Investigation on Facial Skin Colour Perception Induced by Different Lipstick Shades

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

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Abstract

This study examines the colour assimilation effects of lipsticks on perceived facial skin tone among women, focusing on how various shades of lipstick alter skin colour perception and their association with attractiveness. Specifically, six different shades from Maybelline were applied to 10 female faces (5 Chinese and 5 Caucasian), and images were captured using a Canon DSLR camera in a controlled light booth equipped with D65 lighting. Fifteen Chinese female participants from Leeds were invited to view the images on a colour-calibrated display and use a scaling method to evaluate the perceived lightness, redness, yellowness, and attractiveness of the facial skin with each lipstick applied. The findings indicate that lipstick colours significantly influence the perceptual lightness and redness of facial skin, yet have a minimal impact on the yellowness of human faces. Meanwhile, Chinese observers showed slight different preferences for lipstick shades when judging the facial skin tone and attractiveness of Chinese and Caucasian faces – lipsticks with red tone, richer chroma and a higher delta E value are preferred for the Chinese group. Furthermore, significant correlations between perceived skin lightness, redness and perceptual attractiveness were revealed in this study. These results can provide support for makeup marketing strategies, help fashion professionals understand consumer behaviour, and guide individuals in selecting lipstick shades that align with their desired image.

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Chapter 1. Introduction

1.1 Background

The application of cosmetics by women to enhance facial aesthetics is a global practice with historical roots across various cultures (Cordwell, 1976; Liggett, 1974). The use of pigments for self-decoration predates even the wearing of clothes (Jablonski, 2006) and continues universally in present-day societies (Russel, 2010).

The systematic study of the motives behind cosmetic use within social psychology began only in the early 1930s, initially viewed primarily as a method to attract the opposite sex (Lerner, 1932). Later psychological studies expanded this view, identifying the cosmetic application as a complex behaviour intertwined with female self-presentation, impression management, and self-consciousness (Cash, et al., 1982; Power, 2010). According to Russel (2012), self-decoration serves dual purposes: beautification and signification. Beautification includes using cosmetics as a compensatory tool to boost confidence (Goffman, E. Stigma: Notes on the Management of a Spoiled Identity. Prentice-Hall, Englewood Cliffs, NJ, 1963; Cash, et al., 1982; Women's Cosmetic Use and Self-Concept, 1996), while signification reflects the importance placed on makeup in professional settings as an indicator of social and professional standing (Johnson, 2017).

Despite considerable research on why the application of cosmetics is a cross-cultural universal behaviour among women, discussions on how cosmetics specifically enhance facial beauty from a colour perception standpoint are scant.

1.1 Aim and Objectives

Aim

Explore the potential colour assimilation effect caused by lipsticks on Chinese and Caucasian female faces and their relationship with attractiveness.

Objective:

1. Investigate whether different lipstick colours will induce changes in skin colour perception.

2. Explore the correlation between perceptual colour changes with attractiveness.

1.3 Outline of the Thesis

This thesis comprises six chapters: an Introduction, Literature Review, Methodology, Results, Discussion, and Conclusion.

Introduction

This initial chapter sets the stage by presenting the research background, aims, and objectives. It elucidates the motivation behind conducting this research, providing a clear foundation for the studies.

Literature Review

This section delves deeper into the study's background. It discusses methodologies for quantifying colour as perceived by humans, explores the specialised mechanisms behind human colour perception, examines how skin colour metrics can influence levels of attractiveness, and reviews existing research on the interaction between lipstick and skin colour.

Methodology

Here, the experimental design is detailed. This includes the selection of lipstick colours, the process of reproducing the most accurate colours on displays through a set of colour characterisation techniques, and the methodology for collecting responses from observers.

Results

Chapter 4 presents all data collected during the experiment. It explains how these results contribute to the research objectives, setting the stage for the subsequent discussion.

Discussion

This chapter synthesises the findings from the previous chapters, interpreting the data in the context of the research objectives. It explores the implications of the results and relates them to the established literature.

Conclusion

The final chapter summarises the research outcomes and reflects on the implications of the findings. It also offers recommendations for future research, drawing on the insights gained throughout the study.

Chapter 2. Literature Review

2.1 Colour Science

To explore how colour shifts the perceptual attractiveness of female faces, the mechanism behind how colour is perceived by human eyes shall be explained. This section explores the development of colour spaces, specifically CIE XYZ and CIE Lab, which are foundational to the methodologies employed in this research. These colour spaces are intricately linked to human eye colour perception mechanisms. Initially, basic concepts of colour will be introduced to establish and clarify the terminology used throughout this discussion. Additionally, this section will elucidate the critical role of device characterisation in colour management. Such characterisation is essential to ensure colour consistency across different devices, a fundamental requirement for conducting psychophysical experiments involving colour. Understanding these elements allows for a more comprehensive understanding of how colour perception influences and informs the experimental approach.

2.1.1 Mechanism of Colour Perception of Human-eyes

Colour perception is fundamentally an interpretation by the brain, resulting from the interaction between the luminance reflectance of an object and the visual perception of humans. Light, a form of energy within the spectrum of electromagnetic radiation, is selectively perceived by the human eye; only specific wavelengths that are reflected from an object's surface are captured (Westland and Cheung, 2006). The wavelengths ranging from 380 nm to 740 nm are defined as visible light (Ramamurthy and Lakshminarayanan, 2015).

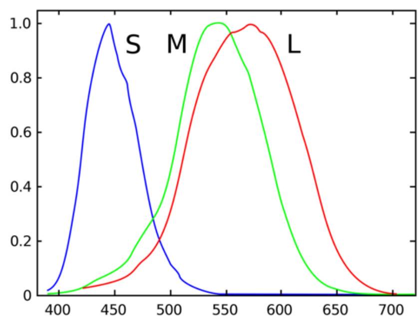


Figure 2.1 The normalised spectral sensitivity of human cone cells of short, middle and long wavelength types https://en.wikipedia.org/wiki/CIE_1931_color_space#/media/File:Cones_SMJ2_E.svg)

The ability of the human eye to perceive these wavelengths depends crucially on its biological structure. Light passes through the layers of the retina until it reaches the photoreceptors, which consist of rods and cones, cells that perceive visual stimuli from the environment. Rods are predominantly active under low luminance conditions, whereas the three types of cones—S, M, and L—are sensitive to specific ranges of wavelengths (Ramamurthy and Lakshminarayanan, 2015). It is noted that S cones, which are sensitive to shorter wavelengths around 420 nm, predominantly respond to blue light. M cones show peak activity at the green wavelength of 530 nm, and L cones are most responsive to 560 nm. Different types of cones are activated under certain visible light. This activation pattern illustrates that colour perception in humans results from the combined activity of these three types of cone cells.

