PERSONAL COLOR ANALYSIS BASED ON COLOR HARMONY FOR SKIN TONE

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ปุณณพัฒน์ ศิริสายัณห์ : การวิเคราะห์สีส่วนบุคคลบนพื้นฐานของความกลมกลืนสีสำหรับสีผิว. (PERSONAL COLOR ANALYSIS BASED ON COLOR HARMONY FOR SKIN TONE) อ.ที่ปรึกษาหลัก : ผศ. ดร.สุจิตรา สื่อประสาร

การวิเคราะห์สีส่วนบุคคล หรือ Personal Colour Analysis เป็นการวิเคราะห์หาสีที่เหมาะสมสำหรับการแต่งกายของแต่ละบุคคล เช่น สีเสื้อผ้า เครื่องประดับ การแต่งหน้า สีที่เหมาะสมคือ สีที่ส่งเสริมให้ผิวพรรณแลดูผ่องใส มีสุขภาพดี เสริมสร้างบุคลิกภาพของบุคคลนั้น ๆ ปัจจัยที่ทำให้แต่ละบุคคลมีสีส่วนบุคคลต่างกันนั้นคือ สีผิว (skin tone) งานวิจัยนี้ศึกษาวิธีการวิเคราะห์สีส่วนบุคคลด้วยการหาความกลมกลืนสีระหว่างสีผิวกับสีตัวอย่าง เลือกตัวอย่างสีผิวจาก Pantone Skintone Guide จำนวน 15 สีที่เป็นตัวแทนของโทนสีผิวอมเหลือง (warm undertone) สีผิวอมชมพู (cool undertone) และสีผิวกลาง (neutral undertone) จับคู่กับสีตัวอย่างที่มีสีสัน ความสว่าง และความอิ่มตัวสีต่าง ๆ จำนวน 128 สี แสดงคู่สีบนหน้าจอคอมพิวเตอร์ทีละคู่ ให้ผู้สังเกตประเมินให้คะแนนความกลมกลืนสี จากผลการทดลองพบว่านอกจากสีภายใต้ผิว (undertone) แล้ว ความสว่างเป็นอีกปัจจัยหนึ่งที่ส่งผลต่อความกลมกลืนสีและสีส่วนบุคคล โดยโทนสีผิวอมเหลืองที่มีความสว่างสูงจะกลมกลืนกับสีของฤดูใบไม้ร่วงซึ่งเป็นสีโทนร้อน โทนสีผิวอมชมพูที่มีความสว่างสูงจะกลมกลืนกับสีของฤดูหนาวซึ่งเป็นสีโทนเย็น แต่สีผิวที่มีความสว่างปานกลางถึงต่ำจะกลมกลืนกับสีของฤดูร้อนซึ่งเป็นสีโทนเย็นเช่นกัน และสีผิวกลางจะกลมกลืนกับสีของทุกฤดู ผลการทำนายความกลมกลืนสีจากแบบจำลองความกลมกลืนสี (universal colour harmony model) พบว่ามีความสอดคล้องกับผลการประเมินด้วยสายตาเพียง 53% แสดงให้เห็นว่า ควรมีการสร้างแบบจำลองความกลมกลืนสีสำหรับการวิเคราะห์สีส่วนบุคคลโดยเฉพาะ

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Personal colour is a method for determining the best colours for a person's clothes, jewelry, make-up, and other accessories. Colours that promote a person’s skin radiance, healthy looks, and great character are appropriate. A person's skin tone defines their personal colours. This study investigated the method for analyzing personal colour using colour harmony between skin tone and sampled colours. Fifteen skin tone samples were selected from the Pantone SkinTone Guide to represent three types of skin undertone: warm, cool, and neutral. They were paired with 128 sampled colours with various hues, lightness, and chroma. The colour pairs were displayed one by one on a computer screen, allowing observers to evaluate colour harmony for each pair. It was found that in addition to skin undertone, skin lightness also affected colour harmony with respect to personal colour. Warm undertones of all lightness groups most harmonised with autumn colours (warm hues); the cool-high lightness group most harmonised with winter colours (cool hues); the cool-medium low lightness group harmonised with summer colours (cool hues); the neutral undertones harmonised with all season colours. The predictions from the universal colour hamony models yielded only 53% agreement with the visual results. This indicated that there should be a colour harmony model specially derived for personal colour analysis.

Field of Study: Imaging Technology		Student's Signature ....
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Punnaphat Sirisayan

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CHAPTER I

INTRODUCTION

How important is colour in everyday life? Colour is extensive and a source of information [1]. Within 90 seconds of people's first contact with either people or items, decisions are made, and between 62 and 90 percent of those decisions are based just on colour. Studies have shown that consumers say colour is crucial when buying salmon [2]. Colour is not only important in marketing, but it also engages emotions and feelings. Undergraduate students' relations between colour and emotion were investigated [3]. The study indicated that dark colours induced mostly negative emotional associations, whereas bright colours mainly induced positive emotional associations. The results were similar for both males and females, in which blue was associated with sadness and white with emotionlessness and purity [4]. In addition, interior design colours can also indicate emotions and feelings. The study by Güneş and Olguntürk related the characteristics of living rooms to six basic emotions [5]. They showed that the two feelings most frequently expressed about the red room were disgust and joy, while sadness, fear, hate, and surprise were the emotions that were least shown in the green room. For the blue room, the most often expressed feelings were neutral and happy, whereas surprise, fear, rage, and sorrow were the least usually expressed, etc.

When more than one colour comes together, it creates an artistic aesthetic, which is related to psychophysics and can be divided into emotional scales such as warm-cool, heavy-light, modern-classical, clean-dirty, active-passive, hard-soft, etc [6]. Such a relationship between the perception of colour is called colour harmony. *Colour harmony* is defined as the degree to which an observer feels that the colours in a combination go or belong together, whether or not the observer likes the combination, or it can be defined as how the viewer feels about the figural colour when compared to its background colour.” [7]. To harmonize anything is to bring it into harmony or to make it compatible [8].

Colour combinations and colour harmony frequently exist in our surroundings, such as in fashion, cosmetics, decorations, advertisements, objects, and food, etc., especially clothes and costumes. From the experiment by Jiang and Cai, four levels of contrasting colours were combined in a two-piece suit as stimuli, the results indicated that the less attractive the clothing was, the higher the colour contrast [9].

The personal colour analysis plays a role in selecting the colours of clothing that match the person, so that the wearer of that colour has a bright face and a better personality. Personal colour can be determined by the colour of the eyes, the colour of the hair or the skin colour [10]. However, getting the right colour for each person is not easy. The most common and popular analysis uses colour fabric placed over the person's body. There are many limitations to the analysis; for example, it should only be done by experts, and each analysis is time-consuming and expensive. The results of the personal colour analysis depend on the experts’ opinions that may differ from one to another, or from general opinions, so the colour recommendations may cast some doubt on their consistency, accuracy, and efficacy [11].

This study aims to find an alternative method of personal colour analysis. Considering how the skin tone looks good with that colour, "harmony”, it may be possible to analyse personal colour based on "harmony” evaluation. This is possibly the first study to examine personal colour using colour harmony evaluation for skin tone and sampled colour. By relying on the majority of observers rather than an expert, whose opinion is uncertain and cannot be validated adhering to scientific principles, the visual assessments were conducted to evaluate colour harmony for skin tone. The visual results were compared with the existing colour harmony model [12]. If the visual results are inconsistent with the predictions from the universal colour harmony model, this could mean that a specific colour harmony model is required for personal colour analysis.

1.1 Objective

To evaluate colour harmony for skin tones paired with colours varying in hue, lightness and chroma.

1.2 Scope of research

This study selected 15 samples for skin tones from Pantone SkinTone Guide to represent three skin undertones: warm, cool, and neutral. The colour samples to be paired with skin tones were representations of personal colour groups obtained from Kim and Kim's [13]. They were 128 colours divided equally into four seasons: spring, summer, autumn, and winter. The visual assessments were conducted in a darkened room, where the colour pairs were displayed on an LCD monitor. Thirty Thai observers, having no experience in personal colour analysis as well as colour harmony evaluation, assessed all 1,920 colour pairs one at a time and rated the degree of colour hamony from -5 (the most disharmonious) to 5 (the most harmonious).

1.3 Expected outcomes

1. Colour harmony scores for skin tones and season colour combinations.
2. Relationships between skin tones and season colours with respect to colour harmony scores.

1.4 Contents of the thesis

Chapter 2 contains the theoretical considerations and literature reviews related to this study. Chapter 3 describes the methodology that is divided into two parts: apparatus and experimentation. The experimentation consists of four parts: the selection of colour samples, the process of colour transformations, the method of visual assessments, and data analysis. Chapter 4 reports the results from the visual assessments, including the observer variance, the effect of two factors: skin undertone and skin lightness, personal colour analysis for the undertone-lightness skin tones, and comparison with the universal colour harmony model. Finally, conclusions and suggestions for future work are given in Chapter 5.

CHAPTER II
THEORETICAL CONSIDERATIONS AND LITERATURE REVIEWS

2.1 Theoretical considerations

This study investigated the method for analyzing personal colour using colour harmony between skin tone and sampled colours. Fifteen skin tone samples were selected from the Pantone SkinTone Guide to represent three types of skin tones: warm, cool, and neutral. They were paired with 128 sampled colours with various hues, lightness, and chroma. The colour pairs were displayed one by one on a computer screen, allowing observers to evaluate colour harmony for each pair. The CIE (Commission Internationale de I' Eclairage) recommends CIELAB as the model that can anticipate the appearance of colours, hence colourimetric values of samples were chosen based on this model. The characterization of LED monitor was necessary because it was utilized to display the desired colours. Consequently, the GOG model was used. This chapter describes the theoretical implications.

2.1.1 Skin undertone

The skin has an important substance that causes the colour of the skin. Melanin pigment, is an important pigment in protecting the skin from sun damage to prevent redness of the skin or scorched from sunburn. The number of melanin-producing cells in different parts of the body is different. The area of the face has the highest concentration of pigment-producing cells. The torso and inner arms have the least number of melanocytes [14]. African-American and Caucasian have the same number of melanoma cells, but the activity of melanoma cells is higher in African-American. The size of the cells is larger and the proportion of pigment within the cell is greater than that of Caucasian.

In addition to sun exposure, ethnic differences also affect skin tone. From measuring the skin colour of 100 Korean women between the ages of 30 and 40, it was found that the mean skin colour values were as follows: lightness (L*)=63.00, redness (a*) =13.11, and yellowness (b*) =18.70 [15]. But different from the average skin colour of 426 Thais aged between 20-40 years with an average of L*=59.30, a*=9.70 and b*=17.90 and 202 Chinese people aged between 20-40 years who The mean skin colour was L*=58.50, a*=9.80 and b*=15.40 [14]. But when compared to a medium African-American, it is found to have an L* of about 46.20 [16]. It can be seen that the brightness of the skin colour varies depending on the race and terrain in which the person lives. Therefore, no fixed rule determines which numbers are high lightness, medium lightness, and low lightness.

Pantone has created a device called the PANTONE SkinTone Guide, a guide created by measuring the actual skin tone of human skin to show the closest to 110 skin tones [17]. It divides skin tones into two categories: warm undertone 53.6% (59 out of 110 samples) and red cool undertone 46.4% (51 out of 110 samples). When all skin tones were graphed between CIE a* and CIE b*, a line with a slope of 60 degrees was used as what separated warm undertone and cool undertone. Based on the calculated skin tone hue angle, a skin tone hue angle greater than 60 degrees is warm undertone, while a skin tone hue angle less than 60 degrees is cool undertone [18] as shown in Figure 2-1

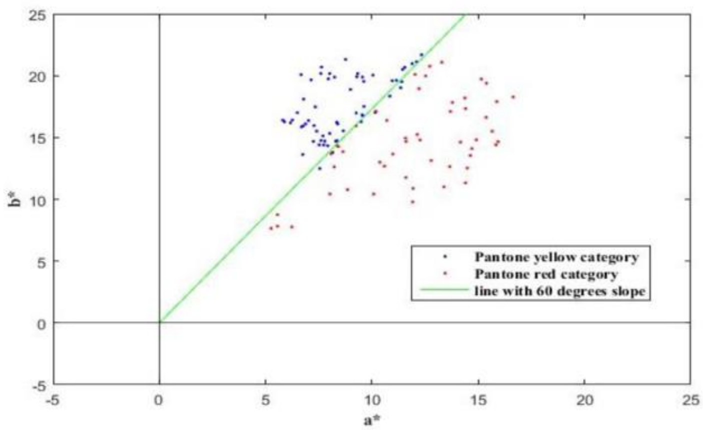

Figure 2-1 Warm undertone and cool undertone on the CIE a* and b*

2.1.2 Personal colour analysis

Personal Colour Analysis is an analysis of colour groups or finding a colour group which group of colours is most suitable for that person. It can be easily done by looking at the Undertone or the colour that appears under the skin. By dividing the skin colour into 3 main types: yellow base, people in this group will have yellowish skin (or warm undertone) which is suitable for warm tone colour groups. And another type is blue base (or cool undertone), people in this group have pink skin which will suit the cool tone colour group [19]. But there is another group in the middle called the neutral group, in between the yellow base type and the blue base type.

In addition, personal colour analysis classifies groups of colours to be more specific. Colour groups are named for the seasons, with spring and autumn suited for a warm undertone, and summer and winter for a cool undertone [20],[21]. As shown in Figure 2-2

Figure 2-2 Examples of colours that are suitable for personal colour in each season.

Most personal colour analysis is done using the “Single Colour Drape” method, which is a method of placing a piece of fabric over the subject's body. Colours that promote a person’s skin radiance, healthy looks, and great character are appropriate. Expert analysis requires a great deal of knowledge and experience.

Because every step is detailed and requires precision in analysis which takes quite a long time to analyze, it may cause the participants to be bored, and the analysis cost per one person is quite high.

2.1.3 Colour harmony

When two colours are placed next to each other and the viewer perceives a pleasing unity or balance, the colours are said to be in harmony [22]. Colour harmony was better understood in the early 20th century thanks to the work of Wilhelm Ostwald, Albert Munsell, and Johannes Itten. The relationships between colours in a colour solid or colour-order system were their attempts to define colour harmony [21]. According to Holtzschue, any combination of hues can be harmonious so long as the lightness and chroma are set correctly [23]. The significance of lightness and chroma was noted by numerous other authors [24]. They've also provided some other elements that might affect colour harmony (e.g. rhythm, balance, proportion, scale etc.) [25]. Even though these studies are frequently at conflict with one another, they all reach the same conclusion: colour harmony can be formed if colours have the same hue, differing lightness values, or equal or similar chroma values [26]. In 2010, has been studied and concluded about three different methods for assessing how people perceive different colour combinations; First, “people’s aesthetic preference for a given combination”. Second, “their perception of harmony for that combination”, and Final, “their preference for its figural colour when viewed against a coloured background.” [7]

2.1.4 Universal colour harmony model

It is an equation used to predict the harmony of two colour pairs by considering from the following 4 factors: Hue similarity, Chroma similarity, Lightness difference and High lightness [12]. Which can be calculated from Equation 2.1

$$CH_U = CH\Delta_H + CH\Delta_C + CH\Delta_L + CH_{Lsum} \quad (2.1)$$

which $CH\Delta_H = -0.7\tanh[-0.7+0.04\Delta H^*_{ab}]$

$CH\Delta_C = -0.3\tanh[-1.1+0.05\Delta C^*_{ab}]$

$CH\Delta_L = 0.4\tanh[-0.8+0.05\Delta L^*]$

$CH\Delta_{Lsum} = 0.3+0.6\tanh[-4.2+0.028(L^*_1+L^*_2)]$

where ΔH^*_{ab} is the CIELAB hue difference.

ΔC^*_{ab} is the CIELAB chroma difference.

ΔL^* is the CIELAB lightness difference. [12]

Predicted CH_U scores range from negative to positive. If the score is positive, then these two colour pairs are harmonious. Negative values indicate that these two colour pairs do not represent harmony together.

