool	0.19	0.05	0.93

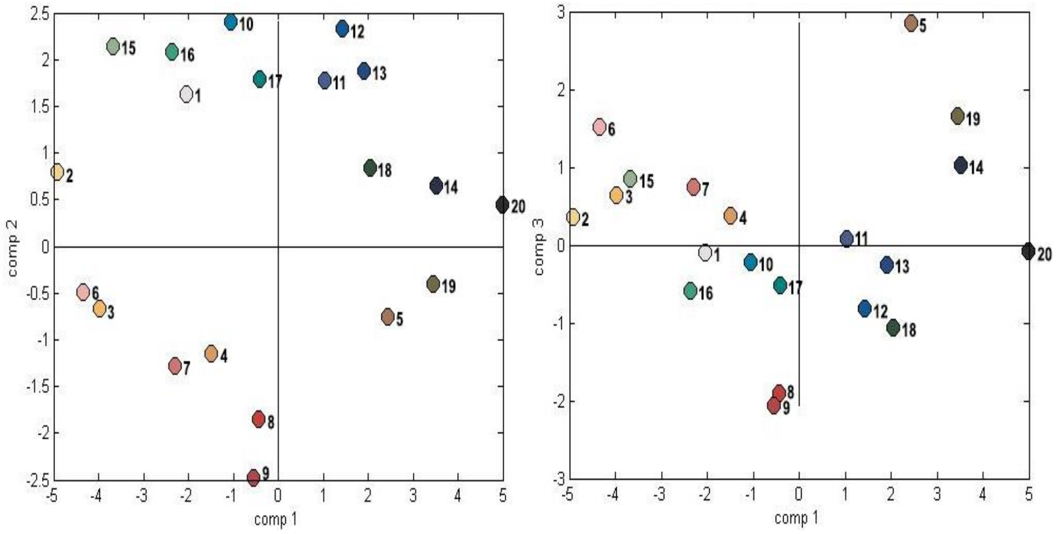


Figure 6.8 The three-dimensional colour emotion spaces for paper samples.

6.4.2 Factor Analysis for Textile Samples

From 87% of the total variance of experimental data with textile sample, three components have been extracted. Table 6.18 summarises them as component 1, 2, and 3. The similar groups of components existing when compared with Ou’s components.

Figure 6.9 illustrates the three-dimensional colour emotion spaces for textile samples (for component 1 and 2; component 1 and 3). The two figures clearly explain that the components extract from the textile samples have similar characteristics as paper samples. Component 1 is strongly related to lightness of the colour (the boundary could be L^*=47); Component 2 is broadly influenced by the hue angle of the colour (grouped by roughly “0° – 99°” and “100° – 360°”); and Component 3 is influenced by the combine of lightness, chroma and hue angle of the colour.

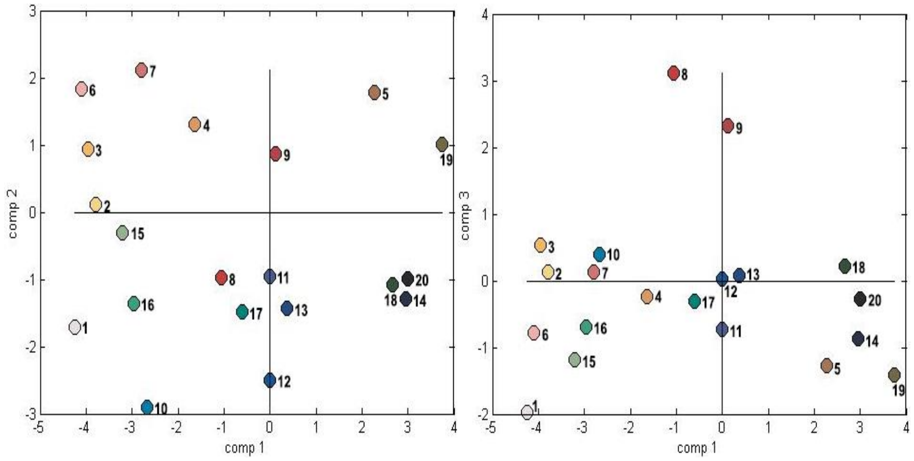


Figure 6.9 The three-dimensional colour emotion spaces for textile samples.

Table 6.18 Factor matrix of colour emotions for textile samples.

	Component		
	1	2	3
Active-Passive	0.94	-0.14	0.28
Fresh-Stale	0.93	-0.22	-0.17
Clean-Dirty	0.80	-0.39	-0.31
Modern-Classic	0.64	-0.30	-0.04
Like-Dislike	0.60	-0.30	-0.51
Hard-Soft	-0.22	0.96	-0.06
Heavy-Light	-0.40	0.88	0.12
Masculine-Feminine	-0.32	0.83	-0.36
Tense-Relaxed	-0.21	0.76	0.54
Warm-Cool	-0.02	-0.13	0.95

Factor analysis is used to examine if this research could extract the same components as Ou. The result shows the similar ranges of components compared with Ou's from both paper samples and textile samples. In general, data collected from the emotion experiment can reflect Ou's colour emotion models well. His model can be used in the next stage of comparison with impulsivity and arousal. Ou's three models extracted from factor analysis are:

$$Colour\ Activity = -2.1 + 0.06[(L^* - 50)^2 + (a^* - 3)^2 + (\frac{b^* - 17}{1.4})^2]^{\frac{1}{2}} \qquad (7.\ 7)$$

$$Colour\ Weight = -1.8 + 0.04(100 - L^*) + 0.45cos(h - 100°) \quad (7.\ 8)$$

$$Colour\ Heat = -0.5 + 0.02(C^*)^{1.07}cos(h - 50°) \quad (7.\ 9)$$

6.5 Colour Influence on Impulsivity, Arousal and Emotions

In this section, in order to reflect the relationship between colour influence on impulsivity, arousal and emotions clearly, sixteen tested colours used in hue experiment and chroma experiment are calculated into emotion values and ranked accordingly.

6.5.1 Hue Influence on Impulsivity, Arousal and Emotions

Three models as colour activity, colour weight and colour heat are determined by factors as L*, a*, b*, h and C*. Six hues used in hue experiment are calculated into emotion values according to the three models.

The colour emotion metric for six hues in three emotion models are summarised in Table 6.19. The orders of colour influence on impulsivity and arousal are introduced in Chapter 4. The comparison and discussion among colour activity, colour weight, colour heat, impulsivity and arousal are discussed by hue only in this section.

Table 6.19 Six hues' emotion values.

	Colour Heat	**Colour Weight**	**Colour Activity**
Yellow	0.76	-0.18	1.67
Purple	-0.47	-0.86	0.57
Blue	-1.49	-0.94	1.45
Red	1.27	-0.40	1.66
Green	-1.60	-0.41	0.62
Orange	1.21	-0.27	1.99

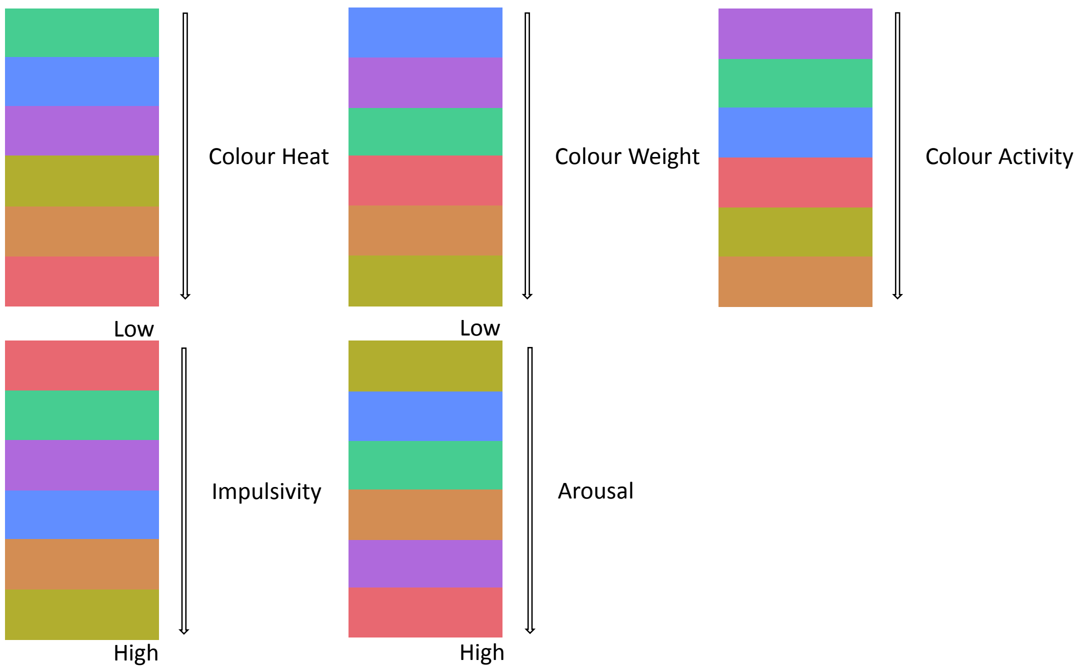


Figure 6.10 The order of six hues in three colour emotion models, impulsivity and arousal.

The rank order of hue influence on three emotions, impulsivity and arousal are summarised in Figure 6.10. From the figure it can be seen that, the emotion status of six hues are partly consistent. The colours as green, blue and purple are colours low in heat, weight and activity. Yellow, orange and red are colours high in heat, weight and activity. The influence of hue on emotion is not consisted with colour influence on impulsivity and arousal. High colour heat, weight and activity colours are mainly at the two ends of impulsivity order. Colours with low heat, weight and activity colours are in the middle of impulsivity order. This happens similarly with arousal order. Consequently, it might can be summarised as that high heat, weight and active colours are more dynamic than low heat, weight and active colours that influence people to have an extreme performance either high/low in impulsivity or arousal.

6.5.2 Chroma Influence on Impulsivity, Arousal and Emotions

Three emotion models as Colour Heat, Colour Weight and Colour Activity are discussed in this section according to the chroma influence on emotions, impulsivity and arousal. The emotion values of thirteen colours used in the Chroma Experiment are summarised in Table 6.20. The influence of chroma on impulsivity, arousal and emotions are shown in Figure 6.11.