2.1.2 CIE Colorimetry

CIE colorimetry was introduced in 1931 by the International Commission on Illumination. This colorimetry is developed based on the essence of human eye photoreceptors, to measure and quantify colours using a universal model that could be widely applied across various industries and devices (Ohno, 2000).

2.1.2.1 CIE Standard Illuminants

Colour is a perception triggered by the reflection of light on the surface of an object, and this perceived colour can vary under different light sources. Therefore, a consistent and appropriate light source is crucial for experiments requiring accurate colour assessment. According to Pointer (2011), two important factors regarding light sources are the Spectral Power Distribution (SPD) and Correlated Colour Temperature (CCT). SPD measures the distribution of energy across different wavelengths of a light source, with the value at 560 nm typically normalized to 100 to represent the relative SPD. This normalization helps compare light sources consistently. CCT, quantified in Kelvin (K), measures the colour temperature of a light source as compared to a black-body radiator at the same temperature. Different light sources have varying CCTs, affecting the perceived colour of an object.

To accurately quantify colours, standard lighting conditions are necessary. The CIE has established standards specifying SPDs for three illuminants used in colorimetry: CIE Standard Illuminant A, D65, and D50. CIE standard D65 light source, with a CCT of 6500K, simulates average natural daylight. It is widely used in colour research for its efficacy in replicating natural lighting conditions, especially in research related to cosmetics.

2.1.2.2 CIE XYZ Tristimulus Values

According to Ohta and Roberston (2005), the tristimulus values of XYZ are defined as follows: X component represents the mix of response curves over the visible spectrum, weighted towards the red end. The Y component corresponds to luminance, directly related to the perception of brightness, and is weighted by the human eye's sensitivity to different wavelengths. The Z component emphasises the blue end of the spectrum, where the cones are sensitive to short-wavelength blue lights. Each tristimulus is calculated using the following formulae:

$$X = \int_{400nm}^{700nm} S(\lambda)x(\lambda)\, d\lambda$$

$$Y = \int_{400nm}^{700nm} S(\lambda)y(\lambda)\, d\lambda \qquad \textbf{Equation 2.1}$$

$$Z = \int_{400nm}^{700nm} S(\lambda)z(\lambda)\, d\lambda$$

where λ represents the visible wavelength range, $S(\lambda)$ is the spectral power distribution of the colour stimulus. $x(\lambda)$, $y(\lambda)$ and $z(\lambda)$ are the spectral sensitivities of these receptors in human eyes, defined by CIE and illustrated in the following figure 2.1.

2.1.2.3 CIE Lab Uniform Colour Space

Following the foundation of XYZ tristimulus, CIE Lab colour space was later introduced. This is a colour space transforming the numerical change of colour into perceptual changes correspondingly. It is also a three-dimensional colour space where L* represents lightness, and a* and b* locate the hue in the space (CIE, 2019). A set of mathematic calculated was conducted upon the colour space using the formulae below:

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

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

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

Equation 2.2

$$f(w) = \begin{cases} (w)^{1/3} & w > 0.008856 \\ 7.787(w) + \frac{16}{116} & w \le 0.008856 \end{cases}$$

where X, Y, and Z represent the tristimulus values of the object colour. X_n, Y_n and Z_n represent the measurement of reference white. Compared to XYZ tristimulus, CIE Laboffers a more direct expression of the colour based on human eye perception, where the a* axis represents the degree of red-green and b* refers to yellow-blue. It is employed in cases where perceptual colour differences need to be explored and discussed as it is more suitable for human vision adaptation, while CIE XYZ is more suitable for mathematical calculations.

The perceived attributes of chroma (C*) and hue (h) can be calculated in CIE Labcolour space by using the formulas below:

$$h^* = (a^*)^2 + (b^*)^2$$

Equation 2.3

$$C^* = arctan\ (\frac{b^*}{a^*})$$

Notably, the hue angle (0° < h < 360°) pinpoints the colour's position within the CIE Lab colour space. A hue nearing 0° or 360° suggests a predilection towards red, whereas angles of 120° and 240° are indicative of green and blue hues, respectively. Chroma quantifies the colour's richness or saturation. Consequently, a higher chroma value is indicative of a more vivid and saturated colour.

2.1.2.4 Colour Difference Formulae

The concept of colour difference between two colours is important in quantitative research on colour. To accurately calculate the colour difference between lipsticks and faces, the CIE Lab colour difference formula is employed (Stephen et al., 2011; Tan and Stephen, 2013; Melgosa et al., 2018; Amano et al., 2020):

$$\Delta L^* = L^*{}_2 - L^*{}_1$$

$$\Delta a^* = a^*{}_2 - a^*{}_1$$

$$\Delta b^* = b^*{}_2 - b^*{}_1$$

Equation 2.4

$$\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

Where $\Delta L^*, \Delta a^*$ and Δb^* describe the colour difference from each axis and ΔE represents the total colour differences.

With the measurements and calculation, the differences between colours can be quantified in this CIE XYZ colour space. Combined with the responses of perceptual colour metrics of the skin, a correlation between perceptual colour and colour measurements can be investigated.

2.1.3 Colour Management

Colour management calibrates the colour on the input and output devices to ensure colour consistency (MacDonald, 1996). As mentioned above, due to the different sizes of colour gamut between different devices, a calibration is required to represent the colour accurately, especially when human observation is involved. To simply explain the characterisation process, the objective is to reproduce colours accurately among different devices, such as digital cameras and displays. The device-independent colour space, CIE XYZ, is involved in interpreting the device-dependent RGB colour space, and a colour profile is built to predict the RGB values based on target colours.