It can predict the correspondence of the score obtained from the assessment called "Visual result" with the predicted value of the Universal colour harmony model called "Predict value" by plotting the graph between the score values. By analyzing the R value or correlation coefficient, the numbers obtained indicate the accuracy and consistency of the two data sets. For example, if R = 1, the score obtained from the assessment corresponds to the score predicted by the Universal Colour Harmony Model (100% consistent) or R = 0.5, it means that the score obtained from the assessment corresponds to the score predicted by the Universal Colour Harmony Model only 50%.

2.1.5 Characterisation of LCD monitor

2.1.5.1 Definitions of LCD

A liquid crystal display (LCD) monitor, typically seen in laptop computers and flat panel monitors, is a type of computer monitor or display that employs LCD technology to provide sharp images. Traditional cathode ray tube (CRT) monitors, which were the former standard and once thought to have higher picture quality than early LCD models, have been supplanted by this technology. Better LCD technology has been developed throughout time, and LCD is now clearly superior to CRT in terms of colour and picture clarity, as well as having the ability to support high resolutions [29].

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2.1.5.2 Display characterization - The GOG Model

A device-dependent matrix that defines the amount of colour signal in a specific imaging device is used to characterize the display in imaging systems before colour management is applied. The device-dependent matrix expresses the image information in terms of device coordinates RGB and colourimetric meanings of those device coordinates along with colourimetric definitions of the XYZ colourimetric coordinates. For colour reproduction to be device independent, accurate display device characterization is essential [30, 31].

The characterisation model that best represents displays is called the GOG (Gain-Offset-Gamma) model. Through the use of this model, XYZ values of digital input can be anticipated. The following equations define the GOG model's [30]

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} X_{R,white} & X_{G,white} & X_{B,white} \\ Y_{R,white} & Y_{G,white} & Y_{B,white} \\ Z_{R,white} & Z_{G,white} & Z_{B,white} \end{bmatrix} \begin{bmatrix} R(d_R) \\ G(d_G) \\ B(d_B) \end{bmatrix} \qquad (2.2)$$

$$I(d_I) = \begin{cases} (I_g d_I + I_0)^{\gamma_I}, & I_g d_I + I_0 \geq 0 \\ 0, & I_g d_I + I_0 < 0 \end{cases} \quad (2.3)$$

for I = R,G,B

Where ($X_{I,\text{white}}$ $Y_{I,\text{white}}$ $Z_{I,\text{white}}$) are *XYZs* of each channel for a white level ($I = R, G, B$), $I(d_I)$ is the channel luminance for digital input d_I, and I_g, I_o, γ_I are gain, offset, and gamma for each channel.

The GOG model characterizes displays from digital input to XYZ values, however colourimetric characterisation has only been sufficiently established for CRTs due to channel interaction and non-constancy of channel chromaticity, while LCDs lack these features. As a result, the S-curve model of the electrooptical transfer function, which has a nonlinear relationship between the digital input and luminance of each channel, should be used to compensate. The S-shaped characteristic of ICs is now, however, converted to the gamma characteristic by chip manufacturers. The GOG model is adequate to describe the display because of this.

A "device independent" image colour must be characterized, but accurate characterisations and accurate display calibrations are two separate issues. The control scheme for the display system affects calibration. Therefore, accurate display calibrations require the GOG model with actual video factors [32].

LUT represents the video look-up table, N is the number of bits in the digital-to-analog converter (DAC), v_{min} and v_{max} are voltages dependent on the computer video signal generator, a_r and b_r, are the CRT video amplifier gain and offset, $V_{c,r}$, is the cut-off voltage defining zero beam current, γ_r, is an exponent accounting for the non-linearity between amplified video voltages and beam currents, and $k_{\lambda,r}$ is a spectral constant accounting for the particular CRT phosphors and faceplate combination. The common components include the DAC, video LUTs, video signal generator and video amplifier. Because the spectral radiance depends of properties of both the graphics display controller and CRT, characterization of adisplay's spectral or colourimetric properties as a function of digital input must not be made independent of the graphics display controller. The terminology 'display system' will be used, accordingly [33].

By normalizing radiometric measurements by the maximum radiant output, Equation 2.4 is shown

$$L_{\lambda,r} = \begin{cases} (L_{\lambda,r.max}\left(k_{g,r}\left(\frac{LUT_r(d_r)}{2^N-1}\right)+k_{o.r}\right)^{\gamma r} ; \\ \quad \left(k_{g,r}\left(\frac{LUT_r(d_r)}{2^N-1}\right)+k_{o.r}\right) \geq 0 \\ 0 ; \left(k_{g,r}\left(\frac{LUT_r(d_r)}{2^N-1}\right)+k_{o.r}\right) < 0 \end{cases} \tag{2.4}$$

Constants $K_{g,r}$ and $k_{o,r}$ are referred to as the system gain and system offset, respectively. This three-parameter gain, offset and gamma model will be referred to as the 'GOG' model. $L_{\lambda,r,max}$ defines the maximum spectral radiance of the red channel for a given CRT set up [33]. It is useful to define a radiometric scalar, R, according to Equation 2.5

$$L_{\lambda,r} = RL_{\lambda,r,max} \tag{2.5}$$

A properly set up display will, in theory, exhibit additivity between its three channels. Thus using the scalars and considering the three channels simultaneously results in Equations 2.6 (a-c) and 2.7 where n counts wavelength [33].

$$R = \begin{cases} \left(k_{g,r}\left(\frac{LUT_r(d_r)}{2^N-1}\right)+k_{o.r}\right)^{\gamma r}; & \left(k_{g,r}\left(\frac{LUT_r(d_r)}{2^N-1}\right)+k_{o.r}\right) \geq 0 \\ 0; & \left(k_{g,r}\left(\frac{LUT_r(d_r)}{2^N-1}\right)+k_{o.r}\right) < 0 \end{cases} \quad (2.6\text{-a})$$

$$G = \begin{cases} \left(k_{g,g}\left(\frac{LUT_g(d_g)}{2^N-1}\right)+k_{o.g}\right)^{\gamma g}; & \left(k_{g,g}\left(\frac{LUT_g(d_g)}{2^N-1}\right)+k_{o.g}\right) \geq 0 \\ 0; & \left(k_{g,g}\left(\frac{LUT_g(d_g)}{2^N-1}\right)+k_{o.g}\right) < 0 \end{cases} \quad (2.6\text{-b})$$

$$B = \begin{cases} \left(k_{g,b}\left(\frac{LUT_b(d_b)}{2^N-1}\right)+k_{o.b}\right)^{\gamma b}; & \left(k_{g,b}\left(\frac{LUT_b(d_b)}{2^N-1}\right)+k_{o.b}\right) \geq 0 \\ 0; & \left(k_{g,b}\left(\frac{LUT_b(d_b)}{2^N-1}\right)+k_{o.b}\right) < 0 \end{cases} \quad (2.6\text{-c})$$

$$\begin{bmatrix} L_{\lambda=1,pixel} \\ \vdots \\ L_{\lambda=n,pixel} \end{bmatrix} = \begin{bmatrix} L_{\lambda=1,r,max} & L_{\lambda=1,g,max} & L_{\lambda=1,b,max} \\ \vdots & \vdots & \vdots \\ L_{\lambda=n,r,max} & L_{\lambda=n,g,max} & L_{\lambda=n,b,max} \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (2.7)$$

Because of the additive nature of the CRT display, Equation 2.7 can be replace with a colourimetric definition shown in Equation 2.8 [33].

$$\begin{bmatrix} X_{pixel} \\ Y_{pixel} \\ Z_{pixel} \end{bmatrix} = \begin{bmatrix} X_{r,max} & X_{g,max} & X_{b,max} \\ Y_{r,max} & Y_{g,max} & Y_{b,max} \\ Z_{r,max} & Z_{g,max} & Z_{b,max} \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (2.8)$$

If the display is viewed in a lit room resulting in ambient flare reflecting off of the CRT's faceplate or as a result of measurable interreflections from neighbouring pixels, this flare must be added into the characterization, as given in Equation 2.9 [33].

$$\begin{bmatrix} X_{pixel} \\ Y_{pixel} \\ Z_{pixel} \end{bmatrix} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{ambient\,flare} + \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{inter-reflection\,flare} + \begin{bmatrix} X_{r,max} & X_{g,max} & X_{b,max} \\ Y_{r,max} & Y_{g,max} & Y_{b,max} \\ Z_{r,max} & Z_{g,max} & Z_{b,max} \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \qquad (2.9)$$

It is useful to think about the relationship between digital and spectral or colourimetric data as a two-stage process. There is a non-linear relationship between digital counts and the radiometric scalars (Equation 2.6) followed by a linear transformation between the device's 'scalars and spectral radiance (Equation 2.7) or CIE tristimulus values (Equation 2.8) [33]

Calibration refers to achieving a predefined set-up for a display system. For example, one could specify a system gain of unity, system offset of zero, system gamma of 1.25, peak white with chromaticities equivalent to CIE Illuminant D65, and peak white luminance of 75 cd/m^2. To do this, one first characterizes the system's properties i.e. the model parameters of Equations 2.6 and 2.7 or 2.8, followed by digital or analog adjustments based on the differences between the characterization and the reference set-up. Characterization is always required in order to define an image's colourin a 'device-independent' fashion. Requiring calibration depends on how the display systemwillbe used. It may be more efficient for the system manufacturer to develop acolour-rendering dictionary (Postscript Level II) or colour profile (ICC version 3.0) than the user [33].

As shown in Equation 2.6 γ defines the inherent non-linearity of all vacuum tubes and traces back to derivations of Child and Langmuir around 1910 [34]. Unfortunately, γ is used today to represent the entire non-linear relationship expressed in Equation 2.6. In order to differentiate between these two definitions of gamma, the term 'system gamma' with the Greek symbol Γ will be used to represent theentire non-linear relationship. Suppose a monitor has its gun amplifier's offset adjusted (most commonly the ‘contrast control’) with a slight negative bias to insure that zero DAC values yield zero spectral radiance [33]

For determine the colourimetry of each channel, first step in characterizing a display system is to determine the matrix elements of Equation 2.8, i.e. the tristimulus matrix. One method is to use published data of each channel's chromaticities and measurements of each channel's luminance, as shown in Equation 2.2. This reduces the cost of the instrumentation dramatically by requiring only a photometer. However, chromaticities are usually published for a given class of CRT; measurements of individual monitors can have very large differences from the published values. This method is not recommended [33].

$$\begin{bmatrix} X_{r,max} & X_{g,max} & X_{b,max} \\ Y_{r,max} & Y_{g,max} & Y_{b,max} \\ Z_{r,max} & Z_{g,max} & Z_{b,max} \end{bmatrix} = \begin{bmatrix} (\frac{x_r}{y_r}) & (\frac{x_g}{y_g}) & (\frac{x_b}{y_b}) \\ 1 & 1 & 1 \\ (\frac{z_r}{y_r}) & (\frac{z_g}{y_g}) & (\frac{z_b}{y_b}) \end{bmatrix} \begin{bmatrix} L_{r,max} & 0 & 0 \\ 0 & L_{g,max} & 0 \\ 0 & 0 & L_{b,max} \end{bmatrix} \quad (2.10)$$

A second method is to use a colourimeter or spectroradiometer and measure each channel's peak output. The spectroradiometer should have good photometric linearity and wavelength accuracy of within ± 0.5 nm for pictorial imagery [34]. Users of these devices should own radiance or irradiance standards and line sources to calibrate their instruments periodically or send them back to the manufacturer for periodic recalibration. Hopefully, the instrument's software is taking suitable account of the instrument's wavelength-sampling increment, range, and bandpass when calculating tristimulus values. Filter colourimeters should have spectral responsivities that are linear transformations of CIE colour-matching functions (all colourimeters attempt to match the 1931 2°observer). As a rule of thumb, the greater the number of filters, the closer the filter fit. It is possible to use a three-filter device with poor filter fit to estimate tristimulus value for displays with identical channel spectral properties by assuming that the inaccurate device is measuring the radiometric scalars. Multiplying the scalars by the tristimulus matrix obtained using an accurate device will result in reasonable tristimulus estimates [34].

The use of the linear matrix Equation 2.8 has the under- lying assumptions of channel independence (output from one channel does not affect another channel), spatial in-dependence (output from one spatial location does not affect another spatial location), and constancy of each channel's chromaticities. Most monitors adhere to these assumptions to varying degrees. The following tests are recommended before trying to use this tristimulus matrix [33].

- Before Testing : Degauss monitor, and roughly calibrate the display system. In particular, set the gun amplifiers' gains and offsets of the three channels to achieve about the required correlated colour temperature, peak luminance and black level [33]
- Channel independence test : Display animage as shown in Figure 3. The background is set to d_r = dg = db with a luminance of 20% of the peak white. (The grey background represents an average of all displayed images.) The central square is arbitrary in size though it is important that its area is larger than the measuring instrument's aperture in order to

minimize interreflections by the background. Display and measure the tristimulus values of each channel's maximum output and the system's peak white. If the system exhibits channel independence, the sum of the three channels should equal the measured peak white. Typically, a lack of channel independence is due to overdriving the gun amplifiers. This is remedied by decreasing each channel's gain (often labelled as the 'contrast' control [33].

- Spatial independence test : The central stimulus is set to the system's peak white. The background is first set to dr=dg=db=0 and the central stimulus is measured. The background is next set also to the peak white and central stimulus remeasured. Differences between the two measurements indicate a lack of spatial independence. A lack of spatial independence relates to power supply limitations, the extent of which is image-dependent [33]

2.2 Literature reviews

Ou et all. [12] Universal models of colour emotion and colour harmony (vol 43, pg 736, 2018). has created a new colour harmony model based on data collected from 12 regions of the world. This new model is calculated from hue similarity, chroma similarity, lightness difference and high lightness principles which the new colour harmony model can predict up to 72% accuracy.

Ou and Luo. [25] In order to create a quantitative model, this study explores the harmony in two-colour pairings. In a psychophysical study for the evaluation of visual harmony, 1431 colour pairs were employed as stimuli. Each colour pair's degree of colour harmony was evaluated using a 10-category scale that ranged from “extremely harmonious” to “extremely disharmonious.” The experimental results revealed a general pattern of two-colour harmony, which served as the basis for the development of a quantitative model and the derivation of harmony-creating principles. Numerous colour harmony rules were formed as a result of the scientific findings, such as the equal-hue rule, which states that the less the chromatic difference, the better the colour harmony yields. high lightness principle: The higher the scores for colour harmony, the higher the lightness sum value, etc.

Hong and Kim. [11] A customized colour analysis system mobile app was created, which identifies the colours of apparel that complement a user's specific skin tone and hair colouring. In the personal colour analysis, skin tone and hair colour are categorized according to factors of lightness. Which can classify people more thoroughly than traditional personal colour analysis. This new analysis does not require an expert to avoid problems such as reducing the time and boredom of analyzing and the annoyance of putting a coloured fabric over the subject's body.

David and Reiner. [19] assessed whether participants preferred apparel with colours associated with variations in melanin levels in White women. In addition to favoring 'cool' blue hues to match fair skin and 'warm' orange/red hues to match tanned skin, observers demonstrated strong preferences for the colours red and blue. According to this finding, clothing colour preferences may be influenced by skin tone.

Hong and Kim. [35] investigated whether wearing different red colours made women appear more attractive to both men and women in photographs and whether there was a difference in how people reacted to different clothing colours based on their physical colour attributes, as determined by the Personal Colour Analysis System. The results indicate that the four different red shades, low chroma/high value, low chroma/medium value, high chroma/medium value, and low chroma/low value can make women appear more attractive in digital photos. This study demonstrates that while examining the meanings of clothing colours, colour value and chroma should be considered variables.