Table 6.20 Thirteen colours' emotion values.

	Colour Heat	**Colour Weight**	**Colour Activity**
Yellow 100%	0.76	-0.19	0.63
Yellow 75%	0.41	-0.11	-0.09
Yellow 50%	0.10	-0.11	-0.60
Yellow 25%	-0.22	-0.11	-0.92
Orange 100%	1.21	-0.26	0.57
Orange 75%	0.75	-0.34	-0.01
Orange 50%	0.36	-0.22	-0.58
Orange 25%	-0.08	-0.17	-0.94
Red 100%	1.29	-0.42	1.46
Red 75%	0.86	-0.47	0.80
Red 50%	0.31	-0.49	-0.13
Red 25%	-0.18	-0.51	-0.63
Reference White	-0.50	-0.45	-0.69

In general, with chroma increase, colours are more warm and active. Yellow is the colour with the highest weight value among the three hues. Red is the colour lightest in weight; and when chroma increase, the red are heavier. Chroma influence on impulsivity and arousal are less significant than emotions. People respond with low impulsivity status with the highest chroma level, which are warmer, more active and light in weight. People perform with high impulsivity status when colours are in the middle chroma level that cooler and less active. People are less arousal with middle chroma level, which are cooler, heavier and less active. On the other hand, people are more arousal with high chroma level that warmer, more active and lighter in weight in general.

Figure 6.11 The order of thirteen chroma in three colour emotion models, impulsivity and arousal.

6.6 Summary

In this chapter, colour influence on emotion was evaluated by using samples in two different materials. They were printed on cardboard and textile fabrics. Ou's colour emotion model for single colours was verified. Meanwhile, the texture influence on colour emotion was explored. Colour influence on emotion, impulsivity and arousal was discussed. From the discussion in this chapter, some results can be summarised:

1) There is no clear pattern to show that texture can influence colour

emotion.

2) Three components can be extracted from the 10 emotions, tense-relax, heavy-light, hard-soft and masculine-feminine are grouped into the first component for paper sample and the second component for textile sample. Active-passive, fresh-stale, clean-dirty, modern-classical and like-dislike are grouped into the second component for paper sample and the first component for textile sample. Warm-cool is the single emotion that grouped into the third component.
3) Ou’s colour emotion models are generally consistent with the data collected from the emotion experiment.
4) Cool colours are lighter in weight and less active; they are also less impulsive and less arousal. On the contrary, warm colours are heavier and more active. Meanwhile people perform more impulsive and high in arousal for most of the warm colours.
5) Chroma influence on emotion, impulsivity and arousal are more complicated, and it is difficult to draw a consistent conclusion.
6) Low chroma levels are generally cooler, lighter in weight and less active. People also performed in middle level of impulsivity and arousal with low chroma levels. High chroma levels are warmer, heavier and more active than low chroma levels. People performed more dramatic with high chroma levels. High chroma orange and red are low in impulsivity, high chroma yellow are high in impulsivity. High chroma orange and red are high in arousal.

Chapter 7 Conclusions

The aim of this research is to explore the impact of colour on impulsivity and arousal, and its relationship with colour emotion. Response time and error rate are two indicators can be used to measure impulsivity and arousal. To achieve this aim, three experiments were carried out in this research.

The hue experiment used game-related psychophysical experiments to explore the hue and chroma influence on impulsivity and arousal. The experiment involves participants playing games. The game containing psychometric test types related to logical ability, spatial structure ability and detail ability. In the hue experiment (hue experiment), six tests (Logical Rule Test, Mathematics Sequence Test, Rotation Test, Spatial Structure Test, Detail Test and Odd One Out Test) were used as stimuli to measure a participant's response time and error rate. Six hues plus reference white were used as backgrounds, on which participants solved the six types of tests.

In the chroma experiment, four types of psychometric tests were used: Logical Rule Test, Mathematics Sequence Test, Rotation Test and Spatial Structure Test. Red, orange and yellow backgrounds in four levels of chroma (100%, 75%, 50% and 25%) were produced. In total thirteen chroma backgrounds (including reference white) were used in the chroma experiment. As in the hue experiment, participants were required to conduct each psychometric tests against thirteen background colours shown on a TV screen.

In the emotion experiment, participants were asked to report their emotional responses to 20 colours both on paper cardboard and textile fabric. Ten scales used were: tense-relaxed, heavy-light, hard-soft, masculine-feminine, active-passive, fresh-stale, clean-dirty, modern-classical, like-dislike and warm-cool.

The findings of three experiments can be summarised as follow.

7.1 Summary of Major Findings and Contributions

7.1.1 Colour Influence on Response Time

- The six test hues in this study can be divided into two groups according to the influence of hue on response time. Yellow, blue and green can be combined into one group as they all can influence people to respond slower. Purple, red and orange are in the group that influence people to react quicker. Middle chroma levels – 50% and 75% – can influence people to think more slowly than low and high chroma levels.
- Hue and chroma have a different influence on response time across different types of psychometric tests. Yellow and blue cause participants to take the longest time to solve the Logical Ability Test. For green and orange, participants responded the quickest when solving the Logical Ability Test. Red/orange and yellow/purple cause participants had the shortest response time for the rotation test and spatial structure test. Participants performed the quickest on the 0% chroma level while the slowest on the 75% and 50% chroma levels.
- Gender difference for hue influence is not significant, however females tended to be quicker to react than males. The chroma influence is also similar in gender, although there is a weak trend that females tended to responded slower than males.
- There is also some indication showing that colour preference might influence on response time.

7.1.2 Colour Influence on Error Rate

- The error rate for yellow and blue is the highest, while red is associated with the lowest error rate. Participants made the fewest errors on the 100% chroma level.
- The influence of hue and chroma on error rate is different across different types of psychometric tests. For the Mathematics Sequence Test, Logical Rule Test and the Rotation Test, yellow and blue produced

the highest error rate. Yellow lead participants to make the most of errors for the Odd One Out Test. Orange lead the most of errors for the Spatial Structure Test.

- Female participants tend to make more mistakes than male participants, either with different hues or with different chroma levels.
- There is no obvious correlation between colour preference and error rate.

7.1.3 Colour Influence on Impulsivity and Arousal

- Hue has a greater influence on arousal than impulsivity. Participants have the lowest impulsivity for red, and the impulsivity status is the highest for yellow. Reddish colours such as purple, red and orange can influence people to be more aroused; while yellow, blue and green result in less arousal than the reddish colours.
- Chroma has a greater influence on impulsivity than arousal. The chroma influence is more complicated than the hue influence on impulsivity and arousal. Although there is no correlation between chroma and arousal, however, a clear trend of red and orange chroma level change on impulsivity can be seen.
- The influence of hue and chroma on impulsivity and arousal are different across test types. Purple and red lead to the highest arousal in most of the psychometric tests. Hue influence on impulsivity is more complicated, and depends on test types. For the Logical Rule Test, low chroma colours and high chroma colours are normally plotted in the high arousal (HA) and high impulsivity (HI) quadrants, colours in middle chroma are more in the low impulsivity (LI) and low arousal (LA) quadrants. Most colours influence except for 100% yellow, 100% red, 75% red and 25% red. On the other hand, most colours made participants react with more errors than average on the Rotation Test, only 100% chroma level and 50% red could influence people to perform with a low error rate. HI and LA are normally found in high and middle chroma levels that influence people to respond with more errors on the Spatial Structure Test, while HA and LI are found mostly in in low

chroma levels.

- Hue can influence female's impulsivity, whereas it is not seen for males. However, there is no difference in chroma influence on impulsivity due to gender.

7.1.4 Colour Emotion versus Impulsivity and Arousal

- Cool colours are lighter in weight and can make people feel more passive than warm colours. The difference of impulsivity is more marked with warm colours. Generally, warm colours are more impulsive and arousing than cool colours.
- With chroma increase, colours are tend to be warmer and active. Red is the hue that is lighter in weight than the orange than the yellow. People are in the middle level of impulsivity and arousal with low chroma levels. High chroma orange and red are relatively low in impulsivity and arousal, high chroma yellow is high in impulsivity.

7.2 Limitations and Recommendations

In this study, owing to the limited study period, only six hues and three hues with five different chroma levels were explored. There are still some uncertainties concerning colour influence on impulsivity according the experiment data collected from this experiment. For example, the influence of hue on impulsivity is not distinct; the chroma influence on arousal is not clear; the influence of colour on the three colour emotion models studied in this research is not correlated well with colour influence on impulsivity and arousal. Hence, these problems are suggested to study further. In future studies, more hues and chroma levels can be explored to clearly establish colour impact on impulsivity. The influence of colour preference on impulsivity and arousal should be investigated in the future, especially how chroma preference impacts on impulsivity and arousal. Zentall *et al*. (1985) found that when doing the MFFT, compared with the black and white tests, children performed with significant lower impulsivity status with colourful tests. In this study, high chroma of red and orange lead to a low impulsivity status. In the future, it would be worth investigating if the colour combinations contain colours having different colour contrast sensitivities influenced on impulsivity.

The nationality of participants were all Chinese. Therefore, culture impact may affect this study, especially in colour emotion section. The age of participants was between 20 and 38; the finding might not be applicable for children and the elderly. The culture impact and age impact can be also explored in the future.

During the experiment, participants were all solve tests on a reference white background, followed by a random sequence of other colour backgrounds. It is difficult to compare results on a reference white background with other hues. In the future research, together with reference white, all colours can be randomly ordered during the experiment, in order to compare the colourful colours with grey scale colours.

The speed-accuracy trade-off cannot be found in this study, as in this study, participants were asked to response to the test as quickly as possible. In the future, more experiments can be designed to control participant’s accuracy, other than speed, in order to find out the trade-off between speed and accuracy.

Meanwhile, other research methods can be involved in this topic to explore the biophysical expression of impulsivity and arousal. These physiological research methods include measuring EEG, eye tracking, blood pressure and heart rate.