The most commonly used colour spaces in practice are RGB, CMYK, HSV, and each colour space has a special application in certain areas of the imaging industry depending on the property of the device. In this section, RGB colour space, usually applied in digital cameras and displays will be introduced. Colour management, a method to ensure the colour consistency between two devices with different colour gamut through colour management using device-independent colour space will be explained.

2.1.4.1 Camera Colour Characterisation

The RGB colour space of a digital camera is considered device-dependent. As noted by Süsstrunk (1999), no single RGB colour space fits all types of RGB devices universally. Standard RGB colour spaces, such as ISO RGB, sRGB, and Adobe RGB, vary, and the choice of which to use depends on the characteristics of the device. The accompanying figure illustrates the variations in colour gamut among human eye perception (Spectrum Locus) and different RGB device colour spaces. The extent of the colour gamut indicates the range of colours that each colour space can reproduce. For instance, an image captured in the sRGB colour space by a digital camera and reproduced on a display with an Adobe RGB colour gamut will have a colour representation limited by the camera's gamut. Although the display's broader gamut suggests it can produce a wider range of visible colours, achieving accurate colour consistency with human perception requires applying precise colour management techniques for colour conversion.

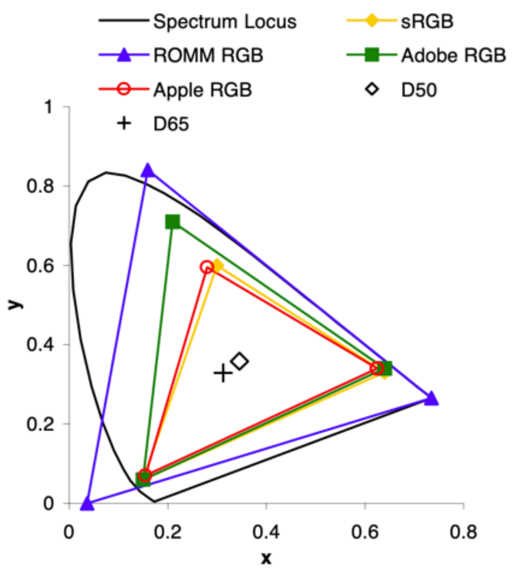


Figure 2.2 x,y-Chromaticity diagrams for sRGB, ROMM RGB, Adobe RGB 98 and Apple RGB (Süsstrunk, Buckley and Swen,1999).

Based on previous literature (Pointer, Attridge and Jacobson, 2001), the procedure of camera characterisation aims to collect the digital signals of the camera by measuring a set of coloured samples, transforming the RGB values into a device-independent colour space, XYZ tristimulus, with the assumption that the camera response is a linear combination of CIE colour-matching functions. By combining measured XYZ and RGB values of training patches together, a mathematical model can be built to predict other pixels that the XYZ tristimulus is not directly measured by a colourimeter. A third-order polynomial regression technique was developed as the mapping method to transform the RGB data of the camera image to CIE XYZ tristimulus values (He et al, 2022). This regression technique minimises the CIE Lab colour difference and performs the best when predicting XYZ tristimulus with a given RGB while building the XYZ prediction model.

2.1.3.2 Display Colour Characterisation

Similar to camera characterisation which transforms RGB input into XYZ tristimulus to ensure the colour consistency captured by a digital camera, display characterisation aims to ensure the colour can be reproduced on the display accurately.

A Gain-Offset-Gamma (GOG) model (Berns, 1996) was employed for display characterisation. Compared to other device characterisation models, the GOG model allows a more flexible adaptation with less input training information (Cho, Im and Ha, 2006). This model transformed between the CIE XYZ tristimulus values and RGB values for display. Within this model, the gain adjusts the contrast of the display. The offset alters the brightness without interrupting the contrast of the image. Gamma modifies mid-tone values to correct for non-linearities between input values and perceived brightness as human eyes act more sensitive to the details of the darker area compared to the lighter area, allowing a natural transition between the dark and the bright. According to Roy S. Berns et al.(1993), measuring a set of neutral colour swatches was recommended to build the prediction model and calculate coefficients for gain (a) - offset (b) - gamma (γ). This method is also suitable for LCD (Liquid Crystal Display) displays (Gibson and Fairchild, 2000) as a LCD display will be hired for lateral experiment.

A chromatic adaptation transform model (CAT16), established in 2017 (Li, et al.), was applied to convert the CIE XYZ tristimulus values from the different lighting conditions. CAT16, approved by the International Commission on Illumination, is a contemporary model that adjusts colour appearance predictions and evaluates colour differences based on human visual perception across two different illuminates. The methodology follows the CAT16 application protocol detailed by Li et al. (2017), thereby aiming to minimise colour differences caused by the unique colour gamut of individual devices. The adjustment and adaptation are vital for the reliable assessment of colour assimilation effects induced by various lipstick shades on different skin tones.

2.2 Factors Influencing the Level of Facial Attractiveness

Facial attractiveness is influenced by several key factors, including averageness, symmetry, and sexual dimorphism (Bronstad and Russell, 2007). Averageness describes how closely a face resembles the mean appearance within a specific population (Rhodes, 2006), while symmetry refers to the mirror-like quality of facial features. Sexual dimorphism involves the extent to which feminine or masculine traits are apparent in a face. While the application of lipsticks does not alter averageness or symmetry, it significantly impacts sexual dimorphism by enhancing feminine traits. This section will focus on how lipsticks influence perceptions of attractiveness through modifications in sexual dimorphism, particularly in terms of colour and contrast (Bronstad and Russell, 2007).

2.2.1 Sexual dimorphism in facial morphology

The dimensions of the lips, which change in terms of their height and width, notably influence perceptions of youthfulness, sexual maturity, and reproductive potential (Danel and Pawlowski, 2007; Lewandowski and Danel, 2018). The colour red, often associated with full, supple lips, plays a significant role in enhancing sexual desirability. This attribute is frequently accentuated with cosmetics, which serve to increase facial contrast and, by extension, enhance perceptions of femininity and attractiveness (Elliot & Niesta, 2008; Jones et al., 2015). Research indicates that the strategic application of cosmetics aims to enhance the contrast between facial features and skin tone, thereby exaggerating gender-specific traits (Russell, 2010).