CHAPTER III

METHODOLOGY

3.1 Apparatus

3.1.1 Spectroradiometer

Model : Konica Minolta CS-2000

Wavelength range : 380 to 780 nm

Spectral bandwidth : 5 nm or less (half bandwidth)

Wavelength resolution : 0.9 nm/pixel

Display wavelength bandwidth: 1.0 nm

Wavelength precision : ±0.3 nm (Median wavelength: 435.8 nm, 546.1 nm, 643.8 nm; Hg-Cd lamp)

Luminance accuracy : ±2%, +1digit

Chromaticity accuracy : ±0.0015x (0.05 cd/m²), ±0.001y

Luminance repeatability : +0.1%, +1digit

Chromaticity xy repeatability : ±0.002

Polarization error : 2 % or less(400 to 780 nm)

3.1.2 Spectrophotometer

Model : Konica Minolta CM-700d

Size of integrating sphere : Φ40mm

Wavelength range : 400 to 700 nm

Wavelength pitch : 10 nm

Observer : 2° observer or 10° observer

Illumination/viewing system : di: 8°, de: 8° (diffused illumination, 8-degree viewing angle), SCI (specular component included) / SCE (specular component excluded)

Half bandwidth : Approx. 10 nm

Repeatability : Spectral reflectance (S.D. within 0.1%), Chromaticity value (S.D. within ΔE*ab 0.04)

Inter-Instrument Agreement : Within ΔE*ab 0.2

3.1.3 LCD monitor

Model : BenQ SW270c

Size : 27" 16:9 wide screen

Screen Area : 23.49 x 13.21" / 596.7 x 335.6 mm

Panel Type : IPS-Type LCD

Resolution : 2560 x 1440 pixels

Maximum Brightness : 300 cd/m^2

Contrast Ratio : 1000:1

Bit Depth / Colour Support : 10-Bit (1.07 Billion Colours)

Colour Gamut : 100% sRGB, 100% Rec. 709, 99% Adobe RGB, and 97% DCI-P3

Dot pitch : 0.2331 x 0.2331 mm

3.1.4 Laptop computer

Computer Model	: HP Laptop 15s-eq3001AU
System	: Windows 11 Home
CPU	: AMD Ryzen 7
RAM	: 16 GB

3.1.5 HDMI cable

UGREEN 8k/ 60hz 4k/120hz 48gbps HDCP 2.2

3.1.6 Software

Simulation Program	: knt_lab run on .NET Framework
Microsoft .NET Framework	: Version 3.5 Service Pack 1 (required at least v2.0.50727)
Spreadsheet	: Microsoft Excel | Microsoft 365

3.2 Experimentation

The objective of this research was to evaluate the degrees of colour harmony for skin tone and colour samples. The resulting colour harmony scores could then be used for personal colour analysis. To do so, a series of colour pairs was generated to display on an LCD monitor. Observers assessed these colour pairs and quantified the degrees of colour harmony for each pair presented. The visual data were then statistically analysed.

Figure 3-1 depicts the experimental processes of this study. In the preparation process, colour samples, including skin tone samples and colour samples that represent personal colour, were prepared, along with an LCD monitor and a method to correctly display the samples on the monitor. The selection of colour samples and the process of colour transformations are described in Sections 3.2.1 and 3.2.2, respectively. The visual experiments were then carried out, where observers assessed colour pairs and rated their degrees of colour harmony. The detailed descriptions for this part are given in Section 3.2.3. Finally, the visual and colourimetric data were analysed using a variety of statistical measures. The data analysis is explained in Section 3.2.4

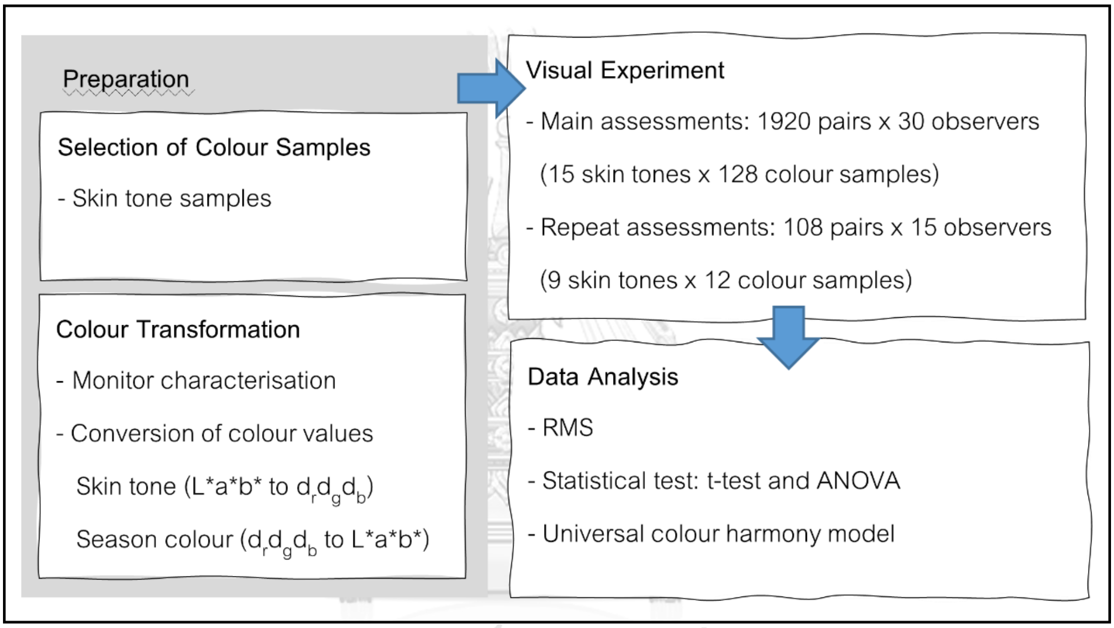


Figure 3-1 An overview of experimentation.

3.2.1 Selection of colour samples

The present study examined colour harmony between skin tones and colour samples as a way to determine personal colour. As a result, there were two sets of colour samples to prepare: skin tone samples and colour samples representative of personal colour.

1) Skin tone samples

The skin tone samples were selected from Pantone SkinTone Guide, which contains a total of 110 skin tones. Colour measurements of all 110 skin tones were made with a spectrophotometer in terms of CIELAB colour values (D65/2, SCI MAV measurement). The distributions of 110 skin tones in a*b* and L*C*ab planes are shown in Figure 3-2. Each Pantone SkinTone patch has a four-digit alpha numeric number representing undertone and tone of the skin colours [17]. The undertone is divided into two types: yellow and red. From the a*b* plot of all SkinTone Guide samples, a 60-degree hue angle line can separated the yellow and red undertones [36]. The range of lightness for yellow and red undertones were 45.45-71.79 and 35.20-66.93, respectively. As for chroma, they were in the range of 17.04-22.38 and 15.17-24.84 for yellow and red undertones, respectively.

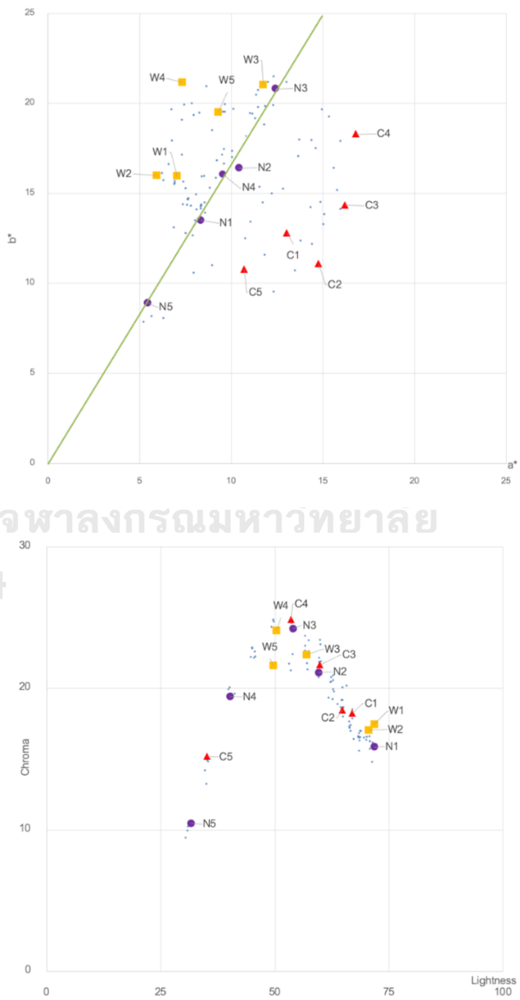


Figure 3-2 Distributions of Pantone SkinTone samples and the samples used in this study.

Given the principles of personal colour, the skin undertone determines a person's best-worn colours in clothing and cosmetics. As a result, five samples for each undertone were selected in such a way that they provided good coverage of all samples, allowing for a good presentation of each undertone. Furthermore, the other five samples were selected along the 60-degree hue angle line to represent neutral undertones. In total, 15 skin tone samples were selected. Table 3-1 summarises the information about the skin tone samples, including the Pantone SkinTone Guide numbers, colourimetric values, and codes used to represent the samples in this study. It's worth noting that a red undertone is the same as a cool undertone.

Table 3-1 The 15 skin tone samples.

Pantone number	L*	a*	b*	C*ab	Code
4Y01	71.79	7.03	15.97	17.45	W1
5Y02	70.52	5.93	15.98	17.04	W2
4Y07	62.80	7.94	19.32	20.89	W3
5Y09	56.92	7.33	21.15	22.38	W4
3Y12	45.45	9.65	19.94	22.15	W5
3R05	66.93	13.02	12.78	18.24	C1
5R06	64.79	14.75	11.08	18.45	C2
4R08	59.87	16.21	14.34	21.64	C3
3R10	53.60	16.81	18.29	24.84	C4
4R14	35.20	10.69	10.77	15.17	C5
2Y02	70.82	8.10	14.09	16.25	N1
1R06	65.29	9.16	15.85	18.31	N2
2Y11	50.36	11.72	21.03	24.08	N3
2Y13	41.18	9.52	17.14	19.61	N4
1R15	31.65	5.45	8.91	10.44	N5

2) Colour samples

To examine whether the colour harmony analysis can be used to determine personal colour, the colour samples paired with the skin tone samples should be accurate representations of personal colour types. Some personal colour principles have been established, such as that warm hues flatter a warm undertone and cool hues complement a cool undertone. Personal colour samples from Kim and Kim's study were used in this study [13]. In their study, personal colours were classified into four groups, named after the four seasons: spring, summer, autumn, and winter. Each group contained 32 colours, resulting in a total of 128 colours. The colourimetric distributions of the colour samples representing personal colour groups, hereafter denoted as "season colours", are shown in Figure 3-3.

Figure 3-3 Distributions of 128 season colours (32 colours in each season).

From Figure 3-3, it can be seen that spring is a warm hue, which is mostly spread across the positive a* and b* axes. And considering lightness and chroma plane, it can be seen that the spring colour group has lightness value from about 30 to 100 and chroma distribution from 20 to 125. That means that spring is a high lightness and high chroma.

Next, Summer is a cool hue which can be seen from the distribution that is concentrated in the middle of the graph and is negatively distributed along the a* and b* axes. And when considering lightness and chroma, it will be found that the lightness distribution is from 15 to almost 100 (similar to the spring distribution), but the chroma is distributed in a narrower area. It ranges from about 0 to 60, so it can be concluded that summer has high lightness but low chroma.

After that, Autumn is a warm hue colour based on its spread, similar to spring distributed along the positive a* and b* axes. Considering the lightness and chroma, it is found that the lightness is concentrated in the region of 40 to 70, and chroma tends to be concentrated between 20 and 60; it is assumed that autumn will also have a low lightness and low chroma.

Finally, Winter is a cool hue, which can be determined by the distribution being more on the negative a* and b* axis than on the positive axis. Looking at the lightness and chroma plane, it is found that the lightness is concentrated, starting from 20 to about 70, but the chroma is more distributed from 0 to about 120. According to the distribution data in the plane. This implies that winter is a colour group with low lightness and high chroma.

Figure 3-4 depicts all experimental samples. In summary, two sets of samples included 15 skin tones and 128 season colours, creating 1920 colour pairs. The skin tones were classified into three undertone types: warm (W), cool (C), and neutral (N). Each undertone consisted of five skin colours varying in lightness from 1 (the highest) to 5 (the lowest). The season colours were classified into four groups. Each group had 32 colours: spring (SP1–SP32), summer (SM1–SM32), autumn (AT1–AT32), and winter (WT1–WT32).

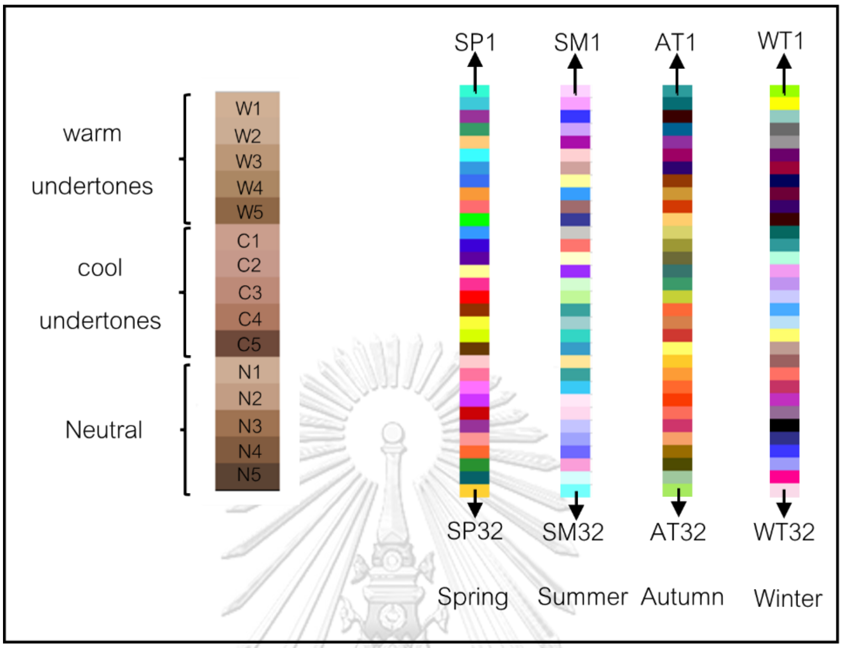


Figure 3-4 All experimental samples.

The skin tones were paired with season colous. Each colour pair was made of two 2”x2.3” (5 cm x 5.8 cm) single colour patches. The observer was seated at a distance of 80 cm from the screen, subtended a visual angle of 3.58 degrees. The samples were presented side by side without a gap against a uniform grey background in the centre of the monitor. Figure 3-5 demonstrates the steps in creating a colour pair.

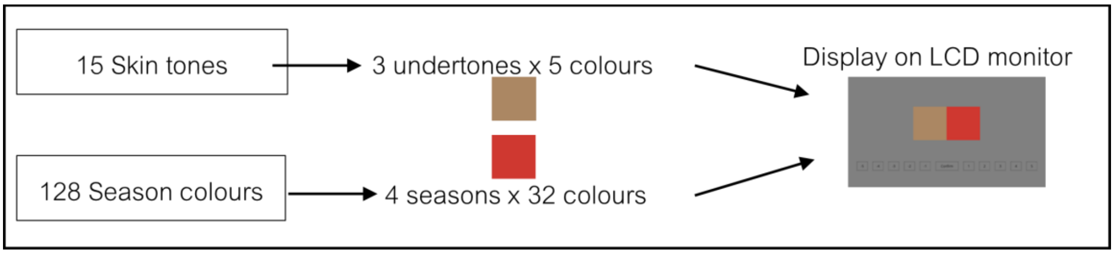


Figure 3-5 A creation of experimental colour pair.

3.2.2 Colour transformation

To display an image on a monitor, digital RGB values (d_r, d_g, d_b) are required. The skin tone samples selected from Pantone SkinTone Guide were physical colour patches that their colour values were measured in terms of CIEL*a*b* under D65/2 condition. In the case of season colours, the digital RGB values were obtained from the study by Kim and Kim [13]. Thus, in order to correctly display colour samples on the monitor, the L*a*b* values of skin tone samples must be converted to digital RGB values via a reverse monitor characterisation model. Conversely, in order to obtain the correct colourimetric values of the samples displayed on the monitor, the digital RGB values of season colours must be converted to L*a*b* values via a forward monitor characterisation model. Section 3.2.2.1 describes the process of monitor characterisation. Conversions between colour values are given in Section 3.2.2.2.