7.3 The Impact of Colour on Impulsivity, Arousal and Emotion in Contemporary Design Practice

From the findings in this study, some suggestions can be proposed to guide designers in their use of colour. A more explicit commentary of how the findings can be used to specific design practices are summarised in four parts as Fashion and Textile Design, Environment Design, Graphic Design and Design Marketing.

Fashion and Textile Design

From previous research (Strauss and LeiBing, 2008), red uniform can arousal people with a better performance. According to the findings from this study, apart from red, all chromatic reddish colours, such as red, orange and purple can improve people's performance. These are all preferred colours for sportswear or functional uniform design, which aims to affect people's bodily behaviour. High chroma yellow is the least arousing colour and influences people to perform slower with more mistakes, which seems to be the colour that designers should avoid in sportswear design. If yellow is really needed, medium chroma yellowish-green colours are more effective improving.

Environment Design

McKean (2014) reported that in Tokyo, blue lights in train stations are claimed to influence people to be less impulsive and to reduce the suicide rate in that location. However, to the author's knowledge, there is no theoretical evidence and basis can support this. From the results in this study, the hue influence on impulsivity is not obvious. All colours having a high chroma level (75% - 100%) can influence people to be less impulsive. From the results in this study, green and blue are the relatively “safe” colours that have little influence on arousal and impulsivity. They can be used in interior design, such as offices or hospitals, where people need to stay calm. For example the “green room” in the theatre (initially painted all walls of that room in green) was first designed for actors to reduce anxiety and nervous.

Graphic Design

In graphic design, colours have various functions that can influence people differently. For example, as colour of warning or remaining signs need to be obvious, and people need to response quick when they see the sign, therefore from the findings in this study, high chromatic red and yellow are colours that more suitable when designing the colour of signs. Another example is located in web design. Apart from aesthetically function, when designers designing the website elements, the mission of colours can be attracting people’s attention. High chroma yellow can influence people to a high level of impulsivity compared with other hues, reddish colours as orange, red and purple can arouse people’s performance. They are all recommended colours in web design to attract people’s attention.

Design Marketing

In the marketing area, choosing the correct colours can make a positive effect on people’s purchasing. For example, in product labelling and packaging design, because yellow is the colour can influence people to be the most impulsive, therefore it might be a suggested colour in the market to encourage people making an impulsive purchase. On the contrary, colourful red and yellowish-green are not recommended, as they can influence people to be less impulsive, and think twice before purchasing. In the marketing of fast food restaurant, every design elements need to work together and try their best to influence people to purchase in a fast speed. From this study, reddish colours and yellow are high recommend in the fast food markets, as they all can influence people with a quick response. On the other hand, greenish and bluish colours are more likely to be used in the expensive food restaurant, which can influence people to stay calm and enjoy their meals.

List of References

Adams, F. M. and Osgood, C. E., 1973. A cross-cultural study of the affective meaning of color. *Journal of Cross-Cultural Psychology*, 4, pp. 135-156.

AL-Ayash, A., Kane, R. T., Smith, D. and Green-Armytage, P., 2015. The influence of color on student emotion, heart rate, and performance in learning environments. *Color Research and Application*, 41 (2), pp. 196-205.

Andrea, G. K. , 2005. Arousal and consumer in-store behaviour. *Brain Research Bulletin*, 67, pp. 428-437.

Arizmendi, T., Paulsen, K. and Domino, G., 1981. The Matching Familiar Figures Test: a primary, secondary, and tertiary evaluation. *Journal of Clinical Psychology*, 37 (4), pp. 812-818.

Arnold, M. B., 1970*. Feelings and Emotions: the Loyola Symposium*. New York: Academic Press.

Ault, R. L., Mitchell, C. and Hartmann, D. P., 1976. Some Methodological Problems in Reflection-Impulsivity Research. *Child Development*, 47 (1), pp. 227-231.

Bakker, I., Voordt, T, J. M. van der., Boon, J. de, and Vink, P., 2014. Pleasure, Arousal, Dominance: Mehrabian and Russell revisited. *Current Psychology*, 33 (3), pp. 405-421.

Barratt, E. S. and Patton, J. H., 1983. Impulsivity: Cognitive, behavioral, and psychophysiological correlates. *Biological Bases of Sensation Seeking, Impulsivity, and Anxiety*, 77, pp.116.

Barton, A. and Hill, A., 2005. Red enhances human performance in contests. *Nature*, 435, pp. 293.

Berlyne, D. E., 1960. *Conflict, arousal and curiosity*. New York: McGraw-Hill.

Berlyne, D. E., 1967. Arousal and reinforcement. In D. Levine (ed.), *Nebraska symposium on motivation: Vol. 15. Current Theory & Research in Motivation.* Lincoln: University of Nebraska Press.

Berns, R. S., 2000. *Billmeyer and Saltzman's Principles of Color Technology*. 3rd ed. New York; Chichester: John Wiley.

Bex, P. J. and Makous, W., 2002. Spatial frequency, phase, and the contrast of natural images. *Journal of the Optical Society of America*, 19 (6), pp. 1096-1106.

Billmeyer, F. W., 1987. Survey of color order systems*. Color Research and Application*. 12(4), pp.173-186.

Birren, F. and Cleland, T. M., 1969. *A Grammar of Color: a Basic Treatise on the Color System of Albert H. Munsell*. New York: Van Nostrand Reinhold Co.

Block, J., Block, J. H. and Harrington, D. M., 1974. Some misgivings about the Matching Familiar Figures Test as a measure of reflection-impulsivity. *Developmental Psychology*, 10, pp. 611-632.

Bonnardel, N., Piolat, A. and Bigot, L. L., 2010. The impact of colour on website appeal and users' cognitive processes. *Displays*, 32, pp. 69-80.

Broek, M. D. van den, Bradshaw, C. M. and Szabadi, E., 1987. Performance of normal adults on the Matching Familiar Figures Test, *British Journal of Clinical Psychology*, 26, pp. 71-72.

Bryman, A. and Cramer, D., 2009. *Quantitative data analysis with SPSS 14,15 & 16. A Guide for Social Scientists*, London and New York: Routledge, Taylor & Francis Group.

Cerbus, G. and Nichols, R. C., 1963. Personality variables and response to color, *Psychological Bulletin*, 60, pp. 566-575.

Chen, S. Y., George, D. M. and Dimakopoulos, D, 2005. A flexible interface design for web directories to accommodate different cognitive styles. *Journal of the American Society for Information Science and Technology*, 56 (1), pp. 70-83.

Christos, C., 1973. Conceptual tempo and its relationship to academic aptitude and school achievement. *Dissertation Abstracts International*, 33, (12A), pp. 6722.

CIE Publication 75:1988., 1988. Spectral Luminous Efficiency Functions Based upon Brightness Matching for Monochromatic Point Sources, 2°, and 10° Fields, Vienna, Austria: *Commission Internationale de l’Éclairage*.

CIE Publication 119:1995., 1995. Industrial Colour Difference Evaluation, Vienna, Austria: *Commission Internationale de l’Éclairage*.

CIE Publication 170-1:2006., 2006. Fundamental Chromaticity Diagram with Physiological Axes-Part 1, Vienna, Austria*: Commission Internationale de l’Éclairage*.

CIE S 014-3E: 2011., 2011. Colorimetry-Part 3: Calculation of CIE Tristimulus Values, Vienna, Austria: *Commission Internationale de l’Éclairage*.

Clarke, T. and Costall, A., 2008. The emotional connotations of color: A qualitative investigation. *Color Research and Application*, 33, pp. 406-410.

Colman, A. M., 2015. *A Dictionary of Psychology*. 4th ed. Oxford: Oxford University Press.

Cupchik, G. C., 1994. Emotion in aesthetics, reactive and reflective models*.* *Poetics*, 23, pp. 177-188.

Cyr, D., Head, M. and Larios, H., 2010. Colour appeal in website design within and across cultures: a multi-method evaluation, *International Journal of Human-Computer Studies*, 68, pp. 1-21.

Davidson, W. B., 1984. Personality correlates of the Matching Familiar Figures Test in Adults. *Journal of Personality Assessment*, 48 (5), pp. 478-482.

Denny, D. R., 1974. The relationship of three cognitive style dimensions to elementary reading abilities. *Journal of Educational Psychology*, 66, pp. 702-709.

Denny, N. W. and List, J. A., 1979. Adult age differences in performance on the Matching Familiar Figures Test. *Human Development*, 22, pp. 137-144.

Denny, N. W., 1982. Attempts to modify cognitive tempo in elderly adults. *International Journal of Aging and Human Development*, 14, pp. 239-254.

Denny, N. W. and List, J. A., 1979. Adult age differences in performance on the Matching Familiar Figures Test. *Human Development*, 22, pp. 137-144.

Ebner, M., 2007. Color Constancy. *Wiley-IS&T Series in Imaging Science and Technology*. Chichester: John Wiley.

Egeland, B., Bielke, P. and Kendall, P. C., 1980. Achievement and adjustment correlates of the Matching Familiar Figures Test. *Journal of School Psychology*, 18 (4), pp. 361-372.

Engeldrum, P. G., 2000. *Psychometric Scaling: a Toolkit for Imaging Systems Development*. Winchester, Mass.: Imcotek Press.

Eysenck, H. J., 1941. A critical and experimental study of colour preferences. *The American Journal of Psychology*. 54 (3), pp. 385-394.

Eysenck, H. J. and Eysenck, S. B. G., 1975. *Manual of the Eysenck Personality Questionnaire*. London: Hodder & Stoughton.

Eysenck, S. B. G. and Eysenck, H. J., 1978. Impulsiveness and venturesomeness: their position in a dimensional system of personality description. *Psychological Reports*, 43. pp. 1247-1255.

Feltman, R. and Elliot, A., 2011. The influence of red on perceptions of relative dominance and threat in a competitive context. *Journal of Sport & Exercise Psychology*, 33, pp. 308-314.

Fortmann R. S., 2013. Effects of hue, saturation, and brightness on color preference in social networks: gender-based color preference on the social networking site Twitter. *Color Research and Application*, 38, pp. 196-202.