Observers from various cultures tend to find female faces with more pronounced feminine features more attractive, highlighting a universal preference for femininity that transcends cultural boundaries (Penton-Voak et al., 2004; Perrett et al., 1998; Little et al., 2008). This preference is consistent across both Caucasian and Chinese populations, indicating a global aesthetic appreciation for feminized faces (Rhodes et al., 2010). Facial femininity is also associated with indicators of good health, such as a higher level of disease resistance (Gray, 2012), and there is widespread agreement across cultures regarding the attractiveness of these traits (Coetzee et al., 2014).

However, the degree of sexual dimorphism can vary regionally and does not uniformly dictate attractiveness, suggesting that facial colour cues might compensate for lower morphological sex differences in ethnically diverse populations (Kleisner et al., 2021). Besides the shape of facial features, facial pigmentation also plays a crucial role in the perception of sexual dimorphism (Bruce and Langton, 1994; Russell, 2003). The natural variations in skin colour between genders—often differing in terms of lightness contrast and hue—serve as reliable cues in judging the sex and attractiveness of human faces. These differences in skin colour, along with how the application of lipsticks can modify perceptual skin colour changes, thereby influencing attractiveness, will be discussed further.

2.2.2 Sexual Dimorphism in Skin Colour

Human skin colour not only varies between individuals but also exhibits significant sexual dimorphism, playing a critical role in gender recognition. Research indicates that skin colour is a primary cue for distinguishing gender, as it often differs markedly between males and females within the same ethnic group (Hill, Bruce, & Akamatsu, 1995; Nestor & Tarr, 2008). Historical evidence, supported by Darwin's theory of natural selection, suggests these differences have been recognized since the 18th century, with females generally displaying lighter skin tones than males—a pattern consistent across various cultures and races (Edwards & Duntley, 1939; Frost, 1988, 2005; Jablonski & Chaplin, 2000, 2002; Jablonski, 2004).

This phenomenon is widely acknowledged in society, where lighter female skin is often seen as a marker of femininity and attractiveness (Carrito et al., 2019). Such variations in skin luminance are not only biological indicators but have also been culturally interpreted to signify health and fertility, aligning with broader societal preferences for lighter-skinned female faces across different cultures and ethnic groups (Stephen, Smith, Stirratt, & Perret, 2009; Tan, Tiddeman, & Stephen, 2018; Lu et al., 2021).

From a biological perspective, lighter skin in females may offer certain reproductive advantages. Although melanin pigmentation originally evolved to protect against UV radiation—particularly in regions closer to the equator—lighter skin has been hypothesized to facilitate greater Vitamin D3 synthesis during critical reproductive phases, such as pregnancy and lactation (Jablonski & Chaplin, 2000; Carrito & Semin, 2019). This capability might explain the evolutionary preference for lighter skin despite its lower natural protection against UV light (Aoki, 2002; Jablonski, 2004). Furthermore, as facial luminance contrast tends to decrease with age, lighter skin is also perceived as a more youthful feature, enhancing the visual signal of higher fertility potential.

Overall, the preference for lighter skin can be seen as a complex interplay of natural, social, and sexual selection processes, influenced by both biological utility and cultural aesthetics. This widespread preference underscores the role of skin colour in sexual dimorphism and its significant impact on perceptions of attractiveness across different societies.

2.2.3 Sexual Dimorphism in Facial Features Contrast to Skin Colour

The contrast between facial features and skin tone is notably more pronounced in females, a distinction that cosmetics can significantly enhance to amplify perceived femininity. Russell (2003) hypothesised that this contrast plays a pivotal role in the perceptual attractiveness of human faces. His research, which presented participants with monochromatic photos featuring enhanced or natural features of both genders, demonstrated a pronounced preference for female faces with greater skin-feature contrast. This finding highlights the importance of skin colour differences in augmenting facial contrast, particularly around the eyes and lips, thus enhancing attractiveness (Russell, 2009; Nestor & Tarr, 2008). Consequently, facial contrast emerges as a key factor in perceptual attractiveness, with cosmetics serving to intensify this effect by either lightening the skin or darkening the features, thereby impacting overall attractiveness (Jones, 2015).

Additionally, the appearance of lips exhibits sexual dimorphism, displaying distinct variations between the sexes (Farkas, 1981; Fink and Neave, 2005). Research indicates that perceptual sexuality relies more heavily on contrast around the eye area than the mouth (Russell, 2009; Stephen et al., 2009), and there is limited sex typicality in lip colours in terms of gender (Jones, 2015). The sex typicality in hue and lightness contrast is not as apparent, which complicates the biological explanation for the predominance of lipstick use among females (Stephen and McKeegan, 2010).

Building on the discussion of sexual dimorphism in skin colour from the previous section, it is hypothesized that lipstick application may enhance sexual dimorphism by affecting the perceptual skin tone rather than merely altering the lip colour. Studies have confirmed that increasing the red-green contrast of the skin can significantly boost the femininity and attractiveness of female faces (Stephen and McKeegan, 2010). Jones (2015) suggested that the red-green contrast in female faces diminishes with age; thus, enhancing this contrast may serve as an indicator of youthfulness (Porcheron et al., 2013). While the lips may not be the most salient cue for gender typicality on their own, their impact is magnified when considered in conjunction with the surrounding skin, creating a more compelling visual cue for femininity and attractiveness.

2.2.4 Perpetual Skin Colour Change Induced by Lips

Skin colouration encompasses more than a singular numeric value like perceptual lightness; it is also significantly influenced by other facial colouration cues, such as hue. The CIE Lab* colour space, which is a three-dimensional framework, offers a comprehensive way to define and quantify the colour gamut. This model is instrumental in quantifying colour differences and can be used into analyse how perceptual colour influence attractiveness level with the combination of psychophysical experiment.

The application of cosmetics, particularly lipstick, can create an illusion of enhanced skin colour, elevating perceived femininity and attractiveness. This impact is especially pronounced in the red-green contrast (a* value) of the lips, which plays a significant role in shaping perceptions of sexual dimorphism and appears to diminish with age (Percheron et al., 2016). Research involving Chinese observers has highlighted that contrasts between eyebrows, lips, and skin are potent indicators of attractiveness and health, emphasizing the critical role of facial colour cues in these perceptions (Lu et al., 2022).