3.2.2.1 Monitor characterisation

To accurately display desired colours on a monitor, a monitor characterisation process is needed. This study employed the GOG model (see Section 2.1) to characterise the LCD monitor. It is worth noting that the characterisation process as well as the visual experiments were carried out in a darkened room to eliminate the effects of ambient light. A training set comprised 33 grey patches (equal digital RGB from 0 to 255 with 8-unit intervals) together with red (255-0-0), green (0-255-0) and blue (0-0-255). The accuracy of the characterisation model was tested using a test set that comprised 27 colours (all possible combinations of digital RGB of 0, 127, and 255). Colour patches were presented on a uniform grey background (R=G=B=128) in the centre of monitor's screen with its white point set to D65.

Figure 3-6 shows a set-up of the characterisaton process. Colour measurements of all samples were made with a spectroradiometer in terms of "xyY" values. The spectroradiometer was positioned in front of the LCD monitor at a distance of about 80 cm. It is worth noting that this distance is the same as observers' position when performing visual experiments. The GOG model was then implemented using a spreadsheet available in Microsoft Excel and the model parameters: k_g, k_o, and gamma (γ) for each channel, were solved. Table 3-2 provides a summary of the model variables that were obtained from characterising the LCD monitor.

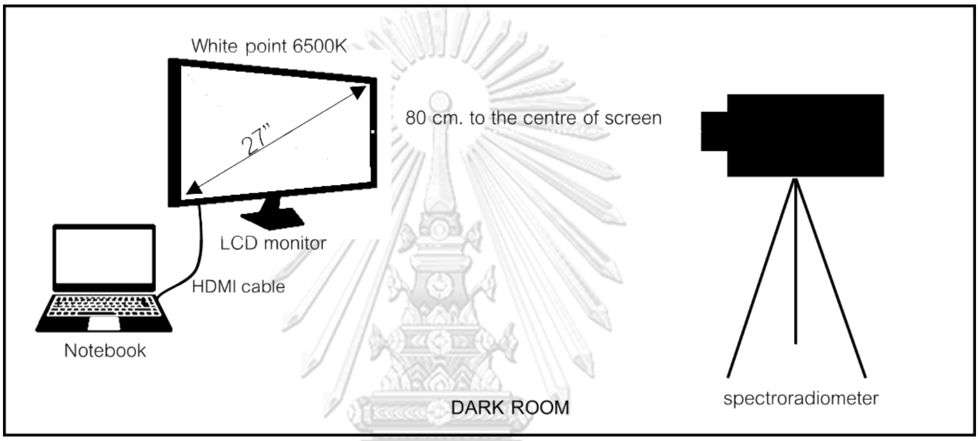


Figure 3-6 A set-up for LCD monitor characterisation.

Table 3-2 The variables in the GOG model.

Variable	Value
White point (X_w, Y_w, Z_w)	95.123, 100.000, 114.187
Red (X, Y, Z)	40.396, 20.414, 1.319
Green (X, Y, Z)	34.560, 71.819, 11.051
Blue (X, Y, Z)	20.006, 71.819, 104.380
For red ($k_{g,r}$, k_O, γ_r)	0.7962, 0.2038, 3.2770
For green ($k_{g,r}$, k_O, γ_r)	0.8036, 0.1964, 3.1778
For blue ($k_{g,r}$, k_O, γ_r)	0.7827, 0.2173, 3.3353

The accuracy of the GOG model was tested using the test set of 27 colours. Colour difference (ΔE^*_{ab}) between calculated L*a*b* values from GOG and measured L*a*b* values from the display was taken as a means of testing the model performance. The small ΔE^*_{ab} value indicates that the displayed colours closely resemble the colour appearance intended for investigation. The average ΔE^*_{ab} value from the 27 colours was 2.61, with a range of 0.963-7.401. These colour differences were considered as small.

3.2.2.2 Conversion of colour values

A reverse monitor characterisation model will transform XYZ values to digital RGB in order to display a colour that has the same colour appearance as is desired. Conversely, a forward monitor characterisation model will transform digital RGB to XYZ so as to obtain colour correlates. For skin tone samples, the reverse GOG model was employed to obtained digital RGB values, as the L*a*b* values were obtained from measuring the physical colour samples. For season colours, the forward GOG model was applied for converting digital RGB values to XYZ values, and then to L*a*b* for data analysis. Figures 3-7 and 3-8 illustrate a computational step for converting colour values of skin tone samples and season colours, respectively.

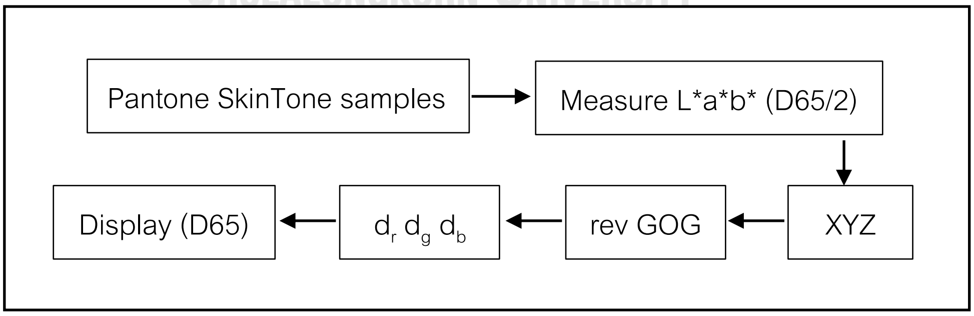


Figure 3-7 Conversions of colour values for skin tones.

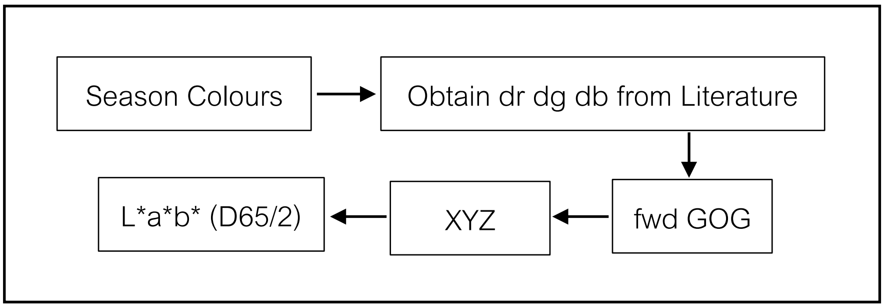


Figure 3-8 Conversion of colour values for season colours.

3.2.3 Visual experiment

Thirty Thai observers, including 15 females and 15 males ranging in age from 21 to 40 years old participated in the visual experiments. All observers had a normal colour vision. Before conducting the actual experiments, each observer was given a definition of colour harmony as follows. *"Figural preference as how much the observer likes the figural colour itself, when viewed against its background colour."* [38] In addition, the following instruction was given to the observers. *"In this experiment, we will show the colour of the human skin colour in combination with other colours. Your task is to rate the degrees of colour harmony from -5 to -1 when the combination is disharmonious, and from 1-5 when the combination is harmonious. The numbers -5 and 5 are the extreme degrees for both ends of the scale."* The observers were also trained how to use the interface of the program specifically created for displaying the experimental colour pairs and obtaining the visual scores of colour harmony.

Observers sat at a distance of approximately 80 cm in front of the LCD monitor. The grey background was displayed on the monitor for 10 seconds, allowing observers to adapt their eyes to the experimental environment (a darken room, a white point of the monitor set to D65) by looking at the grey screen. Having done so, the first colour pair appeared in the centre of the screen for evaluation (Figure 3-9).

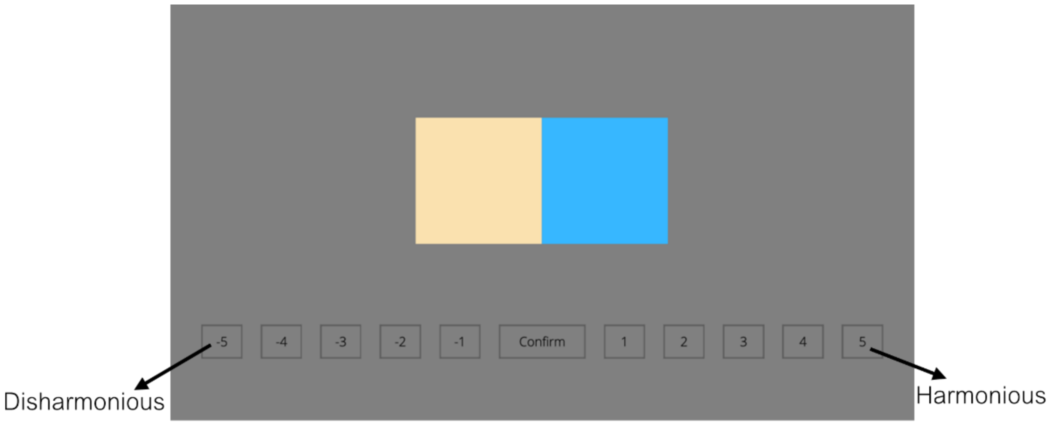


Figure 3-9 Screen layout for visual experiments.

As shown in Figure 3-9, underneath the colour pair was ten buttons arranged in a horizontal line. Each button corresponded to a colour harmony score on an equal interval scale. The scores were separated into two sides: disharmonious (left side of the screen, presented by negative numbers) and harmonious (right side of the screen, presented by positive numbers). The scale ranged from -5 to -1 for disharmonious, where -5 means completely disharmonious and -1 means just disharmonious, and 1-5 for harmonious, where 1 means just harmonious and 5 means completely harmonious.

The observers pressed the relevant button to give a colour harmony score for the colour pair currently presented. They could change the score by pressing other buttons so long as they had not yet pressed the “Confirm” button. Once the “Confirm” button was pressed, the score was recorded. The observers were then presented with a grey background to prevent after-image effects. After 2 seconds, the next colour pair was displayed. The observers continued these steps (Figure 3.10) until all colour pairs in the given session were evaluated. The colour pairs were presented in a random order for each observer.

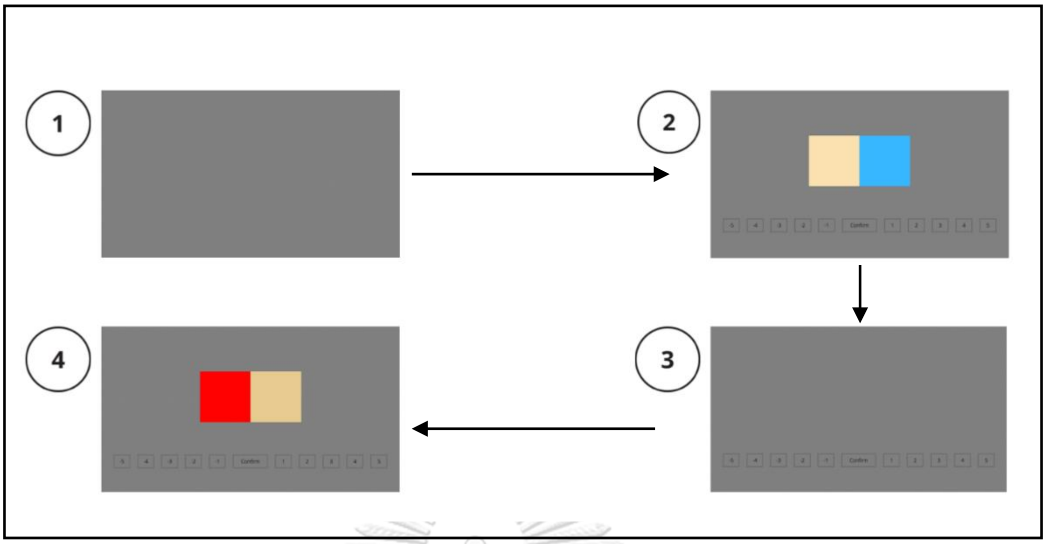


Figure 3-10 Sequence of colour pair’s presentation.

All observers completed all 1,920 colour pairs; the experiments were divided into 6 sessions. Each session contained 320 colour pairs. Observers spent about 20–40 minutes to complete each session. Observers took a 15- to 20-minute break before the next session or came back to do the next session on another day. Fifteen observers were asked to complete one additional session containing 108 colour pairs for the repeatability test. The repeat session took about 15 minutes to complete.

3.2.4 Data analysis

The visual results obtained from 30 observers for 1,920 colour pairs were analysed by many means to investigate relationships between skin tones and personal colours. Statistical measures used for data analysis are given below.

1. The average value from 30 observers was used to represent the colour harmony score for each colour pair.

2. A root-mean-squared (RMS) value was used to investigate reliability of the visual results. For the repeatability test, the RMS between the observer's first and

second responses were calculated by Equation 3.1 (intra-observer agreements). For inter-observer agreement, the RMS between each individual's results and the panel results were calculated by Equation 3.2.

$$\mathrm{RMS} = \sqrt{\frac{\Sigma(x_i - y_i)^2}{N}} \quad (3.1)$$

$$\mathrm{RMS} = \sqrt{\frac{\Sigma(x_i - \bar{x}_i)^2}{N}} \quad (3.2)$$

For intra-observer agreements, x_i represents an observers' first response for colour pair *i* and y_i represents the same observers' second response to the same colour pair. *N* is the total number of colour pairs repeated, that is 108 in this experiment. The mean RMS from 15 observers was calculated to represent intra-observer agreement.

In the case of inter-observer agreements, x_i represents the colour harmony score given by an observer for colour pair *i*, $\bar{x}_i$ represents the mean colour harmony score from all observers for colour pair *i*, and *N* is the total number of coour pairs, that is 1,920 in this study. The level of observer agreement was represented by the mean RMS from 30 observers.

3. A number of statistical hypothesis tests were employed to investigate whether the data support an assumption. These included a paired t-test, independent t-test, and two-way ANOVA.

4. The universal colour harmony model [12] was applied to predict the degrees of colour haromany for each pair. The results were compared with the visual data obtained in this study. A corralation coefficient (r-value), ranging from -1 to 1, was used to indicate the strength of the linear relationship between the visual results and the predicted values. A value of zero means no linear relationship between the two data sets. A value of -1 indicates a perfect negative correlation, and 1 a perfect positive correlation.

5. The measure of correct decision (CD) [25] was used to quantify the performance of the personal colour principles with regard to the visual data obtained in this study. The CD value can be calculated by Equation 3.3.

$$CD = \frac{\sum_i c_i}{N'} \qquad (3.3)$$

c_i represents the percentage of observers whose harmony judgements for colour pair i (in terms of the decision between "harmonious" and "disharmonious") agreed with a given personal colour principles. N is the number of colour pairs.

CHAPTER IV
RESULTS AND DISCUSSIONS

4.1 Observer variance

Thirty observers rated the colour harmony of 1,920 colour pairs (all combinations of 15 skin undertones paired with 128 colour samples) on an integer scale ranging from -5 to 5. The observers were asked to rate the colour harmony based on how beautiful or harmonious they thought the particular skin tone looked when paired with the other colours. The colour harmony scores averaged from 30 observers for each pair were used to represent the visual results. The reliability of the visual data was tested in terms of intra-observer agreement and inter-observer agreement, and the results are discussed in Sections 4.1.1 and 4.1.2, respectively.

4.1.1 Intra-observer agreement

In order to investigate the reliability of the visual results, 108 colour pairs were selected for repeating the experiments. They were 9 skin tones, of which 3 samples were selected from each undertone (warm, cool, and neutral), paired with 12 colour samples, of which 3 colours were selected from each season of personal colour (spring, summer, autumn, and winter). Fifteen observers assessed these colour pairs twice on different occasions. The differences between the two responses to the same colour pairs were calculated in terms of the root-mean-squared (RMS) value. If the RMS value is high, it indicates that observers give distinctive scores for the same pair. This means that the observers are unable to determine their colour harmony scores; the experiments are too difficult, or the observers do not understand how to perform them properly. Alternatively, the observers may not pay attention to the experiments because they are too tedious or take too long, resulting in fatigue. In this case, the results will be random and unreliable.