Frank, M. G. and Gilovich, T., 1988. The dark side of self- and social perception: Black uniforms and aggression in professional sports. *Journal of Personality and Social Psychology*, 54 (1), pp. 74-85.

Gao, X., Xin, J. H., Sato, T., Hansuebsai, A., Scalzo, M., Kajiwara, K., Guan, S., Valldeperas, J., Lis, M. J. and Billger, M., 2007. Analysis of cross-cultural color emotion. *Color Research and Application*, 32, pp. 223-229.

Gerard, R. M., 1958. Differential effects of coloured lights on psycho-physiological functions. *Doctoral dissertation*. University of California, Los Angeles.

Gescheider, G. A., 1997. *Psychophysics: the Fundamentals. 3rd ed*. Mahwah, N.J.; London: L. Erlbaum Associates.

Glicksohn, J., Leshem, R. and Aharoni, R., 2006. Impulsivity and time estimation: Casting a net to catch a fish. *Personality and Individual Differences, 40,* pp. 261-271.

Goldstein, K., 1942, Some experimental observations concerning the influence of colors on the function of the organism. *Occupational Therapy & Rehabilitation,* 21 (3), pp. 147-151.

Goodman, T. M., 2012. International standards for colour. In: Janet, B. eds. *Colour Design: Theories and Applications*. Oxford: Woodhead Publishing in association with the Textile Institute, pp. 177-218.

Gough, H. G., 1965. Conceptual analysis of psychological test scores and other diagnostic variables. *Journal of Abnormal Psychology*, 70, pp. 294-302.

Gorn, G. J., Amitava Chattopadhyay, Tracey Yi, and Darren W. Dahl, 1997. Effects of color as an executional cue in advertising: they're in the shade. *Management Science*, 43 (October), pp. 1387-1400.

Gorn, G. J., Amitava Chattopadhyay, Sengupta, J. and Tripathi, S., 2004. Waiting for the web: how screen color affects time perception. *Journal of Marketing Research*, XLI (May), pp. 215-225.

Gough, H. G., 1965. Conceptual analysis of psychological test scores and other diagnostic variables. *Journal of Abnormal Psychology*, 70, pp. 294-302.

Hagemann, N., Strauss, B. and Jan, L., 2008. When the referee sees red. *Psychological Science*, 19, pp. 769-771.

Hall, R. H. and Hanna, P., 2004. The impact of web page text-background colour combinations on readability, retention, aesthetics and behavioural intention. *Behaviour & Information Technology*, 23 (3), pp. 183-195.

Hard, A. and Sivik, L., 1981. NCS-natural color system-a Swedish standard for color notation. *Color Research and Application*, 6 (3), pp.129-138.

Hathorne, B. L., 1964. *Woven Stretch and Textured Fabrics*. New York: Interscience Publishers.

Hill, R.A. and Barton, R.A., 2005. Red enhances human performance in contests. *Nature*, 435, pp. 293.

Hogg, J., 1969. A principal component analysis of semantic differential judgements of single colors and color pairs. *Journal of General Psychology*, 80, pp. 129-140.

Hsiao, S. W., Chiu, F. Y. and Hsu, H. Y., 2008. A computer-assisted colour selection system based on aesthetic measure for colour harmony and fuzzy logic theory. *Color Research and Application*, 33, pp. 411-423.

Hunt, R. W. G. and Pointer, M., 2011. *Measuring Colour*. 4th ed. Hoboken, N.J.: Wiley-Blackwell.

Husain, G., Thompson, W. F., and Schellenberg, E. G., 2002. Effects of musical tempo and mode on arousal, mood, and spatial abilities. *Music Perception*, 20 (2), pp. 151-171.

Ishihara, S., 1996. *Ishihara's Tests for Colour-Deficiency*. Tokyo: Kanehara.

ISO/CIE 11664-1:2008(E)/CIE S 014-1/E:2006. 2006 (a). Colorimetry-Part 1: CIE Standard Colorimetric Observers, Vienna, Austria: *Commission Internationale de l'Éclairage*.

ISO/CIE 11664-2:2008(E)/CIE S 014-2/E:2006., 2006 (b). Colorimetry-Part 2: CIE Standard Illuminants, Vienna, Austria: *Commission Internationale de l'Éclairage.*

ISO/CIE 11664-4:2008(E)/CIE S 014-4/E:2007., 2007. Colorimetry-Part 4: CIE 1976 L*a*b* Colour Space, Vienna, Austria: *Commission Internationale de l'Éclairage.*

ISO/CIE 11664-5:2009(E)/CIE S 014-5/E:2009., 2009. Colorimetry-Part 5: CIE 1976 L*u*v* Colour Space and u', v' Uniform Chromaticity Scale Diagram, Vienna, Austria: *Commission Internationale de l'Éclairage*.

Itten, J. and Birren, F., 2001. *The Elements of Color: a Treatise on the Color System of Johannes Itten*. New York ; Chichester: John Wiley.

Itten, J. and Hagen, E. V., 2004. *The Art of Color: the Subjective Experience and Objective Rationale of Color. 2nd ed*. New York; Chichester: Wiley.

Iwase, M., Nishida, Y., Kitaguchi, S., Sato, T., Ou, L. and Luo, M. R., 2010. Visual impression of the colour of football uniforms: investigation using moving and static images of football games. *Colour: Design & Creativity*, 7 (4), pp. 1-15.

Jacobs, K. W. and Hustmyer, F. E., 1974. Effects of four psychological primary colours on GSR, heart rate, and respiration rate. *Percept Mot Skills*, 38, pp. 763-766.

James, W., 1884. What is an emotion? *Mind*, 19, pp. 188-205.

Kagan, J., 1965. Impulsive and reflective children: significance of conceptual tempo. In J. D. Krumboltz (ed.), *Learning and the Educational Process*. Chicago: Rand-McNally.

Kagan, J., 1966. Reflection-impulsivity: The generality and dynamics of conceptual tempo. *Journal of Abnormal Psychology*, 71, pp. 17-24.

Kagan, J., Rosman, B. L., Day, D., Albert, J. and Phillips, W., 1964. Information processing in the child: significance of analytic and reflective attitudes. *Psychological Monographs*, 78 (1), pp. 1-37.

Katz, J. M. 1971. Reflection-Impulsivity and Colour-Form Sorting. *Child Developmen*t, 42 (3), pp. 745-754.

Kim, J. and Mueller, C. W., 1978. *Factor Analysis: Statistical Methods and Practical Issues*. Beverly Hills, Calif.: Sage.

Kline, P., 1994. *An Easy Guide to Factor Analysis*. London: Routledge.

Kobbayashi, S., 1981. The aim and method of the color image scale. *Color Research and Application*, 6, pp. 93-107.

Kobbayashi, S., 1991. *Color Image Scale*. Tokyo, London: Kosdansha International.

Koenderink, J. J., 2010. *Color for the Sciences*. Cambridge, Mass.; London: MIT Press.

Kuehni, R. G., 2003*. Color Space and Its Divisions: Color Order from Antiquity to the Present*. Hoboken, N.J.: Wiley.

Kuehni, R. G., 2004. *Color: an Introduction to Practice and Principles*. 2nd *ed.* Hoboken: J. Wiley & Sons.

Kuehni, R. G. and Schwarz, A., 2008. *Color Ordered: a Survey of Color Order Systems from Antiquity to the Present*. Oxford: Oxford University Press.

Küller, R., Mikellides, B. and Janssens, J., 2009. Color, arousal, and performance- A comparison of three experiments. *Color Research and Applications*, 34, pp. 141-152.

Kwallek, N. and Lewis, C. M., 1990. Effects of environmental colour on males and females: a red or white or green office. *Applied Ergonomics*, 21 (4), pp. 275-278.

Kwallek, N, Soon, K. and Lewis, C.M., 2007. Work week productivity, visual complexity, and individual environmental sensitivity in three offices of different color interiors. *Color Research and Application*, 32, pp. 130-143.

Lechner, A., Simonoff, J. S. and Harrington, L., 2012. Color-emotion associations in the pharmaceutical industry: Understanding Universal and local themes. *Color Research and Application*, 37, pp. 59-71.

Lee, Y. J. and Lee, J., 2006. The development of an emotion model based on colour combinations. *International Journal of Consumer Studies*, 30, pp. 122-136.

Ling, J. and Schaik, P. V., 2002. The effect of text and background colour on visual search of Web pages. *Displays*, 23, pp. 223-230.

Lucassen, M. P., Gevers, T. and Gijsenij, A., 2011. Texture affects color emotion. *Color Research and Application*, 36, pp. 426-436.

Lysaker, P., Bell, M. and Beam-Goulet, J., 1995. Wisconsin card sorting test and work performance in schizophrenia. *Psychiatry Research,* 56, pp. 45-51.

Macadam, D. L., 1974. Uniform Color Scales. *Journal of the Optical Society of America*, 64 (12), pp.1691-1702.

Maccoby, E. E. and Jacklin, C. N., 1981. How largeare congnitive gender differences? A Meta-Analysis using w^2 and d. *American Psychologist*, 36 (8), pp. 892-901.

Manay, B., 2007. Color-emotion associations and color preferences: A case study for residences. *Color Research and Application*, 32, pp.144-150.

McKean, C. A., 2014. *How Blue Lights on Train Platforms Combat Tokyo's Suicide Epidemic*. [Online]. [Accessed 26, Jan, 2017]. Available from: https://nextcity.org/daily/entry/how-blue-lights-on-train-platforms-combat-tokyos-suicide-epidemic.

Mehrabian, A., 1996. Pleasure-Arousal-Dominance: a general framework for describing and measuring individual differences in temperament. *Current Psychology/ winter*, 14 (4), pp. 261-292.

Mekarski, J. E., Cutmore, T. R. H. and Suboski, W., 1996. Gender differences during processing of the Stroop task. *Perceptual and Motor Skills*, 83, pp. 563-568.

Merriënboer, J. J. G. V., Jelsma, O., Timmermans, J. and Sikken, J., 1989. Computerized vs. experimenter controlled administration of the matching familiar figures test: mean test scores and reliabilities. *Educational and Psychological Measurement*, 49, pp. 883-892.