In conclusion, the interplay of morphological features and facial pigmentation showcases how sexual dimorphism in human faces is influenced by a complex mix of biological, cultural, and psychological factors that contribute to the determination of attractiveness. The widespread preference for feminised features, along with strategic cosmetic use, underscores the powerful biological cues that drive human attraction. Nonetheless, discussions about changes in perceptual skin colour have predominantly focused on lightness contrasts and have often centred on Caucasian faces. The specific ways in which lipsticks enhance the attractiveness of female faces across different ethnicities remain less well-defined, pointing to a gap in the current understanding and an area ripe for further research.

2.3 Colour Illusion Effects Induced by Lipsticks on Female Faces

Human perception of an object is significantly influenced by its surroundings. Research demonstrates that the perceived similarity between an object and its surroundings can either increase, known as assimilation, or decrease, referred to as a contrast effect (Agostini and Galmonte, 2000; Rizzi and Bonanomi, 2012). These perceptual phenomena, which are psychological rather than physical, depend on the spatial configuration of the background: a uniform background typically induces a contrast effect, while a striped one leads to assimilation.

For instance, von Bezold's simultaneous contrast effect illustrates how the same grey colour blocks appear lighter against a white background and darker against a black background, showcasing a classic contrast effect (Weert, 1991; Soranzo, Galmonte, and Agostini, 2010). This effect demonstrates how the same grey colour blocks appear lighter against a white background and darker against a black background, showcasing a classic contrast effect.

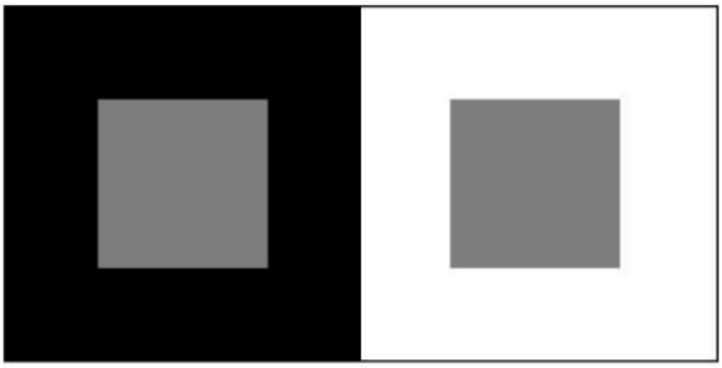


Figure 2.3 von Bezold's simultaneous contrast effect (Soranzo, Galmonte, and Agostini, 2010)

In contrast, the White effect (Moulden and Kingdom, 1989) exemplifies visible assimilation, where grey bars placed on either white or black stripes—though identical—differ in perceptual brightness. Further research indicates that assimilation effects hinge on the luminance difference between the object and its surroundings (Xim Cerda-Company et al., 2018).

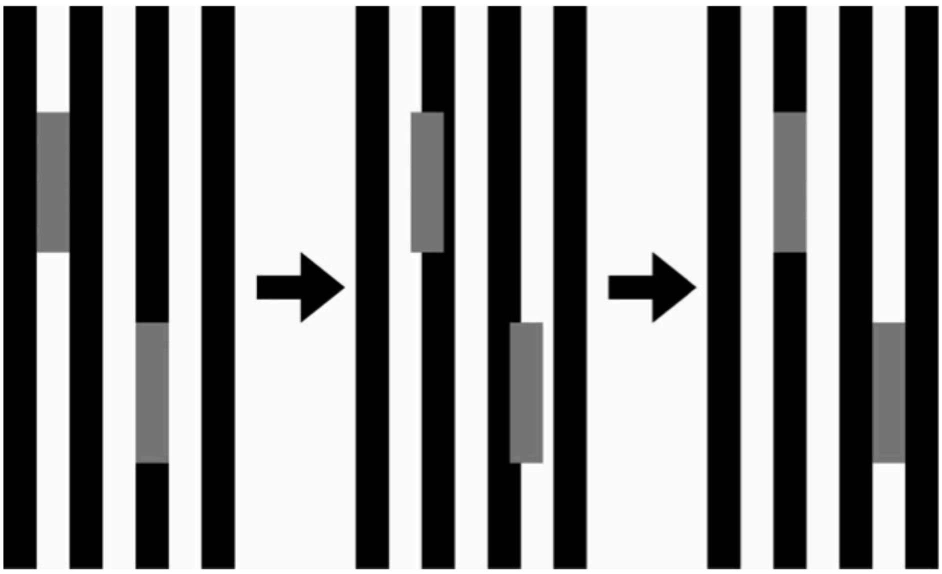


Figure 2.4 the White Effect **(**Xim Cerda-Company et al., 2018)

It is important to note that the typical examples used to illustrate these effects often focus on how the background alters the colour perception of a central area. Typically, it is a smaller part that is assimilated or contrasted by a larger background. This is relevant to human faces, which consist of features surrounded by unified skin colour.

The application of cosmetics can be likened to the effects seen in Bezold's example, where the contrast effect is prominent. However, the specific patterns of colour illusion effects on human skin, induced by cosmetic use, present unique challenges that are not entirely explained by these classical examples. This discrepancy suggests that while traditional colour assimilation and contrast theories provide a foundational understanding, they may need to be adapted or expanded to fully account for the complexities of colour perception on human skin influenced by cosmetics.

2.3.1 Colour Illusion Dectced in Human Body and Faces

In 2017, Morikawa investigated a range of shape and colour illusions specific to the human body, uncovering unique perceptual changes. His research identified a pattern of geometric illusions where surrounding influences predominantly affect human facial and bodily perceptions in assimilative rather than contrastive directions (Morikawa, 2017). For instance, the shape of a shirt's collar can assimilate the perceived shape of the face, and the application of eyeshadow can create a Delboeuf illusion, making the eyes appear larger than they actually are. Unlike geometric illusions observed in non-human subjects, illusions related to the human body tend to show assimilation of shapes, not contrast. This phenomenon has been termed the "Biological Illusion," highlighting a distinctive illusionary size change perceived in the human body.