Table 4-1 shows the RMS values between observers' first and second responses for 108 colour pairs of 9 females, 6 males, and all 15 observers. The mean results revealed that the agreements within themselves for male observers were better than those for female observers. However, when the minimum and maximum values were considered, it was discovered that male observers' performance varied greatly between observers. Female observers, on the other hand, performed similarly across observers, so the range between min and max RMS values was small. It is possible that most females have similar attitudes towards colour as a source of beauty. They would then be more familiar to judge what colour combinations looked beautiful. However, in the case of males, the performance highly depends on the individual: some males do not pay much attention to colour, whereas others could be very attentive. Hence, for those who were reckless, the agreements between the two responses may be poor. The attentive males may form a criterion in their mind what they thought was beautiful, so they were able to give consistent responses.

Table 4-1 RMS for intra-observer agreement

RMS value	Female	Male	All observers
Mean	1.90	1.64	1.76
Min	1.68	0.54	0.54
Max	2.07	2.60	2.60

The intra-observer agreements were not high on average, as the mean RMS values were below 2, i.e. about 20% error. Given the nature of visual experiments, 20-30% errors are expected. The previous studies also showed the level of consistency of observer responses within this range [25]. Thus, it could be assumed that all observers gave consistent responses and the visual data were reliable. Furthermore, to investigate whether the first and second responses were significantly different, a paired t-test was employed with a null hypothesis that the mean difference between the two responses is zero. The null hypothesis is accepted at a significance level of 0.05 or with a confidence interval of 95%. The results are shown in the Table 4-2. When the null hypothesis is accepted, the agreement from assessment and repeat scores is not significantly different with the 95% confidence. If the computed paired t-value (t Stat) is upper than the critical t-value (or the p-value is lower than 0.05), the null hypothesis will be rejected or the alternate hypothesis will be accepted. That means there is a significant difference between the assessment and repeat scores with the 95% confidence.

Table 4-2 A statistical analysis, using a paired t-test, for intra-observer agreements.

	Assessment score	Repeat score
Average	-0.080	0.008
Variance	7.976	7.318
Observations	1,620	1,620
Pearson Correlation	0.781	
df	1619	
t Stat	-1.940	
P(T<=t) two-tail	0.053	
t Critical two-tail	1.961	

From Table 4-2, it was found that the Pearson correlation value was 0.781, meaning the data analyzed were related to each other. The resulting p-value is 0.053, which is greater than 0.05, thus accepting the null hypothesis, confirming the reliability of the visual results.

4.1.2 Inter-observer agreement

The inter-observer agreement indicates how well the observers agree with one another. The results were represented by the RMS values between each individual observer's scores and the panel results averaged from all observers. Table 4-3 summaries the results for 15 females, 15 males, and all 30 observers. The agreement between all observers was within a range of 2-3 RMS values, which had the same level of consistency of observer responses as the previous studies [25].

Table 4-3 RMS for inter-observer agreement

RMS value	Female	Male	All observers
Mean	2.45	2.77	2.62
Min	2.00	1.96	1.96
Max	3.28	3.84	3.83

The mean RMS of females was lower than that of males. This means that females scored in the same direction. Females scored different from the majority at about 25%, whereas males scored different from the majority at about 28% on average. It was also found that a range of RMS from minimum to maximum values for females was narrower than that of males. This means differences between the observer who had the best agreement with the panel and the observer who was the worst for females were smaller, indicating better agreement between female observers. It could be that females had similar principles for beautiful combinations of colours.

The independent t-test was employed with a null hypothesis that there is no significant difference between male and female RMS results (Table 4-4). The results revealed that the agreement between observers with the same gender was not different between females and males. This means that both female and male observers agreed well with the panels.

Table 4-4 A statistical analysis, using an independent t-test, for inter-observer agreements.

	Female	Male
Average	2.418	2.718
Variance	0.161	0.331
Observation	15	15
df	28	
t Stat	-1.654	
P(T<=t) two-tail	0.109	
t Critical two-tail	2.048	

4.2 Effect of skin undertone

The experimental colour pairs were generated by combining a skin tone sample with the other colour from four season groups of personal colour. There were 15 skin tone samples divided into three skin undertones: warm, cool, and neutral, with 5 samples assigned to each undertone. The results were then analysed separately for each type of undertone. This was done with the underlying assumption that personal colour is determined by the type of skin undertone. When combined with colours from the same season group, the same skin undertone will look equally best. First, the best and worst pairs for various skin undertone types were compared, and the results are shown in Section 4.2.1. Section 4.2.2 discusses the effect of skin undertones on the colour harmony scores of four seasons.

4.2.1 The best and worst harmonious colour pairs

Based on all observer's average scores from 1,920 colour pairs, the scores were rearranged in a sequence of harmonious pairs for warm undertone, cool undertone, and neutral group. The results of the top ten best and the top ten worst of the 640 colour pairs in the warm undertone group are shown in Table 4-5, and the result for the cool undertone group (640 pairs) in Table 4-6, and the result for neutral undertone group (640 pairs) in Table 4-7.

Table 4-5 The top ten best and worst colour pairs for the warm undertone group.

	Sample	Skin tone	Season colour	Average score
1		W2	SM10	3.03
2		W1	WT7	3.00
3		W1	WT11	2.93
4		W1	WT12	2.90
5		W2	SM12	2.83
6		W2	WT7	2.83
7		W1	AT3	2.80
8		W1	WT22	2.80
9		W2	WT22	2.73
10		W3	WT22	2.70
.	.	.	.	.
641		W4	SP11	-2.53
642		W5	WT29	-2.57
643		W5	WT25	-2.60
644		W1	SP11	-2.63
645		W2	WT1	-2.63
646		W4	WT1	-2.63
647		W2	SP11	-2.67
648		W5	WT1	-2.67
649		W3	WT1	-2.83
640		W3	SP11	-3.13

From Table 4-5, the best harmonious pair was “W2” paired with “SM10” with an average score of 3.03, and the worst harmonious pair was “W3” paired with “SP11” with an average score of -3.13. It is noticeable from the table that the majority of the top ten best pairs were those with reddish colours. This agrees with the personal colour principle that warm undertones look best with warm hues such as red, orange, brown, etc. In contrast, warm undertones look worst with cool hues such as green, blue, pink, etc. The results of the worst pairs also agree with this principle, as most pairs were those coupled with green. However, when considering season colours, there were 7 out of 10 best pairs that were coupled with winter colours. These results contradict the principle that warm undertones harmonise with spring and autumn colours [19]. It was also found that the top ten best pairs were those of warm undertones with high lightness levels. In contrast, the top worst pairs were those of warm undertones with low lightness levels.

From Table 4-6, the best harmonious pair was “C2” paired wtih “SM12” with an average score of 3.03, and the worst harmonious pair was “C4” paired with “WT1” with an average score of -2.77. Based on the principles of personal colour, cool undertones look best with summer and winter colours [19]. The findings agreed well with the principles, as 8 out of 10 best pairs were those of summer and winter colours. However, for the worst pairs, the results contradicted with the principles, as 6 out of 10 worst pairs were those of winter colours. It was also found that the high colour harmony scores were obtained for colour pairs with high lightness skin tones.

Table 4-6 The top ten best and worst colour pairs for the cool undertone group.

	Sample	Skin tone	Colour code	Average score
1		C2	SM12	3.03
2		C3	SM12	2.87
3		C1	SP31	2.77
4		C2	SP22	2.73
5		C1	SM12	2.70
6		C2	WT9	2.67
7		C1	WT22	2.60
8		C2	WT22	2.53
9		C1	SM26	2.50
10		C3	WT22	2.50
.	.	.	.	.
641		C5	WT15	-2.10
642		C4	WT29	-2.17
643		C4	SP11	-2.23
644		C5	WT29	-2.23
645		C5	WT1	-2.33
646		C2	SP20	-2.43
647		C3	WT1	-2.63
648		C1	SP11	-2.70
649		C2	SP11	-2.70
640		C4	WT1	-2.77

Table 4-7 The top ten best and worst colour pairs for the neutral undertone group.

	Sample	Skin tone	Colour code	Average score
1		N1	SM12	2.87
2		N4	SM12	2.73
3		N3	SM12	2.67
4		N1	SP31	2.63
5		N5	SM12	2.63
6		N1	SP18	2.60
7		N1	WT9	2.57
8		N1	WT12	2.57
9		N1	WT7	2.50
10		N1	WT22	2.50
.	.	.	.	.
641		N2	SP11	-2.07
642		N1	SP11	-2.10
643		N3	WT1	-2.17
644		N3	SP11	-2.20
645		N5	AT30	-2.23
646		N1	WT1	-2.43
647		N5	WT1	-2.47
648		N3	WT29	-2.50
649		N2	WT1	-2.57
640		N4	SP11	-2.63

From Table 4-7, the best harmonious pair was “N1” paired with “SM12” with an average score of 2.87, and the worst harmonious pair was “N4” paired with “SP11” with an average score of -2.63. Grey seemed to be the best colour to couple with neutral undertones, as there were 4 pairs with grey in the top five best harmonious pairs. The top ten best pairs were mixed with both warm (reddish) and cool (bluish) hues. This indicates that neutral undertones harmonise with both warm and cool hues. As for the season colours, the majority of the top ten best were summer and winter colours. The similar trend to warm and cool undertones was also found that neutral undertones with high levels of lightness were prevalent in the top ten best pairs. In addition, the bright green colours unflatter all skin undertones, as among the top ten worst harmonious pairs were those of bright green coupled with all skin undertones.

4.2.2 Analysis of skin undertone and season colour

A two-way ANOVA was employed to investigate the impacts of skin undertones and colours classified into four seasons on the colour harmony scores. The result from the two-way ANOVA will identify the factors (skin undertone and season colour) that influence the colour harmony scores and whether there is an interaction between the two factors. Firstly, the test was performed for each type of skin undertone, i.e. warm, cool, and neutral. For each type, there were 5 different skin colours, denoted by the numbers 1 to 5, where 1 represented that particular skin undertone with the highest lightness and 5 the lowest, and the numbers in between represented the lightness in descending order.

Personal colour analysis assumes that the same type of skin undertone will be harmonious with colours from one season but disharmonious (or have significantly low colour harmony scores) with those from another. For example, the warm undertone is expected to have significantly higher colour harmony scores with summer colours than with the other season colours. However, the warm undertones with different lightness levels (warm 1 to warm 5) are expected to yield no significant difference. In the two-way ANOVA, the hypotheses for the factor of skin lightness are as follows.

$H_0 \quad : \quad \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5$

$H_1 \quad : \quad \mu_1 \neq \mu_2 \neq \mu_3 \neq \mu_4 \neq \mu_5$

Where H_0 is a null hypothesis, representing that the mean scores of all warm undertones are not different. H_1 is an alternative hypothesis, representing that the mean scores of all warm undertones are different, or at least one group is different. The null hypothesis is accepted at a significance level of 0.05 or with a 95% confidence interval.

The hypotheses for the factor of season colour are as follows.

$H_0 \quad : \quad \mu_1 = \mu_2 = \mu_3 = \mu_4$

$H_1 \quad : \quad \mu_1 \neq \mu_2 \neq \mu_3 \neq \mu_4$

Where H_0 is a null hypothesis, representing that the mean scores of all four seasons are not different. H_1 is an alternative hypothesis, representing that the mean scores of all four seasons are different, or at least one group is different. The null hypothesis is accepted at a significance level of 0.05 or with a 95% confidence interval. Table 4-8 summarises the results of two-way ANOVA for the three types of skin undertone.

As can be seen from Table 4-8, the colour harmony scores for each season were significantly different for all skin undertone types, indicating that season colours had impacts on the colour harmony of skin undertones. However, significant differences were also found within the skin tones of the same undertone types, implying that the same undertones did not yield the same colour harmony when paired with the same colours. There was no interaction between the two factors (undertone lightness and season). This revealed that skin undertones with different levels of lightness and season colours affected the colour harmony scores separately.

Table 4-8 A statistical analysis, using two-way ANOVA for each type of skin undertone.

Undertone	Source	df	P-value
Warm	Season	3	0.000*
	Skin lightness	4	0.000*
	Interaction	12	0.671
Cool	Season	3	0.006*
	Skin lightness	4	0.000*
	Interaction	12	0.963
Neutral	Season	3	0.000*
	Skin lightness	4	0.000*
	Interaction	12	0.952

* Significant differences

For further analysis, the two-way ANOVA was performed to test the influence of skin undertone and season colour. The average scores from all 5 lightness levels were taken as the colour harmony scores of each undertone type. The results are shown in Table 4-9.

Table 4-9 A statistical analysis, using two-way ANOVA for different types of skin undertone.

	df	P-value
Season	3	0.000*
Undertone	2	0.116
Interaction	6	0.246

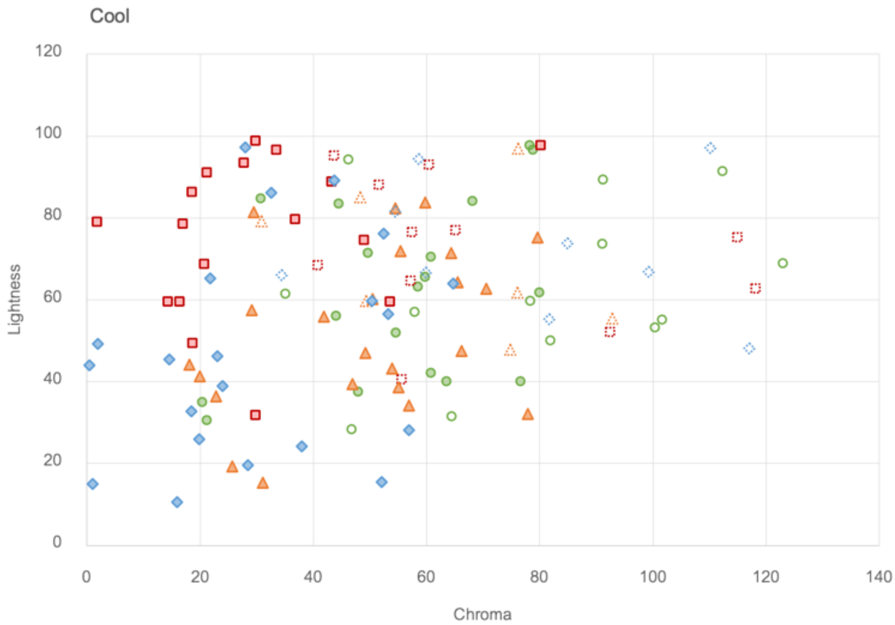
* Significant differences

The results in Table 4-9 showed that colour harmony scores from different seasons were significantly different. However, skin undertone had no influence on the colour harmony scores, as the results from different undertone types were statistically insignificant. Both statistical tests (Tables 4-8 and 4-9) fail the assumption of personal colour analysis in that the same undertone should yield the same results and different undertones should produce different colour harmony for different seasons. Provided that the concept of personal colour analysis is valid, the results implied that at least one skin tone should not have been classified into the same type of undertone, resulting in significant differences within the same type. By the same token, when skin tones that did not belong to the same type were grouped together, they produced high variance, resulting in insignificant differences between different undertone types.