Messer, S., 1976. Reflection-impulsivity: A review. *Psychological Bulletin,* 83, pp. 1036-1052.

Murray, J. E. and Jackson, D. N., 1964. Impulsivity and color-form abstraction. *Journal of Consulting Psychology*, 28 (6), pp. 518-522.

Nerger, J. L., Volbrecht, V. J. and Haase, K. A., 2003. The Influence of Rods on Colour Naming During Dark Adaptation. In: Mollon, J.D., Pokorny, J. and Ken, K., ed. *Normal and Defective Colour Vision*. Oxford, New York: Oxford University Press Inc, pp. 173-178.

Nuessle, W., 1972. Reflectivity as an influence on focusing behaviour of children. *Journal of Experimental Child Psychology*, 14, pp. 265-276.

Oas, P., 1985. The psychological assessment of impulsivity: a review. *Journal of Psychoeducational Assessment, 3*, pp. 141-156.

Olutchik, R. and Praag, H. M., 1995. The nature of impulsivity: definitions, ontology, genetics, and relations to aggression. Hollander, E. & Stein, D. *Impulsivity and Aggression.* Chichester; New York: Wiley & Sons.

Osgood, C. E., Suci, G. J. and Tannenbaum, P. H.,1975. *The Measurement of Meaning*, University of Illinois Press, pp. 31-75.

Ostwald, W. and Birren, F. 1969. *The Color Primer: a Basic Treatise on the Color System of Wilhelm Ostwald*. New York: Van Nostrand Reinhold Co.

Ou, L. C., Luo, M. R., Woodcock, A. and Wright, A., 2004. A study of colour emotion and colour preference. I. Colour emotions for single colours. *Color Research and Application*, 29 (3), pp. 232-240.

Ou, L. C., Luo, M. R., Woodcock, A. and Wright, A., 2004. A study of colour emotion and colour preference. II. Colour emotions for two-colour combinations. *Color Research and Application*. 29 (4), pp. 292-298.

Ou, L. C., Luo, M. R., Woodcock, A. and Wright, A., 2004. A study of colour emotion and colour preference. III. Colour preference modeling. *Color Research and Application*, 29 (5), pp. 381-389.

Ou, L. C. and Luo, M. R. 2006. A colour harmony model for two-colour combinations. *Color Research and Application*, 31(3), pp.191-204.

Ou, L. C., Luo, M. R., Sun, P. L., Hu, N. C., Chen, H. S., Guan, S. S., Woodcock, A., Caivano, J. L., Huertas, R., Alain, T., Billger, M., Izadan, H. and Richter, K., 2012. A cross-cultural comparison of colour emotion for two-colour combinations. *Color Research and Application*, 37, pp. 23-43.

Ou, L. C., Luo, M. R., Sun, P. L., Hu, N. C. and Chen, H. S., 2012. Age effects on colour emotion, preference, and harmony. *Color Research and Application*, 37, pp. 92-105.

Ough, C. S. and Amerine, M. A., 1967. Rosé Wine Color Preference and Preference Stability by an Experienced and an Inexperienced Panel. *Journal of Food Science*, 32, pp. 706-711.

Pelli, D. G. and Farell, B., 1999. Why use noise? *Journal of the Optical Society of America*, 16, pp. 647-653.

Pelli, D. G. and Peter, B., 2013. Measuring contrast sensitivity. *Vision Research*, 90, pp. 10-14.

Plutchik, R., 1980a. *Emotion, a Psych Evolutionary Synthesis*. New York: Harper & Row.

Plutchik, R. and Kellerman, H., 1980b. *Emotion: Theory, Research and Experience*. New York; London: Academic Press.

Plutchik, R., 1995. A theory of ego defences, in H.R. Conte & R. Plutchik, *ed*., *Ego Defences: Theory and Measurement*, pp.13-37, John Wiley, New York.

Porteus, S. D., 1959. T*he Maze Test and Clinical Psychology.* Palo Alto, CA: Pacific Books.

Porteus, S. D., 1973. *Porteus Maze Test: Fifty Years' Application*. Palo Alto, CA: Pacific Books.

Prokop, P. and Fančovičová, J., 2013. Does colour matter? The influence of animal warning coloration on human emotions and willingness to protect them. *Animal Conservation*, 16, pp. 458-466.

Read, M. A., Sugawara, A. I. and Brandt, J. A., 1999. Impact of space and color in the physical environment on preschool children's cooperative behavior. *Environment and Behavior*, 31 (3), pp. 413-328.

Robertson, A. R., 1977. The CIE 1976 Color-Difference Formulae*. Color Research and Application*, 2, pp. 7-11.

Rowe, C., Harris, M. and Roberts, S., 2005. Seeing red? Putting sportswear in context. *Nature*, 437, pp. E10.

Sarason, I. G., 1980. *Test Anxiety: Theory, Research and Applications*. Hillsdale, NJ: Erlbaum.

Saito, M., 1996. Comparative studies on color preference in Japan and other Asian regions: with special emphasis on the preference for white. *Color Research & Application*. 21, pp. 35-49.

Sato, T., Kajiwara, K., Xin, J. H., Hansuebsai, A. and Nobbs, J., 2001. Numerical expression of colour emotion and its application. *Proceedings of* *the 9th Congress of the Association Internationale de la Coleur (AIC),* pp. 4421.

Schauss, A. G., 1979. Tranquilizing effect of color reduces aggressive behavior and potential violence. *Orthomolecular Psychiatry*, 8 (4), pp. 218-221.

Shin, Y., Kim, Y. and Kim, E. Y., 2010. Automatic textile image annotation by predicting emotional concepts from visual features. *Image and Vision Computing*, 28 (3), pp. 526-537.

Solli, M. and Lenz, R., 2011. Color emotions for multi-colored images. *Color Research and Application*, 36, pp. 210-221.

Solís-Cámara R. P. and Solís-Cámara R. V., 1987. Is the Matching Familiar Figures Test a measure of cognitive style?: a warning for users. *Perceptual and Motor Skills*, 64, pp. 59-74.

Stanford, M. S., Greve, K. W., Boudreaux, J. K., Mathias, C. W. and Brumbelow, J. L., 1996. Impulsiveness and risktaking behavior: Comparison of high-school and college students using the Barratt impulsiveness scale. *Personality and Individual Differences*, *21*, pp. 1073-1075.

Sydney, S. Z. and Dwyer, A. M., 1989. Color effects on the impulsivity and activity of hyperactive children. *The Journal of School Psychology*, 27, pp. 165-173.

Sykes, J. and Brown, S., 2003. Affective gaming, measuring emotion through the gamepad. *CHI 2003: New Horizons*, pp. 732-733.

Tangkijviwat, U., Rattanakasamsuk, K. and Shinoda, H., 2010. Color preference affected by mode of color appearance. *Color Research and Application*, 35, pp. 50-61.

Tarrant, A., 2002. Light and Colour. In: Green, P. and MacDonald, L. eds. *Colour Engineering: Achieving Device Independent Colour*. Chichester: Wiley.

Theatrecrafts, 2017. *More about the Green Room* [Online]. [Accessed 17, May 2017]. Available from:

http://www.theatrecrafts.com/pages//home/glossary-of-technical-theatre-terms/more-about-the-green-room/.

The College of Liberal Arts and Sciences, W. O. U., 2013. *Transition Metal Complexes and Color* [Online]. [Accessed 10, June, 2013]. Available from: http://www.wou.edu/las/physci/ch462/tmcolors.htm.

Tiryaki, M. S., 2005. Assessing wheter black uniforms affect the decisions of Turkish soccer referees: Is finding of Frank and Gilovich's study valid for Turkish culture? *Perceptual and Motor Skills*, 100, pp. 51-57.

Tonnquist, G., 1986. Philosophy of Perceptive Color Order Systems. *Color Research and Application*, 11 (1), pp. 51-55.

Valberg, A., 2005. Light, Vision, *Color. Chichester*: John Wiley.

Valdez, P. and Mehrabian, A., 1994. Effects of color on emotions. *Journal of Experimental Psychology: General*, 123 (4), pp. 394-409.

Venkatesh, D., Ramachandra, D. L., Suresh Baboo, N. and Rajan, B. K., 2002. Impact of psychological stress, gender and colour on visual response latency. *Indian J Physiol Pharmacol*, 46 (3), pp. 333-337.

Wang, B., 2010. *Colour Ink Formulation for a Multi-ink Printer,* (Department of Colour Science, The University of Leeds, MA dessertation).

Webster, C. D. and Jackson, M. A., 1997. *Impulsivity: Theory, Assessment and Treatment.* New York, London: Guilford Press.

Weijers, H. G., Wiesbeck, G. A. and Böning, J., 2001. Reflection-impulsivity, personality and performance: a psychometric and validity study of the Matching Familiar Figures Test in detoxified alcoholics. *Personality and Individual Differences*, 31, pp. 731-754.

Wilson, G. D., 1966. Arousal properties of red versus green. *Percept Mot Skills*, 23, pp. 947-949.

Wright, B. and Rainwater, L., 1962. The meanings of color. *Journal of General Psychology*, 67, pp. 89-99.

Xin, J. H. and Cheng, K., 2000. Quantitative evaluation of colour emotion. *JSPS Fund Meeting*, pp. 71-86.

Xin, J. H., Chen, K. M., Taylor, G., Sato, T. and Hansuebsai, A., 2004. Cross-regional comparison of colour emotions Part I: Quantitative analysis. *Color Research and Application*, 29, pp. 451-457.

Xin, J. H., Chen, K. M., Taylor, G., Sato, T. and Hansuebsai, A., 2004. Cross-regional comparison of colour emotions Part II: Qualitative analysis. *Color Research and Application*, 29, pp. 458-466.

Xin, J. H., Shen, H. L. and Lam, C. C., 2005. Investigation of texture effect on visual colour difference evaluation. *Color Research and Application*, 30, pp. 341-347.

Yildirim, K., Akalin-Baskaya, A. and Hidayetoglu, M. L., 2007. Effects of indoor color on mood and cognitive performance. *Building and Environment*. 42 (9), pp. 3233-3240.