Further to geometric assimilation, the effect of colour in creating contrast or assimilation on human features had not been thoroughly explored until recently. Kobayashi et al. (2017) extended this line of inquiry to colour perception, particularly focusing on the hues of lips and skin. Their research provided empirical evidence that the colour of lipstick can have an assimilative impact on the overall facial complexion. This finding supports the common belief that lipstick can make the skin appear lighter, redder, or darker, and suggests a reversal of the typical pattern observed in other subjects, where a larger area usually influences a smaller part. In their study, three lip colours—enhanced red, lighter, and darker shades relative to nude lips—were applied to computationally generated average faces from the Shiseido Co. Ltd database to assess these effects. The special assimilation effect observed in human faces may also be considered a biological illusion, reflecting a pattern where lightness induction due to geometric illusion on the human body shows assimilation rather than contraction. This pioneering research delves into how perceptual skin colour changes with varied lip colours.

These findings underscore a unique illusional effect that exists solely on the human body, whether through shape or colour assimilation. When combined with research on factors determining the attractiveness of human faces, the prevalent use of coloured cosmetics, especially lipstick, by females appears rational and scientifically grounded.

2.3.2 Colour Assimilation of Complexion Induced by Lipsticks

The research conducted by Kiritani et al. (2017) expanded the exploration of how lipstick influences perceived skin colouration by incorporating a diverse array of skin tones and lipstick colours, applied to digital faces. This study utilised four digitally generated faces from the Shiseido Co. Ltd database, representing yellowish and reddish skin tones at two different lightness levels. Participants were shown these faces with five different lip colours—orange, red, pink, violet, and bare—under consistent lighting conditions.

The study's findings revealed that, in addition to perceptual changes in lightness, chromatic assimilation also plays a significant role; red lipstick, for instance, enhances the redness of reddish skin regardless of the skin's absolute lightness. Similarly, orange lipstick tends to exaggerate the yellowness of yellowish undertones. Importantly, there was a positive correlation between perceived lightness and attractiveness, with red lipstick consistently enhancing perceived attractiveness and lightness across all skin tones. Orange lipstick was particularly favoured on yellowish skin, possibly because facial yellowness, which indicates carotenoid levels and perceived healthiness in Caucasian populations (Stephen, Coetzee, and Perrett, 2011), aligns with cultural associations of health and vitality. Pink lipstick was preferred on redder skin and significantly enhanced perceived lightness across all faces, though it was not deemed the most attractive. Violet lipstick scored the lowest in attractiveness and had minimal impact on enhancing perceived skin lightness.

These findings corroborate previous research suggesting that lighter and redder skin is often associated with higher fertility and better health, thus being perceived as more attractive. However, it's crucial to acknowledge the study's limitations: the perceptual hue changes were only examined within the same skin undertone, and the participant pool was restricted to twenty Japanese females. Additionally, attractiveness is a subjective human perception influenced by cultural, interpersonal, and intrapersonal differences (Little et, al., 2015). Given the variability in attractiveness perceptions across different cultural contexts, further research involving a more diverse participant base is essential to validate these findings universally.

2.4. Preference of Lipstick Colours

Lipstick colour preference varies by geographic region. Chanel Beauty (2023) published a statistic, showing the 20 best-sellers of lipstick products in France, Italy, the UK, South America, the USA, and Asia. Researchers from Chanel distributed the lipstick products into 8 clusters by colour. The result shows that the Asian region, including China, Japan, Singapore and South Korea has a strong preference for saturated red and orange-red hue colours with a medium lightness.

2.4.1 Cultural Difference

Lipstick colour preference significantly varies by geographic region and is influenced by cultural background and beauty standards. A study by Chanel Beauty (2023) showcasing the 20 best-selling lipstick products in regions including France, Italy, the UK, South America, the USA, and Asia revealed distinct preferences. Notably, in Asia—including China, Japan, Singapore, and South Korea—there is a strong preference for saturated red and orange-red hues with medium lightness.

Saito (1996) highlighted the importance of considering cultural backgrounds as a variable in colour preference research. Similarly, Jones and Hill (1993) noted that beauty standards vary across cultures, suggesting that cultural context plays a significant role in the preferences for cosmetic products. To control for cultural biases in evaluating facial colour metrics and their attractiveness, researchers often select observers from specific cultural backgrounds, such as those raised in a Chinese environment, who tend to prefer lighter and fairer skin tones. This preference influences choices in cosmetic products, such as foundations that are lighter than the wearer's natural skin colour (Chen and Jablonski, 2022).

Further exploring the influence of lipstick colours on perceptions of complexion, Kiritani et al. (2021) conducted a comprehensive study with a diverse and larger cohort of participants. This study involved Chinese and Japanese university students of both genders, with subgroups consisting of 10 participants each. Interestingly, only Japanese females were familiar with the similar-colour makeup technique, which involves applying cosmetics that closely match the skin's colour. Using a prototypical face generated from the Shiseido Co. Ltd. database, researchers applied seventeen different lipstick hues, ranging from yellow to violet, and used a paired comparison technique to assess the correlation between various lipstick shades and perceived beauty, naturalness, enhancement of a ruddy complexion, and overall skin acceptability.

The findings indicated that cultural differences significantly influence preferences, often outweighing gender differences. Japanese women, for instance, tend to associate the aesthetic appeal of makeup with its naturalness, while Chinese women prioritize the enhancement of a ruddy complexion, showing a strong preference for red lipstick shades. In contrast, Japanese females knowledgeable about the similar-colour makeup technique preferred orange-red tones, perceiving them as most attractive due to their similarity to natural facial skin. Red-purple shades were perceived as the least appealing and natural, despite their association with a ruddy complexion.

Future research could benefit from incorporating a broader diversity of skin colours to better understand the complex interplay between lipstick application and perceptual beauty standards, potentially solidifying the findings related to biological illusions in colour perception.

2.4. 2 Impression Induced by Lipsticks

Lipstick colours significantly influence the impressions formed by observers, shaping perceptions of attractiveness, femininity, and social status. The hue of the lipstick plays a crucial role in these psychological and social responses.

Red is widely acknowledged as enhancing femininity and attractiveness. Studies suggest that red lipstick evokes men's biological impulses, making women appear more attractive (Gueguen and Jacob, 2012; Kar et al., 2018). This response is linked to evolutionary cues where red signals health and vitality.