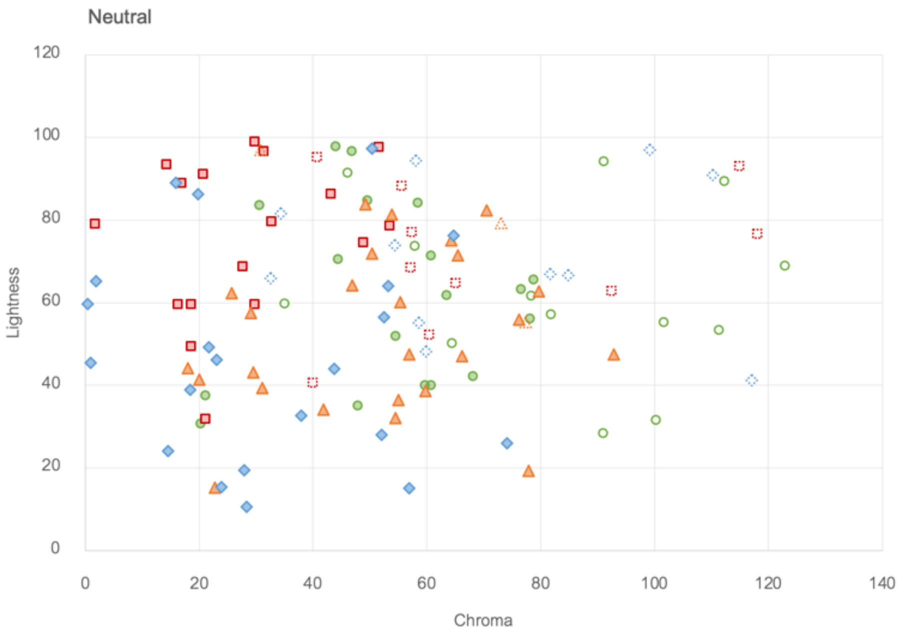
Figure 4-1 shows the positive (harmonious) and negative (disharmonious) scores averaged from 5 lightness levels for each skin undertone type for four season colours. For all skin undertone types, there was no clear trend for which season performed better than the others, or for lightness and chroma levels that would provide harmonious pairs.

(a) warm undertone

Figure 4-1 Positive (solid symbols) and negative (open symbols) colour harmony scores of four seasons in lightness-chroma plots for (a) warm, (b) cool, and (c) neutral undertone.



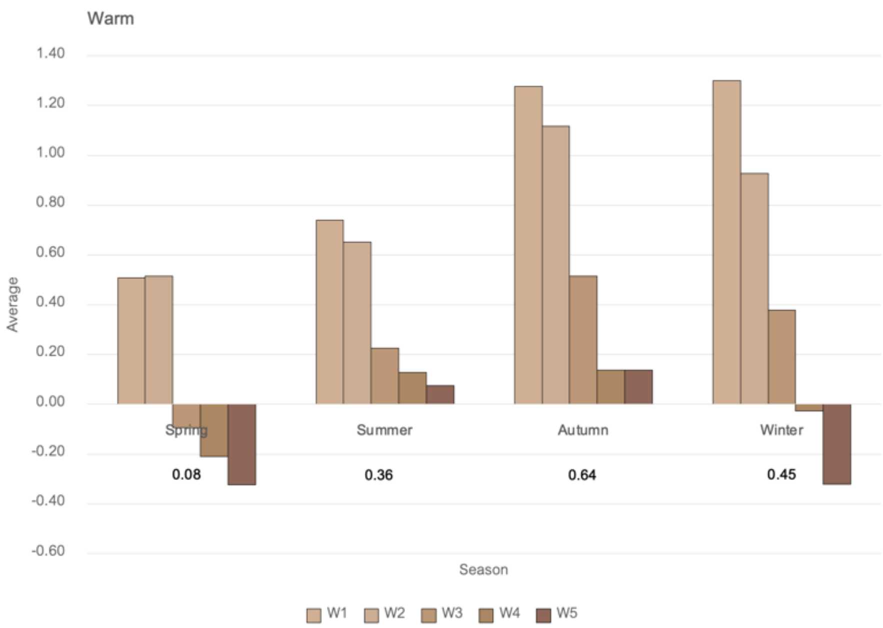
(b) cool undertone



(c) neutral

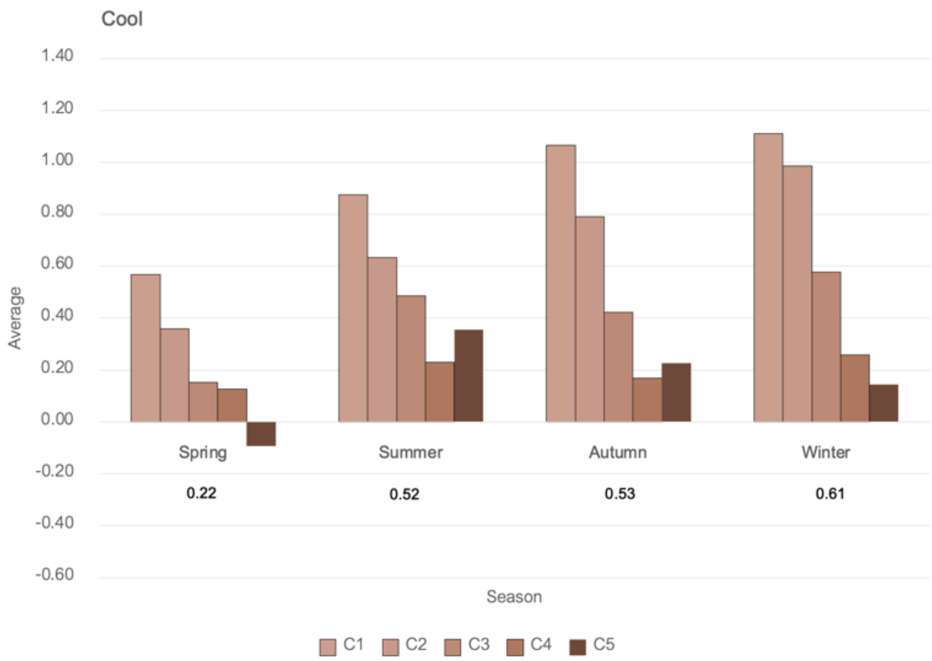
Figure 4-1 (continued)

Figure 4-2 shows the average scores of colour harmony for skin undertones paired with each season. The clear trends for each undertone could be observed, where the same undertones varying in lightness produced significantly different results for each season. The light skin tones for all undertones performed the best and the colour harmony scores decreased with skin lightness. The case of warm undertones with spring colours showed the most robust trend. The warm undertones with high lightness skin tones (W1 and W2) gave positive scores, whereas the medium to low lightness skin tones (W3, W4 and W5) produced disharmonious pairs. Thus, the average score across 5 skin tones with warm undertones was close to the score of zero with high variance. It is not surprising to see significant differences between skin tones when a statistical test was applied. Moreover, when comparing between different skin undertones, the differences were not significant because the average scores across all lightness for each undertone group had too high variance. In addition to skin undertone, the results revealed that skin lightness had an impact on colour harmony. Not all skin lightness with the same undertone should be classified into the same group, as they performed significantly different from one another.

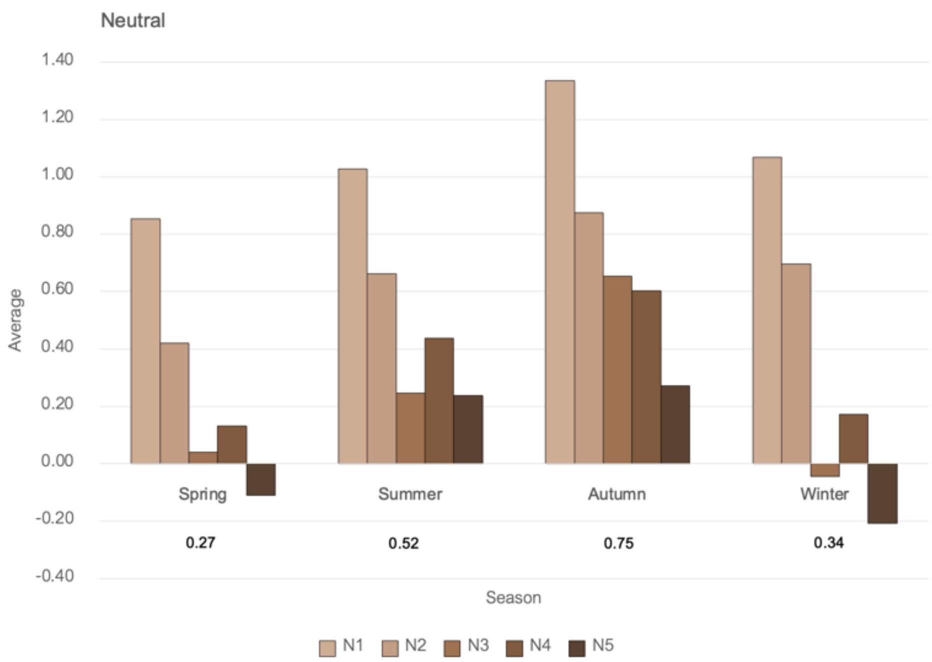


(a) Warm undertone

Figure 4-2 The average scores of all skin undertones for each season. (a) Warm undertone (b) Cool undertone (c) Neutral



(b) Cool undertone



(c) Neutral

Figure 4-2 (continued)

The results of the top ten best harmonious pairs and the average scores for skin undertones varying in lightness indicated that the lightness level of skin tone played an important role in achieving harmonious pairs. However, according to personal colour principles, lightness of skin tone has no influence on personal colour; only skin undertone affects the result. It is possible that even though the observers were told to regard the colour samples as skin tone samples, they may not be able to do so. This is because the skin tone appear in a uniform colour patch, unlike natural human skin that has uneven tone. The finding that colours with high lightness produced high colour harmony scores conform with the study by Ou and Luo [25] where uniform colour patches were used.

4.3 Effect of skin lightness

The results from Section 4.2 indicated the effects of skin lightness on colour harmony scores. Hence, this section will explore the extent of skin lightness in more detail. Section 4.3.1 shows the results of colour harmony scores for four seasons based on skin lightness. Section 4.3.2 presents the effects of both undertone and lightness of the skin tones on personal colour analysis.

4.3.1 Analysis of personal colour according to skin lightness

To investigate the effect of skin lightness, the 15 skin tone samples were re-arranged and re-grouped based on lightness values. The results are shown in Table 4-11. The skin tones were classified into three groups: high, medium, and low lightness. The high lightness group contained four skin tones that had lightness values higher than 66. There were 8 skin tones in the medium lightness group, with lightness values between 45 and 66. The three low-lightness skin tones were those with lightness values below 45. It is worth noting that the classification of skin tone lightness varies depending on the lightness range of the skin tone samples under study [39]. From Table 4-10, it can be seen that various skin undertones can be classified into the same lightness groups.

Table 4-10 Skin tone samples in descending order of lightness.

Code	Sample	L*	Classification
W1		71.79	High
N1		70.82	
W2		70.52	
C1		66.93	
N2		65.29	Medium
C2		64.79	
W3		62.80	
C3		59.87	
W4		56.92	
C4		53.60	
N3		50.36	
W5		45.45	
N4		41.18	Low
C5		35.20	
N5		31.65	

Table 4-11 summarises the results of a two-way ANOVA for each lightness group and the four seasons. If all the skin tone samples belong to the same group, the colour harmony scores between different skin tone samples within the same group must not be statistically different. The results showed that this concept held true for the high and low lightness groups. In the case of medium lightness, there were significant differences in colour harmony scores between skin samples. It could be because there were more skin tone samples with various undertones classified as medium lightness. The range of lightness was large, so some skin tone samples should not have been in the same group. On the other hand, it is as expected that colours from different seasons yielded significant differences in colour harmony scores.

Table 4-11 A statistical analysis, using two-way ANOVA for each lightness group.

Classification		df	P-value
High	Season	3	0.000*
	Skin tone	3	0.234
	Interaction	9	0.911
Medium	Season	3	0.000*
	Skin tone	7	0.000*
	Interaction	21	0.851
Low	Season	3	0.005*
	Skin tone	2	0.059
	Interaction	6	0.895

* Significant differences

For further investigation, since there were all three types of undertone in the same medium lightness group and the statistical test showed the significant differences between them, the skin samples in this group were further divided according to the undertone type. The results of the two-way ANOVA are given in Table 4-12. Note that for each undertone-medium lightness group, the p-values for the factor of season were less than 0.05, indicating the significant differences between seasons. Therefore, only the p-values of the skin tone factor are shown in the table.

Table 4-12 shows the average colour harmony scores for each season based on undertone-medium lightness groups. The warm undertones should be harmonized with warm hues, i.e. colours in spring and autumn [19]. However, the results showed that for all warm skin undertones with medium lightness, spring colours produced negative results, i.e. the warm undertone combined with these colours were not beautiful. The results from three samples were not statistical different. Nevertheless, the best results for warm-medium lightness skin tones were found for autumn.

Table 4-12 Results of the two-way ANOVA for medium lightness with different undertone.

Undertone	Lightness	Season				df	p-value
		Spring	Summer	Autumn	Winter		
Warm medium lightness	W3	-0.094	0.226	0.523	0.374	2	0.028
	W4	-0.209	0.127	0.136	-0.031		
	W5	-0.323	0.074	0.139	-0.335		
	Average	-0.209	0.142	0.266	0.002		
Cool medium lightness	C3	0.359	0.632	0.796	0.990	2	0.002*
	C4	0.153	0.484	0.420	0.581		
	C5	0.125	0.229	0.167	0.261		
	Average	0.213	0.449	0.461	0.611		
Neutral medium lightness	N2	0.421	0.664	0.882	0.690	1	0.001*
	N3	0.041	0.247	0.667	-0.066		
	Average	0.231	0.455	0.775	0.313		

* Significant differences

Cool undertones are suitable for cool hues, i.e. colours in summer and winter [19]. The results confirmed that the cool-medium lightness skin tones looked best with winter colours. However, the results were statistically different between different skin samples. The neutral undertones could go well with either warm or cool hues. The results showed significant differences between two samples of the same neutral undertone and medium-lightness group.

The discrepancy between the undertone-medium lightness results and the concept of personal colour analysis leads to the assumption that there are more than one factors of skin tone contributing to personal colour. It is possible that both undertone and lightness of skin tone play an important role in determining personal colour.

The study by Hong and Kim [11] classified personal colour into 12 groups based on skin undertone (yellow, complex and pink), skin lightness (light, medium and dark), and hair colour (light, medium and dark). The 12 personal colour groups are combinations of three undertones and four basic groups, namely star, sun, moon, and sunset. For example, Yellow Star is for a person with yellow undertone, light skin, and light hair. White Sun is for complex (or neutral) undertone, light skin, and medium and dark hair. Pink Moon is for pink undertone, medium and dark skin, and light and medium hair. Yellow Sunset is for yellow undertone, medium and dark skin, and medium and dark hair. This principle implies that classifying personal colours into four seasons might not be sufficient, and there are more than one factors influencing personal colours.

In addition to undertone, the skin tone can also be divided into high, medium, and low lightness. As a result, the same undertone with different lightness levels may not have the same harmonious colours.

4.3.2 Analysis of skin undertone and lightness

To confirm the above assumption that both undertone and lightness of skin tone affect personal colour, the 15 skin tone samples were first divided into three undertone types. Then, for each undertone type, the skin tones were further divided according to the lightness levels.

Table 4-13 summaries new groups of skin tone samples for personal colour analysis. The results of a two-way ANOVA showed that the colour harmony scores for skin tones in the same group were not significantly different (p-value>0.05), indicating that they were correctly assigned to the same group. On the other hand, the colour harmony scores between different seasons were significantly different (p-value<0.05), revealing that the same skin tone yielded different colour harmony for different season colours.

Table 4-13 Skin tone samples grouped by undertone and lightness levels.

Undertone	Lightness	Code	Average colour harmony score			
			Spring	Summe r	Autum n	Winter
Warm	High	W1, W2	0.511	0.696	**1.213**	1.112
	Medium	W3, W4	-0.152	0.177	**0.330**	0.171
	Low	W5	-0.323	0.074	**0.139**	-0.335
Cool	High	C1, C2	0.464	0.754	0.933	**1.051**
	Medium-Low	C3, C4, C5	0.062	**0.356**	0.270	0.328
Neutral	High	W1, W2	0.637	0.845	**1.114**	0.876
	Medium-Low	W3, W4, W5	0.021	0.308	**0.516**	-0.043

From Table 4-13, it can be seen that the same undertones but difference in lightness perform differently for different seasons. The cool-high lightness group gave best results with winter colours, whereas cool-medium low lightness were best with summer colours. Note that both summer and winter colours are cool hues and by the personal colour principles, they complement cool undertones. These findings confirm that both undertone and lightness of the skin affect personal colours.