Zentall, S. S., Falkenberg, S. D. and Smith, L. B., 1985. Effects of color stimulation on the copying performance of attention-problem adolescents. *Journal of Abnormal Child Psychology*, 3, pp. 501-511.

Zentall, S. S. and Anne, M. D., 1989. Color effects on the impulsivity and activity of hyperactive children. *Journal of School Psychology*, 27, pp. 165-173.

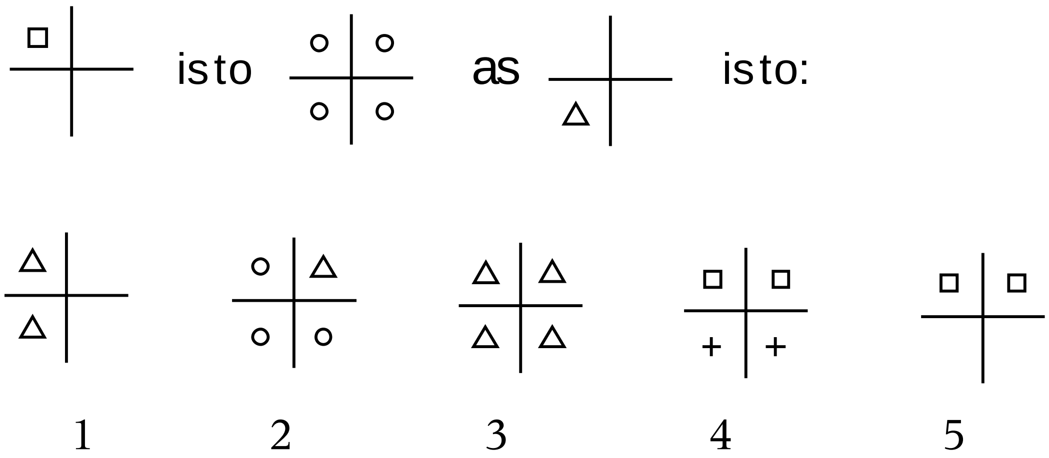
Zentner, M. R., 2001. Preferences for colours and colour--emotion combinations in early childhood. *Developmental Science*, 4, pp. 389-398.

Appendix A
Participants Instructions in Hue Experiment

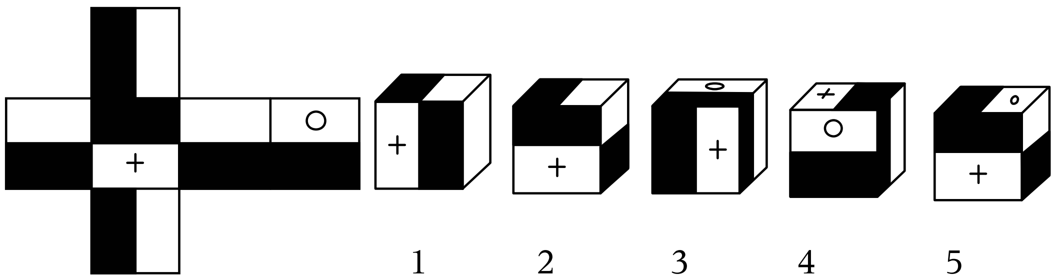
Instruction Session1

In this session, you will need to solve 45 puzzles on the screen. These puzzles are split into 3 types of questions, which are:

1. In this type of test, you are required to choose, from a set of alternatives, which diagram will complete a similar analogy to the first example. Please finish the following example, to make sure you fully understand this test.

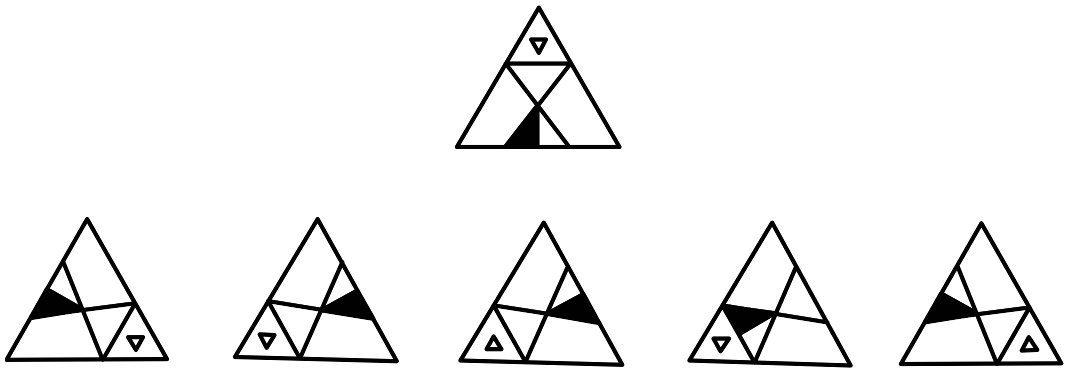


2. In this type of test, you need to look at the unfolded shape, and then choose which of the objects below would best represent the first object if it were folded. Please complete the following test, to make sure you fully understand the rule.



3. In this type of test, you are shown a shape in the middle of the page. Below they are five other shapes. You have to decide which of the

alternatives is identical to the original shape. It will still be identical to the original if it has been turned around. It will not be the same as the original if it has been turned over, or the proportions, parts have been changed. Please complete the example below; to make sure you fully understand the test.



1 2 3 4 5

In this experiment, you are required to look at a big screen in the dark environment. The tests are shown on this big screen. When you finish each test, speak out loudly the answer, the experimenter will be recorded the sound. Only the first reaction will be recorded, you don't have the chance to change your answer. After you give the answer to the current test, the experimenter will help you to load the next test. Don't make any pause in the experiment as the reaction time to each test and the total length of the test is recorded.

After this session, you are required to participate in the Session 2. A week later, you have to repeat all the sessions once.

We are looking for the winner, who makes fewest mistakes within the shortest over all time in all the experiment. There will be a prise for the WINNER!

Instruction Session2

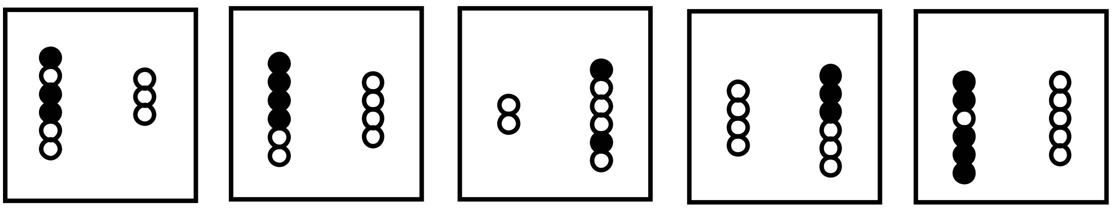
In this session, you will need to solve 45 puzzles on the screen. These puzzles are split into 3 types of questions, which are:

1. In this type of test, you are given a string of numbers. You have to work out the number that is missing from the string (marked ?). Please finish the following example, to make sure you fully understand this test.

9 16 25 36 ?

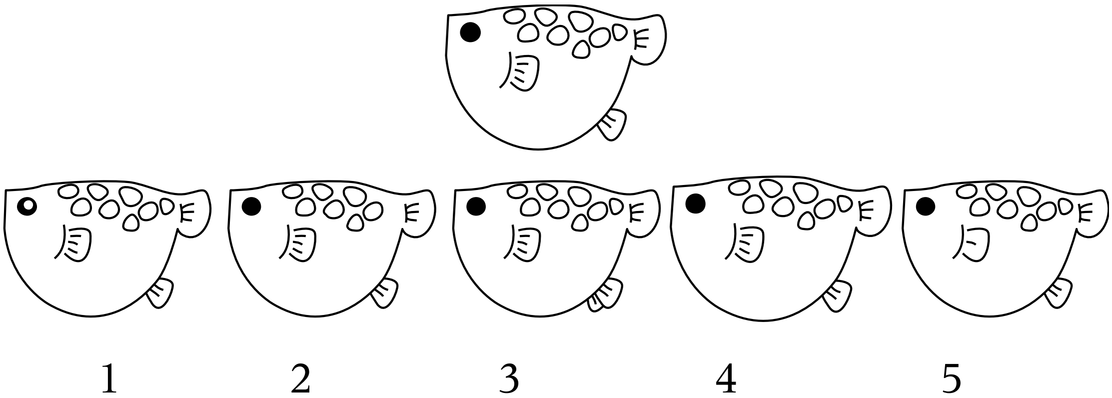
47	48	49	50	51
1	2	3	4	5

2. In this type of test, you need to decide which of the objects is the "odd one out". Please complete the following test, to make sure you fully understand the rule.



1 2 3 4 5

3. In this type of test, you are shown a pattern in the middle of the page. Below they are five other patterns. You have to decide which of the alternatives is exactly the same to the original pattern. Please complete the example below; to make sure you fully understand the test.



In this experiment, you are required to look at a big screen in the dark environment. The tests are shown on this big screen. When you finish each test, speak out loudly the answer, the experimenter will be recorded the sound. Only the first reaction will be recorded, you don't have the chance to change your answer. After you give the answer to the current test, the experimenter will help you to load the next test. Don't make any pause in the experiment as the reaction time to each test and the total length of the test is recorded.

A week later, you have to repeat all the sessions 1 and 2 once.

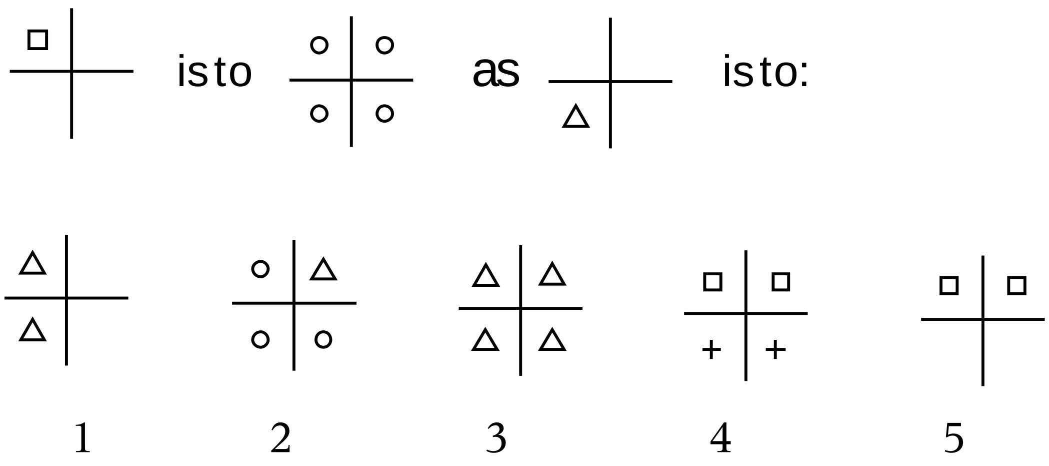
We are looking for the winner, who makes fewest mistakes within the shortest over all time in all the experiment. There will be a prise for the WINNER!