According to Wu, Gong, and Lee (2024), the more significant the difference in the a* (red-green axis) and L* (lightness) values between the lips and the surrounding skin, the more charming the colour appears. Lip colours that are closer to magenta and match the skin's lightness are perceived as cute, suggesting that both contrast and hue play roles in the induced impression.

The intensity and choice of lipstick colour are not only about aesthetic appeal but also convey social signals. Mileva et al. (2016) and Zhang (2019) have shown that darker or more vivid lipstick colours can enhance perceptions of dominance and social status. Interestingly, Zhang (2019) also found that attractiveness is a primary consideration in lipstick colour choice regardless of the social context, highlighting the pervasive influence of aesthetic considerations in cosmetic use.

It is important to note that many studies primarily reflect male perspectives on the attractiveness of lipstick colours, potentially overlooking female viewpoints. This oversight can skew interpretations and suggest a need for more inclusive research approaches that also consider women's reasons for choosing certain lipstick colours beyond mere attractiveness. Therefore, all external observers invited in the later experiment will be females.

This section of the review underscores the complex interplay between lipstick colour, perceived attractiveness, and social signalling, revealing the depth of influence that such a small aspect of appearance can exert on social interactions and personal identity.

2.5 Summary

This literature review explores the complex interplay between cosmetic applications, particularly lipsticks, and their perceptual effects on facial attractiveness, focusing on colour assimilation and cultural variations. The discussion begins by establishing foundational concepts in colour science, specifically how human perception is influenced by the colours surrounding an object. Key studies, such as those by Agostini and Galmonte (2000) and Rizzi and Bonanomi (2010), provided insights into the mechanisms of colour assimilation and contrast effects, explaining how backgrounds can alter the perception of objects within their vicinity.

The impact of lipstick on human facial perception was then examined, illustrating how different colours can alter the perceived skin colouration through assimilative effects. Research by Kiritani et al. (2017) expanded upon previous findings by showing that lipstick not only changes perceived skin lightness but also hue, thereby influencing perceived attractiveness. This highlights the importance of considering both lightness and chromatic dimensions in the analysis of cosmetic effects.

Furthermore, the review delved into geographical variations in lipstick colour preferences, revealing distinct trends that reflect deeper cultural and regional aesthetic inclinations. Statistical data from Beauty (2023) and studies by researchers like Saito (1996) and Kiritani et al. (2020) elucidated how cultural backgrounds and beauty standards influence individual choices in cosmetics. These studies collectively emphasized a prevailing preference for lighter and redder skin, which is associated with health and fertility, across various cultures, particularly in East Asia.

The literature review also critically assessed the limitations inherent in the existing research, such as potential biases introduced by small sample sizes and the use of synthetically generated digital faces. It called for more inclusive and comprehensive studies that encompass a broader array of skin tones and cultural backgrounds to enhance the generalisability of the findings.

In summary, the review illuminated the complex relationship between cosmetic use and perceptions of beauty, driven by both biological cues and cultural conditioning. It underscored the role of colour assimilation effects in cosmetics, which not only enhance certain facial features but also conform to culturally conditioned standards of beauty, thereby reinforcing the multifaceted nature of aesthetic preferences in contemporary society.

Chapter 3. Methodology

3.1 Overview

Inspired by previous research (Kiritani et al., 2017), this study aims to explore the effect of lipstick colours on the visual perception of actual human faces. Prior investigations using software like Adobe Photoshop to apply and modify lipstick shades have predominantly relied on computer-generated imagery (CGI) for investigating colour assimilation effects induced by lipstick application. This approach, while informative, introduces inherent biases—especially due to the use of predefined skin tones which might predispose the results towards certain colour assimilation effects. Recognising these limitations, this study applied/utilised a methodology involving real human subjects, chosen for random selection of skin colours of Chinese and Caucasian females, to fill the previous research gap. The experimental framework is divided into two primary stages: the first focuses on colour image capture of real human faces wearing different lipstick shades and comprehensive device characterisation for ensuring accurate and consistent colour reproduction; the second stage is to conduct psychophysical experiments based on facial images shown on a professional-level display to collect visual assessment data from observers regarding skin colour perception on lightness, redness, yellowness and attractiveness.

3.2 Stage One: Experiment Preparation

3.2.1 Selection of Lipstick Shades

Recognising the impracticality of everyday use of pure yellow or violet shades among Chinese females, and the procurement challenges of such specific shades, the study opts for transitional colours within these hues. These are differentiated by variations in lightness and saturation. This selection criteria, focusing on matte finishes to minimise reflection and gloss interference, aligns with the study's aim to isolate and examine the interplay between colour illusion effects and perceptual attractiveness. For this research, six lipsticks from the Maybelline Super-stay Ink Crayon Lipstick collection were selected, spanning a range from light orange, light pink, dark pink, dark orange, red and dark purple, chosen for their vibrancy and matte texture.

Figure 3.1 Lipstick colour selected, derived from Maybelline's official website.

3.2.2 Image Capture and Colour Measurement

Ten participants, comprising five Leeds-based Chinese females and five Leeds-based Caucasian females, were enlisted to capture facial images across the six lipstick shades and to measure their skin and lip colour data. The six lipsticks were separately applied to each participant following a specific sequence from lightest to darkest shades to mitigate pigment staining effects. Each shade was applied with a disposable brush and layered three times for optimal colour vibrancy. Participants were seated in a VeriVide light booth that provided a neutral grey surrounding and even D65 illumination, their facial images were captured using a Canon EOS 6D Mark II digital camera under a consistent of focus length 24mm, ISO 500, shutter speed 1/50, aperture f10 and manual exposure, controlled remotely to ensure uniformity in camera position and settings throughout the experiment. Participants maintained a neutral expression during image capture to minimise facial expression influences, particularly for subsequent attractiveness assessments. Seventy facial colour images, including bare lips and six lipsticks, were captured in total with a distance of 60cm from the camera and the colourimeter.