In the case of warm undertone, when the skin was light, autumn colours (warm hues) provided the best colour harmony scores, closely followed by winter colours. The colour harmony score for spring (warm hues) was also positive. However, when the skin was medium or low in lightness, the colour harmony scores for spring were negative. This means that it creates an unattractive combination between skin tone and season colour. In addition, for all lightness levels, warm undertones were best with autumn colours but in varying degrees. Similarly, neutral-high lightness produced positive scores for all four seasons. This is expected because neutral undertones are supposed to go well with both warm and cool hues. Nevertheless, neutral undertone with medium-low lightness had negative results for winter colours

In conclusion, based on the results of this study, to best determine personal colours for skin tone, the skin tone should be classified according to undertone and then further classify into subgroups by lightness of the skin. However, the results are still unclear to determine attributes of colours that yielded best colour harmony scores for the undertone-lightness skin tone group.

4.4 Personal colour analysis for undertone-lightness skin tone

To determine personal colour for the combinations of undertone-lightness skin tone, the relationships between colourimetric values of the colour samples in the four seasons and the colour harmony scores for each skin undertone-lightness group were investigated. The results for hues, and lightness and chroma, are given in Sections 4.4.1 and 4.4.2, respectively.

4.4.1 Hue and skin tone

Figures 4-3, 4-4 and 4-5 are plots between hue angle of 128 season colours against colour harmony scores obtained from pairing with warm, cool and neutral, respectively. For each undertone, the skin tones were also grouped by lightness. The trendlines show the relationships between hues of the season colours and the degree of colour harmony produced by pairing with the skin undertone-lightness group.

Overall results showed that the high lightness groups for all undertones gave the best colour harmony compared to the same undertones with lower skin lightness. They tended to yield positive results for all hues. In addition, the worst colours for all undertones and lightness combinations were in vivid green region. This could be because the experiments were conducted in a dark room, so vivid green appeared too bright, as the human visual system is most sensitive to green. The observers felt that the very bright colour in a dark environment hurt their eyes and gave low scores for colour harmony. The results also showed high scores for red for all undertone-lightness skin groups. These findings conform with psychological principles that red is an attractive colour for everyone [35].

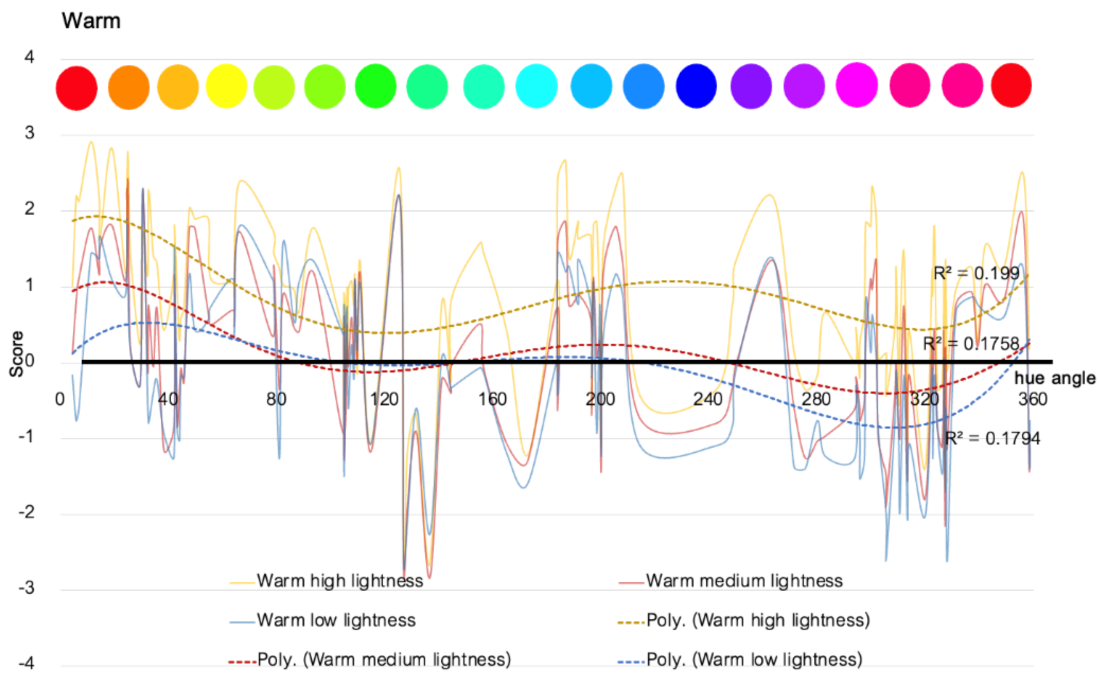


Figure 4-3 Relationships between hue of season colours and visual data for warm undertone.

The same trends were found for the same undertone with different lightness. For warm undertones, high colour harmony scores were found for red, yellow, and yellow-green (warm hues). The scores dropped for green, purple, and magenta (cool hues). The high lightness skin yielded all positive results, while the lower lightness skin produced negative results in some colours. This shows that undertone affects hue that will yield colour harmony, and skin lightness will enhance that effect.

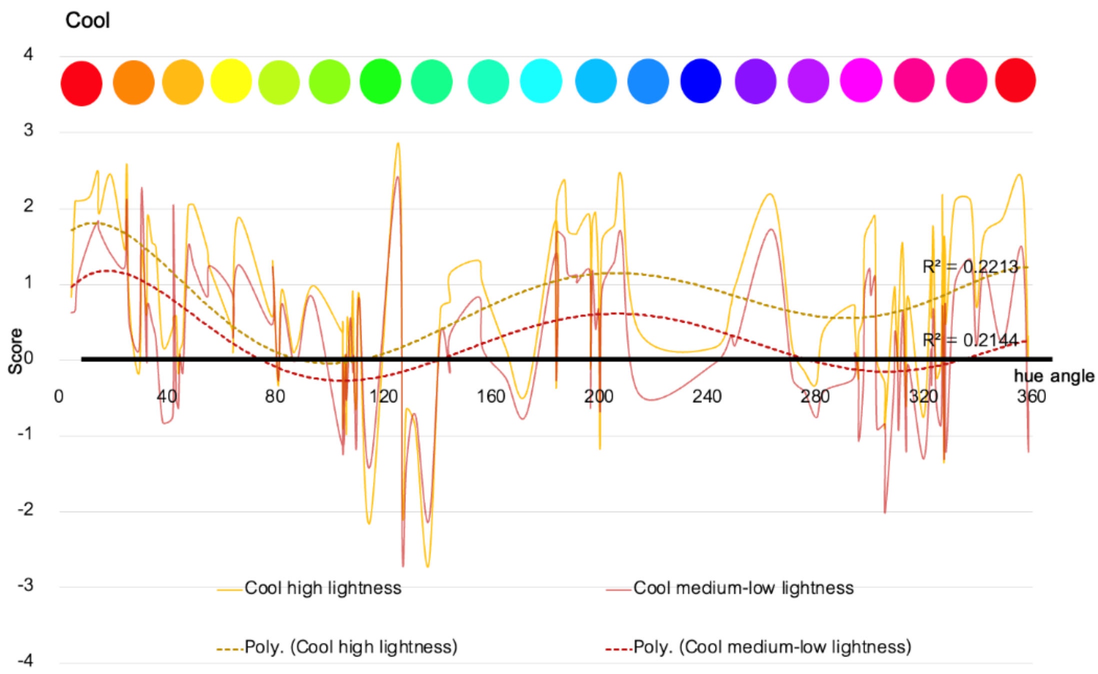


Figure 4-4 Relationships between hue of season colours and visual data for cool undertone.

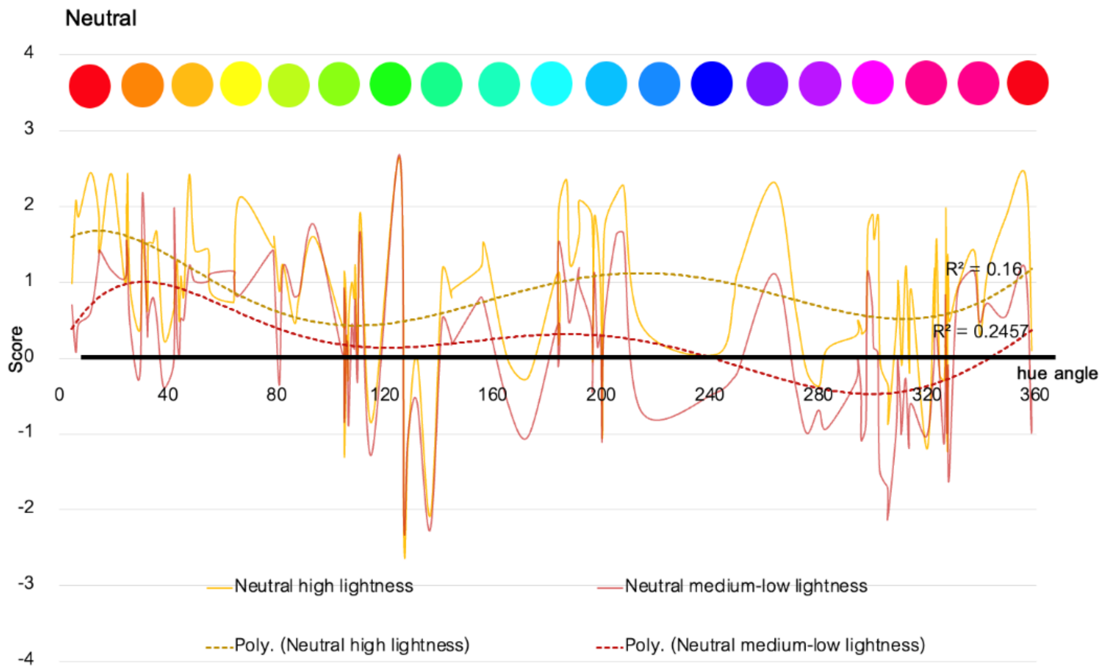


Figure 4-5 Relationships between hue of season colours and visual data for neutral undertone.

Cool undertone was found to harmonise with cool hues (cyan, bluish, blue). The red colours were also attractive for cool undertones with different lightness. The trendlines showed that colours with low scores of colour harmony were yellow, yellow-green, and green. The results showed that colour harmony degrees varied by lightness.

The trends of neutral undertone were similar to cool undertone. However, trendlines were smoother than cool undertone. This is because neutral undertone gave similar results for all hues, as neutral undertone harmonized with both warm and cool hues.

4.4.2 Lightness and chroma and skin tone

Besides hue of warm and cool tones, the season of personal colour are organized according to lightness and chroma. The spring colours are in warm hues with high lightness and chroma, whereas the summer colours are in cool hues with high lightness but low in chroma. The autumn colours are in warm hues with low lightness and chroma. The winter colours are in cool hues with low lightness but high in chroma.

Figure 4.6 shows the relationships between lightness and chroma and warm undertone. It was found that warm undertones with high lightness harmonised with all lightness levels of colour samples, as the trendline was above zero from L* of 10 to 100. In the case of chroma, the colour harmony scores were positive from C^*_{ab} of 0 to 90, indicating low to high chroma levels. This indicated that warm-high lightness skins had high colour harmony with colours with all lightness and chroma levels, i.e. spring and autumn colours when taking the results of hue into account. The similar trends were found for lower lightness skins with a lesser degree of colour harmony, in that the lower the lightness and chroma of season colours, the better the colour harmony scores. However, the warm-medium and warm-low lightness skins performed badly with medium to high chroma (the colour harmony score of zero at chroma of 50). They most harmonised with low lightness and low chroma colours, i.e. autumn colours.

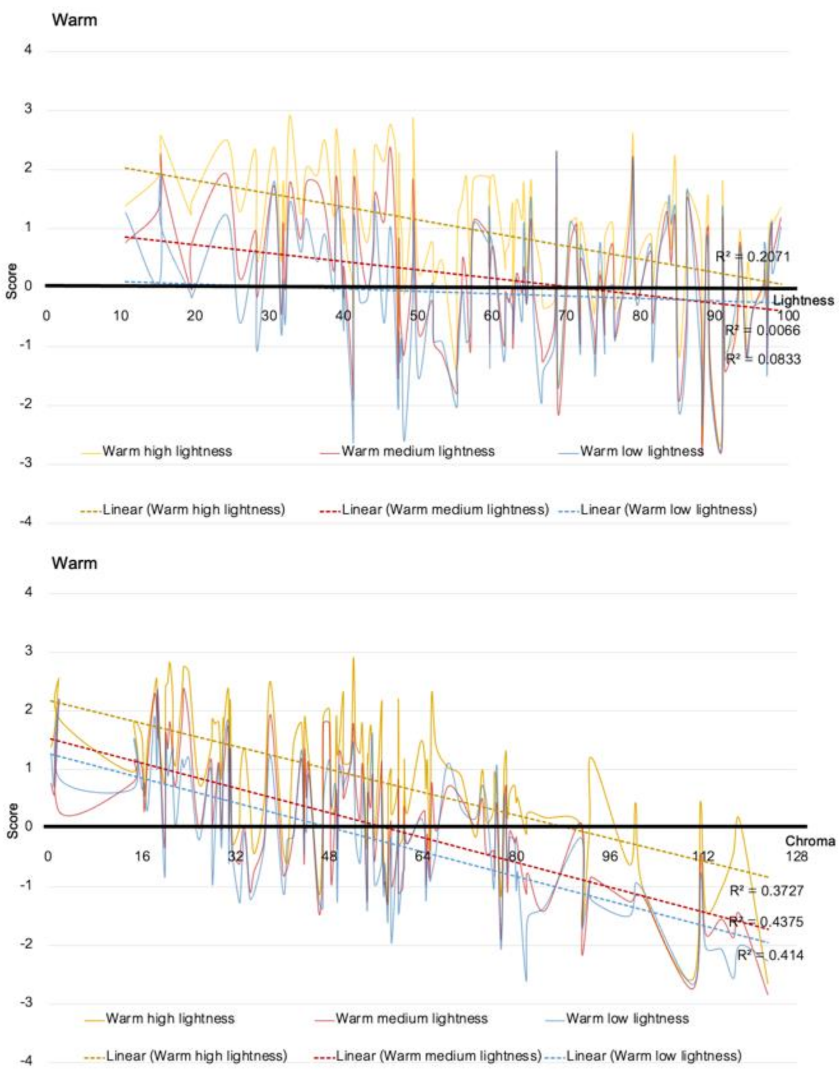


Figure 4-6 Relationships between lightness (top) and chroma (bottom) and visual data for warm undertone.

The trendlines for cool undertones (Figure 4-7) showed that both lightness groups gave almost all positive colour harmony scores for all lightness levels of season colours (the scores of zero at L*=90 and 85 for high and medium-low lightness, respectively). Nevertheless, lower lightness gave better colour harmony scores. As for chroma, similar trends to warm undertone were found: colours with medium to high chroma (C^*_{ab} of 50 and above) produced negative colour harmony scores when paired with cool undertones for all lightness groups. The cool-high lightness group gave better results than the medium-low lightness group, i.e. the chroma levels can be varied in a wider range. Hence, the cool-high lightness group could harmonise well with summer, autumn and winter colours. For the cool-medium low lightness group, summer and autumn colours gave better results compared to other season colours.