Appendix B
Participants Instructions in Chroma Experiment

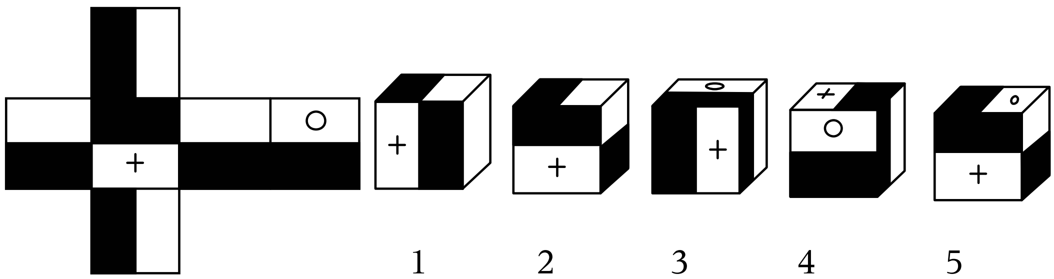
Instruction Session1

In this session, you will need to solve 60 puzzles on the screen. These puzzles are split into 2 types of questions, which are:

1. In this type of test, you are required to choose, from a set of alternatives, which diagram will complete a similar analogy to the first example. Please finish the following example, to make sure you fully understand this test.



2. In this type of test, you need to look at the unfolded shape, and then choose which of the objects below would best represent the first object if it were folded. Please complete the following test, to make sure you fully understand the rule.



In this experiment, you are required to look at a big screen in the dark environment. The tests are shown on this big screen. When you finish each test, speak out loudly the answer, the experimenter will be recorded the sound. Only the first reaction will be recorded, you don't have the chance to change your answer. After you give the answer to the current test, the experimenter will help you to load the next test. Don't make any pause in the experiment as the reaction time to each test and the total length of the test is recorded.

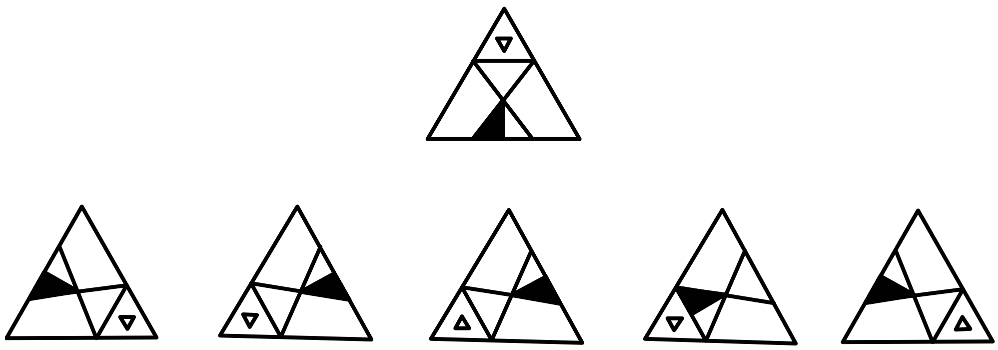
After this session, you are required to participate in the Session 2. A week later, you have to repeat all the sessions once.

We are looking for the winner, who makes fewest mistakes within the shortest over all time in all the experiment. There will be a prise for the WINNER!

Instruction Session2

In this session, you will need to solve 60 puzzles on the screen. These puzzles are split into 2 types of questions, which are:

1. . In this type of test, you are shown a shape in the middle of the page. Below they are five other shapes. You have to decide which of the alternatives is identical to the original shape. It will still be identical to the original if it has been turned around. It will not be the same as the original if it has been turned over, or the proportions, parts have been changed. Please complete the example below; to make sure you fully understand the test.



1 2 3 4 5

2. In this type of test, you are given a string of numbers. You have to work out the number that is missing from the string (marked ?). Please finish the following example, to make sure you fully understand this test.

9 16 25 36 ?

47	48	49	50	51
1	2	3	4	5

In this experiment, you are required to look at a big screen in the dark environment. The tests are shown on this big screen. When you finish each test, speak out loudly the answer, the experimenter will be recorded the sound. Only the first reaction will be recorded, you don't have the chance to change your answer. After you give the answer to the current test, the experimenter will help you to load the next test. Don't make any pause in the experiment as the reaction time to each test and the total length of the test is recorded.

A week later, you have to repeat all the sessions 1 and 2 once.

We are looking for the winner, who makes fewest mistakes within the shortest over all time in all the experiment. There will be a prise for the WINNER!

Appendix C
Participants Instructions in Emotion Experiment

Instructions 1

Please read the instructions carefully. They will help you complete the tasks correctly.

This experiment is based on a paired comparison procedure.

20 colour samples will be presented.

The objective of the experiment is to compare a colour-emotion word pair and to pick one of them in association with the colour presented. For example, you will be asked the question: “Which word and in what degree is more closely associated with the colour presented?” Please do not hold or touch the samples.

5 numbers under each word represent the degree of emotion from 5 (the highest) to 1 (the lowest).

10 Colour-emotion word pairs1:

Clean – Dirty

[Clean, adjective (not dirty); Dirty, adjective (not clean)]

Fresh – Stale

[Fresh, adjective (new); Stale, adjective (no longer new or fresh)]

Like – Dislike

[Like, verb (to enjoy or approve of something or someone); Dislike, verb (to not like someone or something)]

Heavy – Light

[Heavy, adjective (weighing a lot); Light, adjective (not heavy)]

Hard – Soft

[Hard, adjective (not easy to bend, cut, or break); Soft, adjective (not hard or firm)]

Masculine – Feminine

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[1] All the definitions of colour-emotion words are from Cambridge Advanced Learner’s Dictionary.

[Masculine, adjective (having characteristics that are traditionally thought to be typical of or suitable for men); Feminine, adjective (having characteristics that are traditionally thought to be typical of or suitable for a woman)]

Warm – Cool

[Warm, adjective (having producing a comfortable high temperature, although not hot); Cool, adjective (slight cold)]

Modern – Classical

[Modern, adjective (designed and using the most recent ideas and methods); Classical, adjective (Traditional in style or form)]

Active – Passive

[Active, adjective (busy with a particular activity); Passive adjective (not acting to influence or change a situation)]

Tense – Relaxed

[Tense, adjective (nervous and worried and unable to relax); Relaxed, adjective (feeling happy and comfortable because nothing is worrying you)]

Instructions 2

Please read the instructions carefully. They will help you complete the tasks correctly.

This experiment is based on a paired comparison procedure.

20 colour textile samples will be presented.

The objective of the experiment is to compare a colour-emotion word pair and to pick one of them in association with the colour presented. For example, you will be asked the question: “Which word and in what degree is more closely associated with the colour presented?” Please do not hold or touch the samples.

5 numbers under each word represent the degree of emotion from 5 (the highest) to 1 (the lowest).

10 Colour-emotion word pairs2:

Clean – Dirty

[Clean, adjective (not dirty); Dirty, adjective (not clean)]

Fresh – Stale

[Fresh, adjective (new); Stale, adjective (no longer new or fresh)]

Like – Dislike

[Like, verb (to enjoy or approve of something or someone); Dislike, verb (to not like someone or something)]

Heavy – Light

[Heavy, adjective (weighing a lot); Light, adjective (not heavy)]

Hard – Soft

[Hard, adjective (not easy to bend, cut, or break); Soft, adjective (not hard or firm)]

Masculine – Feminine

[Masculine, adjective (having characteristics that are traditionally thought to be typical of or suitable for men); Feminine, adjective (having characteristics that are traditionally thought to be typical of or suitable for a woman)]

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[2] All the definitions of colour-emotion words are from Cambridge Advanced Learner’s Dictionary.

Warm – Cool

[Warm, adjective (having producing a comfortable high temperature, although not hot); Cool, adjective (slight cold)]

Modern – Classical

[Modern, adjective (designed and using the most recent ideas and methods); Classical, adjective (Traditional in style or form)]

Active – Passive

[Active, adjective (busy with a particular activity); Passive adjective (not acting to influence or change a situation)]

Tense – Relaxed

[Tense, adjective (nervous and worried and unable to relax); Relaxed, adjective (feeling happy and comfortable because nothing is worrying you)]

Appendix D
The Repeatability of Colour in Hue Experiment

		L*	C*	h(°)
Day1	Grey	67.29	0.42	61.53
	Red	67.08	65.69	55.88
	Yellow	68.12	68.97	351.25
	Blue	64.89	64.23	163.64
	Purple	65.58	65.34	128.93
	Orange	68.61	64.63	22.09
	Green	65.22	65.85	272.79
Day2	Grey	67.47	0.64	60.18
	Red	67.20	66.71	55.83
	Yellow	68.14	68.94	351.49
	Blue	64.74	64.68	163.44
	Purple	65.39	65.76	128.80
	Orange	68.44	65.06	22.34
	Green	65.12	66.10	272.92
Day3	Grey	67.42	0.54	62.46
	Red	67.01	64.53	55.96
	Yellow	68.11	68.57	351.23
	Blue	64.90	62.89	164.20
	Purple	65.61	64.31	128.88
	Orange	68.54	63.72	21.89
	Green	65.23	65.16	272.59
Day4	Grey	67.18	0.50	61.47
	Red	66.87	65.01	55.82
	Yellow	67.98	68.71	351.24
	Blue	64.70	63.07	164.15
	Purple	65.41	64.42	128.85
	Orange	68.42	64.11	21.90
	Green	65.1	65.53	272.80
Day5	Grey	67.53	0.48	63.20
	Red	67.20	65.29	55.83
	Yellow	68.35	68.86	351.20
	Blue	65.07	63.64	163.97
	Purple	65.79	64.92	128.90
	Orange	68.80	64.24	21.92
	Green	65.50	65.73	272.76
Day6	Grey	66.78	0.60	55.14
	Red	66.62	65.69	55.78
	Yellow	67.66	68.41	351.48
	Blue	64.36	63.66	163.76
	Purple	65.09	64.92	128.82