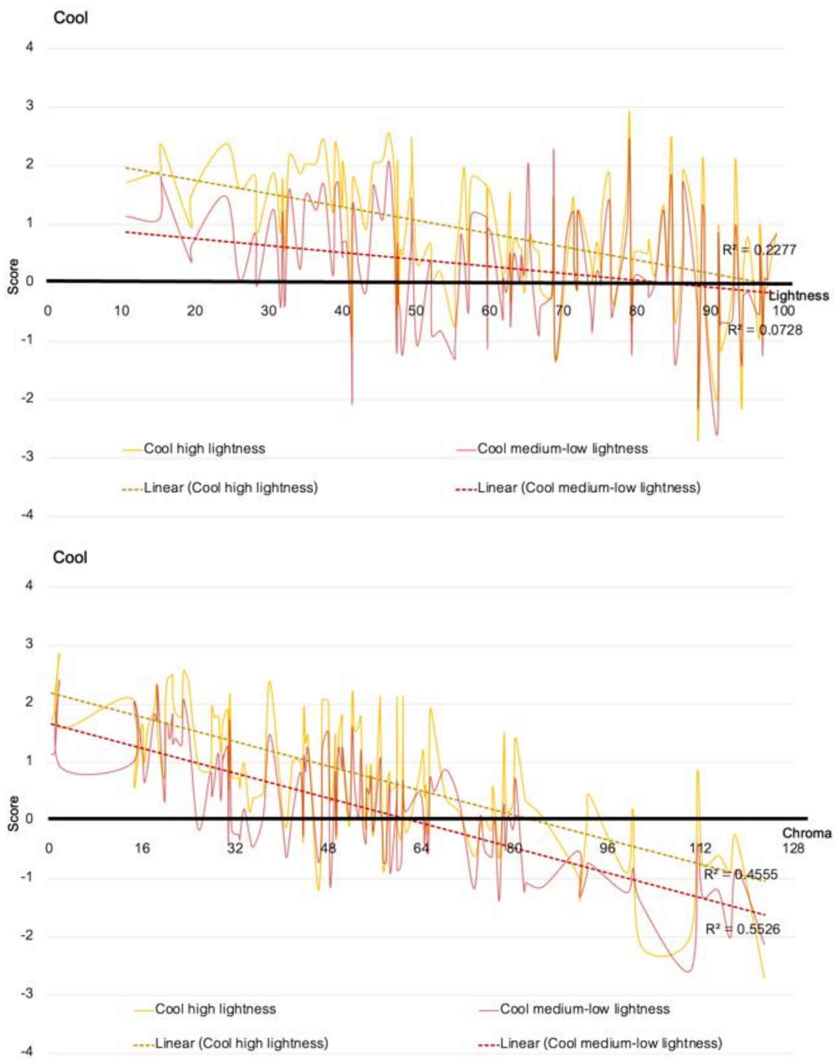


Figure 4-7 Relationships between lightness (top) and chroma (bottom) and visual data for cool undertone

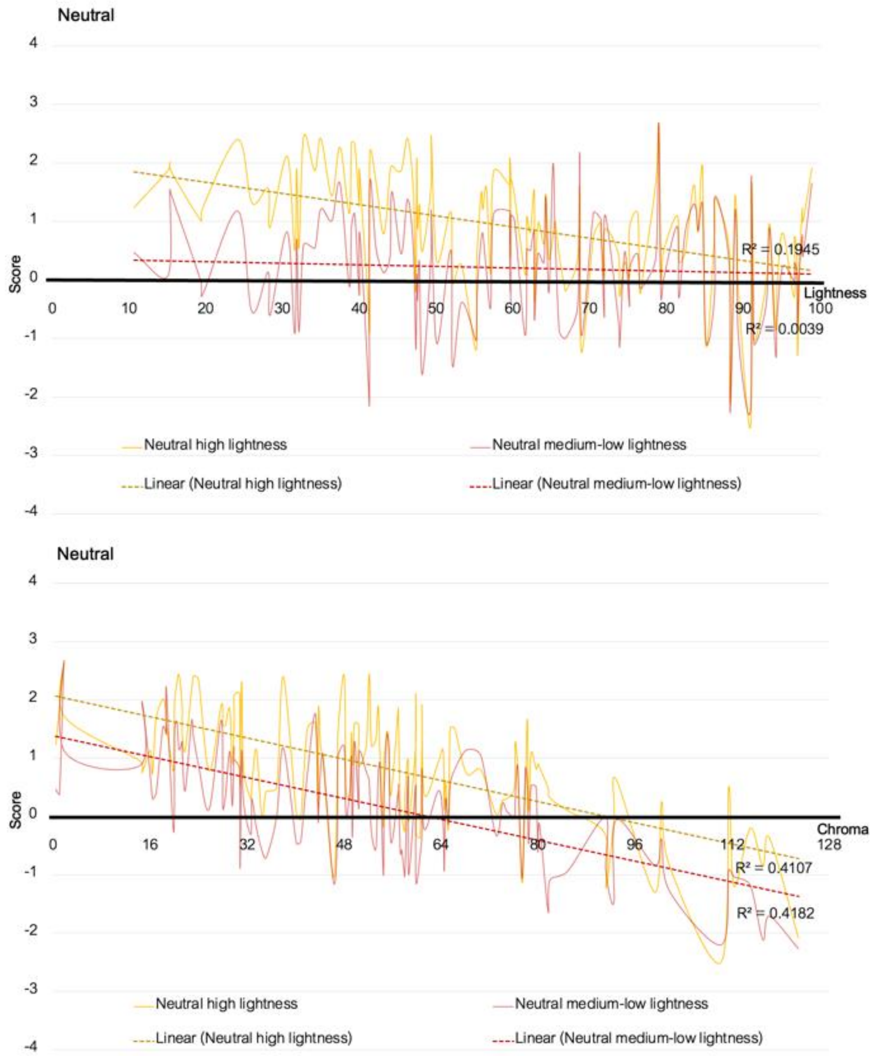


Figure 4-8 Relationships between lightness (top) and chroma (bottom) and visual data for neutral undertone.

From Figure 4-8, the neutral undertones of all lightness levels harmonized with all lightness levels from low to high of season colours. This trend was different from warm and cool undertones, where the skin tones with low lightness harmonised well with low to medium lightness, but never with high lightness levels. The similar trends to warm and cool undertones were found for chroma, i.e. the lower chroma season colours gave better colour harmony scores with neutral undertones for all skin lightness groups. When the average score was zero (neither harmonious nor disharmonious), the chroma level was at 90 for the neutral-high lightness group, and at 60 for the medium-low lightness group. This means that the high lightness skin tones could harmonise well with colours from low to high chroma, while the medium-low lightness skin tones harmonized with colours with low to medium chroma. In conclusion, the neutral-high lightness skin tones harmonised with all season colours, while the neutral undertones with medium-low lightness harmonised with summer and autumn colours.

4.5 Comparison with the universal colour harmony model

To investigate whether the existing colour harmony model could predict the results for skin tone and apply to personal colour analysis, the colour harmony scores for all 1,920 pairs were calculated by the universal colour harmony model (see Section 2.1). The correlation coefficient (r-value) was calculated to indicate the agreement between the predicted values and the visual results obtained in this study. Figure 4-9 shows the plot between the predicted values and the visual results, together with the r-value. The r-value was 0.53, meaning that only 53% of data were in agreement. In other words, the universal colour harmony model could give correct predictions for 53% of the colours paired with skin tones. This level of accuracy is considered to be low, as there is about 50% chance that the prediction will be wrong. This finding reveals that the existing colour harmony model is yet unsuitable for personal colour analysis. There should be a model specifically designed for personal colour analysis.

To investigate how well the universal colour harmony model agrees with the personal colour principles, the CD measure (see Section 3.2.4) was employed. The CD values were also calculated for the visual results. The results are summarised in Table 4-14.

Figure 4-9 Perceived colour harmony values against predicted values.

The CD values range from 0 to 1, where 0 indicates that all observers (or data) disagree with the given principle and 1 indicates that all observers (or data) agree with this principle. The personal colour principles tested are as follows.

- Warm undertones give *positive* colour harmony scores for spring and autumn colours (warm hues).
- Warm undertones give *negative* colour harmony scores for summer and winter colours (cool hues).
- Cool undertones give *positive* colour harmony scores for summer and winter colours (cool hues).
- Cool undertones give *negative* colour harmony scores for spring and autumn colours (warm hues)
- Neutral undertones give *positive* colour harmony scores for all season colours (both warm and cool hues)

Table 4-14 Test results of existing colour harmony principles in terms of CD values for season

		Warm undertone			Cool undertone		Neutral	
		High lightness	Medium lightness	Low lightness	High lightness	Medium – Low lightness	High lightness	Medium – Low lightness
Spring	Universal Model	0.42	0.25	0.13	0.66	0.78	0.39	0.13
	Visual Data	0.58	0.47	0.45	0.43	0.48	0.59	0.50
Number of pairs		64	64	32	64	96	64	96
Summer	Universal Model	0.59	0.83	**0.94**	0.30	0.09	0.34	0.03
	Visual Data	0.40	0.48	0.46	0.61	0.55	0.62	0.54
Number of pairs		64	64	32	64	96	64	96
Autumn	Universal Model	0.66	0.44	0.19	0.47	0.70	0.61	0.17
	Visual Data	**0.69**	0.55	0.52	0.35	0.45	0.61	0.58
Number of pairs		64	64	32	64	96	64	96
Winter	Universal Model	0.59	0.83	**0.94**	0.34	0.18	0.39	0.06
	Visual Data	0.34	0.47	0.56	0.64	0.56	0.63	0.49
Number of pairs		64	64	32	64	96	64	96

The results showed that the best agreement (0.94) with the principles for the universal colour harmony model was for the warm-low lightness skins with summer colours and the warm-low lightness skins with winter colours. The best agreement (0.69) for the visual results was for the warm-high lightness skins with autumn colours. The worst agreement (0.03) for the universal colour harmony model was for the neutral-medium low lightness skins with summer colours. The worst agreement (0.34) for the visual results was for the warm-high lightness skins with winter colours. Overall results showed that both colour harmony model and visual results were not well in agreement with the personal colour principles.

The colour harmony model seemed to predict well for the pairs that were disharmonious but greatly fail for attractive pairs. On the other hand, the agreements for visual results were in moderation with all principles. This is because the universal colour model, albeit derived to fit all available colour harmony databases, was created for general usage. The model does not specialise in skin tones, in which observers may have different criteria when judging what is attractive. The visual results also did not do well with the principles for a number of possible reasons. First of all, the season colours provided are in digital RGB values, which are device-dependent colours. The actual colour appearance of these colours are unknown. Therefore, they may not accurately follow the personal colour principles and are not good representations of personal colour types. Alternatively, the colour samples used in the study were uniform colour patches, which may be hard for observers to regard them as skin tones. The findings confirm that a colour harmony model specifically designed for personal colour analysis should be developed.

CHAPTER V
CONCLUSIONS

5.1 Conclusions

This study investigated the method of analysing personal colour utilising colour harmony evaluation. The experimental samples consisted of 1,920 colour pairs created by combining 15 skin tone samples with 128 colour samples. The samples were displayed on an LCD monitor as a pair of uniform colours placed side by side. Observers assessed the colour pairs one by one and rated the degree of colour harmony using an integer scale ranging from -5 (completely disharmonious) to 5 (completely harmonious). Data analysis was performed to identify relationships between skin tone and colour that result in a high degree of colour harmony.

Thirty Thai observers (15 females and 15 males) aged 20 to 40 years old participated in the visual assessments. They were informed of the purpose of the experiment as well as the definition of colour harmony. To investigate the reliability of the visual results, intra- and inter-observer agreements were performed using RMS and statistical tests. The mean RMS between two responses of the observers in repeated experiments was 1.76. The paired t-test revealed that differences between observers' first and second responses were insignificant. The mean RMS between each observer's results and the panel results was 2.62. The independent t-test showed no significant differences in the results between males and females. The visual results were, thus, considered reliable.

To follow the personal colour principles that are defined by skin undertone, the skin tone samples were selected from the Pantone SkinTone Guide to represent warm, cool, and neutral undertones, with five skin tones for each undertone. The colour samples were 128 personal colours that were separated into four groups named by season: spring, summer, autumn, and winter, with 32 colours in each group. The colours in the spring and autumn groups were mainly warm hues. In contrast, the colours in the summer and winter groups were mainly cool hues. The colours in the different season groups were also different in lightness and chroma. Table 5-1 summarises the colour aspects of experimental samples.

Table 5-1 Summary of experimental samples.

Undertone	Warm	Cool	Neutral
15 Skin tones	5 samples varied in L* from 45–72	5 samples varied in L* from 35–67	5 samples varied in L* from 31–71

Season colours	Spring	Summer	Autumn	Winter
Hue	Warm	Cool	Warm	Cool
Lightness	Medium – High	Medium – High	Low – High	Low - High
Chroma	Low – High	Low – Medium	Low – Medium	Low – High

The results from the top ten most harmonious pairs for each skin undertone were in line with the personal colour principles that warm hues complement a warm undertone, cool hues flatter a cool undertone, and a neutral undertone is appealing with both hues. It could also be observed that among the most harmonious pairs were those paired with skin tones of high lightness.

The results from a two-way ANOVA indicated that skin tones with the same undertone produced significantly different colour harmony scores, which should not have been the case. For all four seasons, the colour harmony scores increased in order with skin lightness for each undertone. This revealed that skin lightness affected colour harmony with respect to personal colour. The results also showed that colours from different seasons yielded significantly different colour harmony scores, confirming that they were properly separated into different groups.

To investigate the effect of skin lightness, the skin tones were re-classified into three groups: high, medium, and low lightness skins. Despite being in the same groups, the skin tones produced significantly different colour harmony scores. Because they were separated solely by lightness, skin tones in the same lightness group had different undertones. This revealed that in order to determine personal colours, skin tones should be classified by both skin undertone and lightness.

The newly divided groups of skin tones, firstly by undertone and then further classified into subgroups by lightness, contained seven groups: warm-high, warm-medium, warm-low, cool-high, cool-medium-low, neutral-high, and neutral-medium-low lightness skins. It was found that all skin tones in the same groups performed similarly and were not significantly different. Based on the average scores of colour harmony, warm undertones of all lightness groups most harmonised with autumn colours (warm hues); the cool-high lightness group most harmonised with winter colours (cool hues); the cool-medium low lightness group harmonised with summer colours (cool hues); the neutral undertones harmonised with all season colours.

Table 5-2 summarises the results of personal colour analysis based on relationships between colourimetric values of all season colours and the colour harmony scores for each undertone-lightness skin tone group. The results revealed that classifying personal colours into four groups may not be sufficient for determining the best-worn colours for a particular skin tone. There may be more factors involved in finding the ideal colours.

Table 5-2 Personal colour analysis for the undertone-lightness skin tones.

Skin tone	Season
Warm-high lightness	Spring, Autumn
Warm-medium lightness	Autumn
Warm-low lightness	Autumn
Cool-high lightness	Summer, Autumn, Winter
Cool-medium-low lightness	Summer, Autumn
Neutral-high lightness	Spring, Summer, Autumn, Winter
Neutral-medium-low lightness	Summer, Autumn

5.2 Suggestions

This study used colour pairs of uniform coloured patches as experimental samples and instructed observers to regard them as a skin tone paired with clothing colour. Even though the observers were well informed of the purpose of the study before carrying out the experiments, they may not be able to strictly follow the instructions, as the actual human skin is not uniform, and it was possibly difficult to imagine them in real life situations. For future studies, the samples should be an image of a human figure or face, where the sampled colours are simulated onto the image as skin tone and clothing colours.

In this study, the visual assessments were conducted in a darkened room. The most disharmonious pairs for all skin tone groups were vivid greens. This was because they appeared too bright on a monitor in a dark environment, since the human visual system is most sensitive to green light. The observers felt that the bright colours hurt their eyes and rated them as disharmonious. The future study could consider reducing monitor brightness and conducting the visual experiments in a normally lit room.

The predictions from the universal colour harmony model were not in good agreement with the visual results obtained in this study. They also did not conform to the personal colour principles. This suggested that a derivation of a colour harmony model be specially designed for personal colour analysis.

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