		L*	C*	h(°)
	Orange	68.15	64.45	22.22
	Green	64.79	65.63	272.92
Day7	Grey	67.36	0.48	63.26
	Red	67.12	65.45	55.82
	Yellow	68.19	68.96	351.27
	Blue	64.91	63.55	164.00
	Purple	65.63	64.88	128.85
	Orange	68.66	64.49	21.95
	Green	65.31	65.79	272.75
Day8	Grey	67.21	0.59	54.98
	Red	67.01	65.75	55.78
	Yellow	68.07	68.68	351.38
	Blue	64.79	63.78	163.83
	Purple	65.50	65.05	128.83
	Orange	68.56	64.53	22.17
	Green	65.18	65.76	272.85
Day9	Grey	67.59	0.48	56.26
	Red	67.33	65.44	55.79
	Yellow	68.40	69.07	351.24
	Blue	65.14	63.47	164.13
	Purple	65.84	64.7	128.86
	Orange	68.87	64.43	21.90
	Green	65.52	65.82	272.79
Day10	Grey	66.93	0.86	67.34
	Red	66.85	66.44	55.77
	Yellow	68.20	68.67	351.04
	Blue	64.94	63.37	164.02
	Purple	65.76	64.60	128.75
	Orange	68.77	64.43	21.80
	Green	65.43	65.72	272.66
Day11	Grey	67.49	0.65	62.50
	Red	67.26	65.64	55.84
	Yellow	68.34	68.92	351.43
	Blue	65.40	63.68	164.01
	Purple	66.05	65.11	128.87
	Orange	69.02	64.48	22.05
	Green	65.60	65.68	272.66
Day12	Grey	67.71	0.72	67.76
	Red	67.43	65.72	55.91
	Yellow	68.46	69.05	351.45
	Blue	65.17	63.84	163.89
	Purple	65.92	65.14	128.79
	Orange	68.94	64.61	22.13
	Green	65.53	65.7	272.63

		L*	C*	h(°)
Day13	Grey	67.24	0.58	60.24
	Red	67.05	65.66	55.80
	Yellow	68.13	68.84	351.34
	Blue	64.79	64.04	163.61
	Purple	65.53	65.24	128.83
	Orange	68.60	64.53	22.05
	Green	65.22	65.66	272.74
Day14	Grey	67.38	0.61	60.22
	Red	67.18	65.86	55.88
	Yellow	68.24	68.97	351.41
	Blue	64.95	64.04	163.74
	Purple	65.69	65.31	128.82
	Orange	68.75	64.81	22.20
	Green	65.34	65.85	272.77

Appendix E
The Repeatability of Colours in Chroma Experiment

		L*	C*	h(°)
Day1	Grey	66.32	1.96	110.43
	Red100%	65.85	61.17	56.86
	Red75%	66.54	50.32	57.70
	Red50%	67.74	30.86	54.71
	Red25%	66.83	12.84	52.78
	Orange100%	67.40	62.47	21.73
	Orange75%	67.82	47.31	21.14
	Orange50%	65.55	34.40	23.36
	Orange25%	64.65	18.18	22.04
	Yellow100%	67.21	67.7	351.13
	Yellow75%	63.80	51.19	350.46
	Yellow50%	64.40	34.70	350.60
	Yellow25%	63.92	18.04	355.95
Day2	Grey	67.41	2.29	112.21
	Red100%	67.07	62.72	56.96
	Red75%	67.71	51.61	57.91
	Red50%	68.91	31.68	55.12
	Red25%	67.96	13.23	53.80
	Orange100%	68.58	63.67	22.07
	Orange75%	69.00	48.22	21.51
	Orange50%	66.68	35.11	23.90
	Orange25%	65.77	18.56	22.84
	Yellow100%	68.42	68.57	351.28
	Yellow75%	64.90	51.90	350.59
	Yellow50%	65.51	35.15	350.81
	Yellow25%	65.02	18.19	356.54
Day3	Grey	67.36	2.02	108.09
	Red100%	66.88	62.56	56.70
	Red75%	67.57	51.49	57.53
	Red50%	68.78	31.61	54.60
	Red25%	67.85	13.21	52.54
	Orange100%	68.45	63.86	21.82
	Orange75%	68.85	48.39	21.21
	Orange50%	66.52	35.27	23.39
	Orange25%	65.59	18.68	22.09
	Yellow100%	68.25	68.75	351.23
	Yellow75%	64.73	52.16	350.52
	Yellow50%	65.33	35.43	350.63

		L*	C*	h(°)
	Yellow25%	64.85	18.46	355.98
Day4	Grey	67.49	2.32	110.08
	Red100%	67.12	63.30	56.82
	Red75%	67.86	52.09	57.75
	Red50%	69.12	31.98	54.93
	Red25%	68.14	13.42	53.62
	Orange100%	68.79	64.34	22.03
	Orange75%	69.22	48.79	21.55
	Orange50%	66.82	35.50	23.88
	Orange25%	65.89	18.81	22.85
	Yellow100%	68.56	69.08	351.41
	Yellow75%	65.00	52.38	350.78
	Yellow50%	65.62	35.52	350.99
	Yellow25%	65.12	18.44	356.70
Day5	Grey	67.48	2.08	107.65
	Red100%	67.03	62.50	56.75
	Red75%	67.72	51.44	57.60
	Red50%	68.92	31.63	54.70
	Red25%	67.99	13.25	52.84
	Orange100%	68.60	63.88	21.84
	Orange75%	69.02	48.37	21.33
	Orange50%	66.68	35.24	23.61
	Orange25%	65.79	18.67	22.30
	Yellow100%	68.40	68.93	351.35
	Yellow75%	64.90	52.18	350.64
	Yellow50%	65.51	35.36	350.82
	Yellow25%	65.03	18.40	356.39
Day6	Grey	67.43	2.14	112.12
	Red100%	67.05	63.17	56.77
	Red75%	67.73	52.01	57.60
	Red50%	68.89	31.87	54.75
	Red25%	67.94	13.28	52.98
	Orange100%	68.58	64.18	22.02
	Orange75%	69.00	48.75	21.45
	Orange50%	66.62	35.48	23.62
	Orange25%	65.72	18.84	22.31
	Yellow100%	68.43	68.88	351.20
	Yellow75%	64.84	52.35	350.44
	Yellow50%	65.46	35.64	350.73
	Yellow25%	64.93	18.51	355.82
Day7	Grey	67.67	2.26	108.23
	Red100%	67.34	63.36	56.82

		L*	C*	h(°)
	Red75%	67.99	52.19	57.71
	Red50%	69.18	32.12	54.92
	Red25%	68.21	13.50	53.43
	Orange100%	68.88	64.41	22.13
	Orange75%	69.29	48.87	21.64
	Orange50%	66.91	35.63	23.98
	Orange25%	65.98	18.90	22.88
	Yellow100%	68.74	69.06	351.47
	Yellow75%	65.19	52.40	350.80
	Yellow50%	65.81	35.58	351.02
	Yellow25%	65.31	18.50	356.85
Day8	Grey	67.43	2.06	110.89
	Red100%	67.05	62.46	56.81
	Red75%	67.72	50.86	57.24
	Red50%	68.92	31.53	54.73
	Red25%	67.99	13.15	52.71
	Orange100%	68.61	63.68	21.86
	Orange75%	69.04	48.26	21.28
	Orange50%	66.68	35.12	23.51
	Orange25%	65.77	18.54	22.10
	Yellow100%	68.43	68.72	351.18
	Yellow75%	64.91	52.01	350.40
	Yellow50%	65.50	35.22	350.63
	Yellow25%	65.10	18.36	355.54
Day9	Grey	65.10	15.78	110.91
	Red100%	67.63	62.48	56.85
	Red75%	68.24	51.27	57.74
	Red50%	69.45	31.44	54.80
	Red25%	68.52	13.12	52.88
	Orange100%	69.11	63.70	21.72
	Orange75%	69.53	48.13	21.22
	Orange50%	67.15	35.06	23.65
	Orange25%	66.25	18.53	22.39
	Yellow100%	68.87	69.09	351.17
	Yellow75%	65.35	52.06	350.47
	Yellow50%	65.98	35.19	350.61
	Yellow25%	65.50	18.23	356.09
Daay10	Grey	66.42	2.17	104.33
	Red100%	66.07	62.31	56.76
	Red75%	66.74	51.34	57.62
	Red50%	67.92	31.61	54.69
	Red25%	66.97	13.30	52.87

		L*	C*	h(°)
	Orange100%	67.64	63.43	22.11
	Orange75%	68.05	48.16	21.53
	Orange50%	65.70	35.14	23.84
	Orange25%	64.78	18.70	22.60
	Yellow100%	67.44	67.99	351.46
	Yellow75%	63.94	51.64	350.84
	Yellow50%	64.52	35.14	351.08
	Yellow25%	64.05	18.36	356.64
Day11	Grey	67.41	2.65	111.57
	Red100%	67.31	66.02	56.69
	Red75%	67.93	54.51	57.69
	Red50%	69.07	33.63	55.23
	Red25%	68.01	14.12	54.46
	Orange100%	68.91	66.34	22.95
	Orange75%	69.26	50.68	22.26
	Orange50%	66.73	37.05	24.59
	Orange25%	65.72	19.63	23.54
	Yellow100%	68.67	69.10	351.80
	Yellow75%	64.90	53.34	351.16
	Yellow50%	65.48	36.61	351.42
	Yellow25%	64.92	19.09	357.32