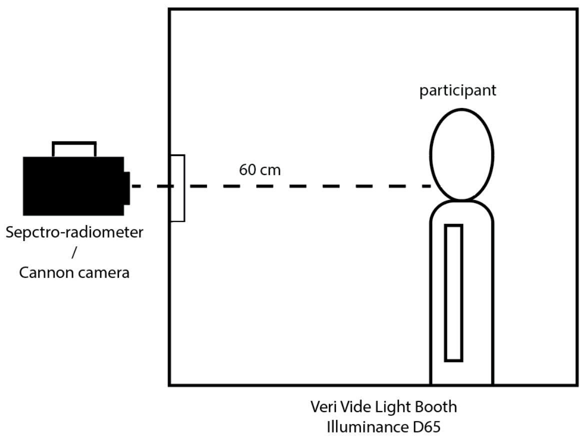


Figure 3.2 Environment of photos captured and data measurement in the lighting booth.

As for colour measurement of lips and the skin, six facial points were measured for each participant's bare face using the Konica Minolta Spectroradiometer CS-2000 with a spot size of 1mm. The colour measurements focused on regions such as the cheekbones, nose tip, chin, and lips (as detailed in Figure 3.3), following the methodology of Kerdsawad, et al (2019) and He, et al (2022). The colour measurement process was repeated for each lipstick application.

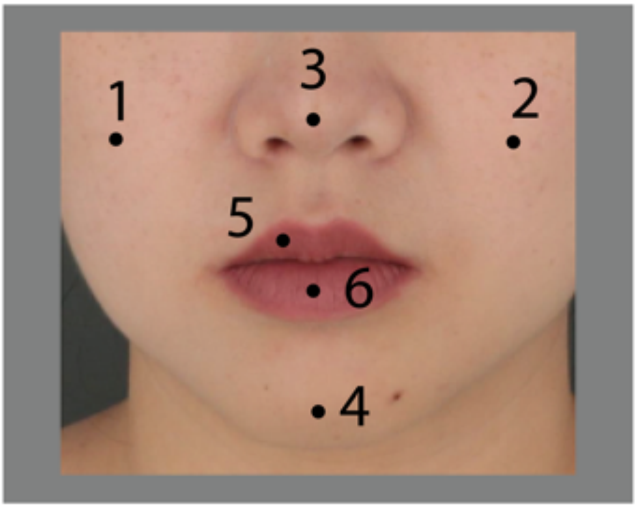


Figure 3.3 Points measured by CS-2000.

3.2.3 Colour Characterisation for Images

To accurately present the facial colour and skin colour on the display, a series of characterisation processes from the camera to the monitor were applied and the process will be explained in the following section.

3.2.3.1 Camera Colour Characterisation

A camera colour characterisation model was built using the face and lip colour chart as the training dataset. Firstly, the spectral power distribution (SPD) across 400-700 nm was measured at the interval of 1 nm for each of the colour patches using Konica Minolta Spectroradiometer CS-2000 under the same conditions as the facial image capture. The corresponding CIE XYZ tristimulus values were calculated using direct selection methods, the CIE1931 Colour Management Functions (CMFs), and the measured SPD of the 6500K illumination.

Secondly, images of both the lip-skin colour chart and facial skin colour chart were captured at the same position under D65 illumination as the human face using the digital camera with the same settings, and the average RGB values of each colour patch were derived from the captured image in MATLAB. Besides, a subset of facial skin colour and lip colour data measured in this study was also used as a training dataset, including the CIE XYZ tristimulus values calculated from the measured SPD and RGB values derived from facial images.

A third-order polynomial regression technique was applied as the mapping method to transform the RGB data of the camera image to CIE XYZ tristimulus values (He et al, 2022). This regression technique minimises the CIE Lab colour difference and performs the best when predicting XYZ tristimulus with a given RGB.

The training data of RGB and CIE XYZ values were derived from both real human facial images and colour charts captured in the previous section. With the training dataset, a prediction model for estimating skin and lip colours from RGB to CIE XYZ values was generated using the third-order polynomial regression technique. The model performance was evaluated using the training dataset as the testing dataset, and the average CIE Lab colour difference of all samples is 2.2 units.

In terms of the application of this study, the number of training patches is n = 782 (including 480 colour chart patches, and 280 data from the captured human images). i is the ordinal number of the testing data. L_0、a_0、b_0 are calculated from instrument measurement of the training dataset. L_i、a_i、b_i are predicted by the developed camera colour characterisation model.

3.2.3.2 Display Colour Characterisation

A BenQ colour professional display (51.84cm*32.40cm, LCD backlit, Adobe RGB colour space) was used to show participants the facial images for visual assessment. Given that the colour space and gamut of the display is highly dependent on the device used, a colour characterisation process of the display is necessary for accurate colour reproduction.

The BenQ display is set into Adobe RGB colour space with 6500 K, GAMMA 2.2, brightness 24, contrast 50 and sharpness 5. A set of colour patches, including r, g, b and grey patches from 0 – 255, was presented on the screen separately and the centre of each patch was measured using the Konica Minolta CS-2000 spectroradiometer (1°field of view, spot size 1mm) to collect the spectral power distribution. The action was performed in a completely dark room to avoid external lighting interference. With the CIE XYZ tristimulus values calculated, a Gain-Offset-Gamma (GOG) model (Berns, 1996) was employed to develop a reverse colour characterisation model for this display so that the target colour with specific CIE XYZ values can be transformed to the display RGB colour space.

3.2.3.3 Chromatic Adaptation Model

The standard white points of the display with the settings mentioned in the previous section and the light booth environment were measured using the CS-2000 spectroradiometer, respectively. Considering that the white points of the lighting environment in the VeriVide light booth and the BenQ display are not the same, a chromatic adaptation transformation was performed to ensure that observers evaluate facial images with accurate colour reproduction.

The CAT16 chromatic adaptation transform model, established in 2017 (Li, et al.), was applied to adapt the colours with The CIE XYZ tristimulus values in the light booth condition to those in the BenQ display colour space. All facial images captured in this experiment were processed in the order of camera colour characterisation, chromatic adaptation transform, and display colour characterisation. Last, the characterised photos were cropped into 700x600 pixels. Only the lower face (from mid-nose to chin) was shown to the observer to reduce the influence of face features. The figures below show an example of a face before and after the characterisation.

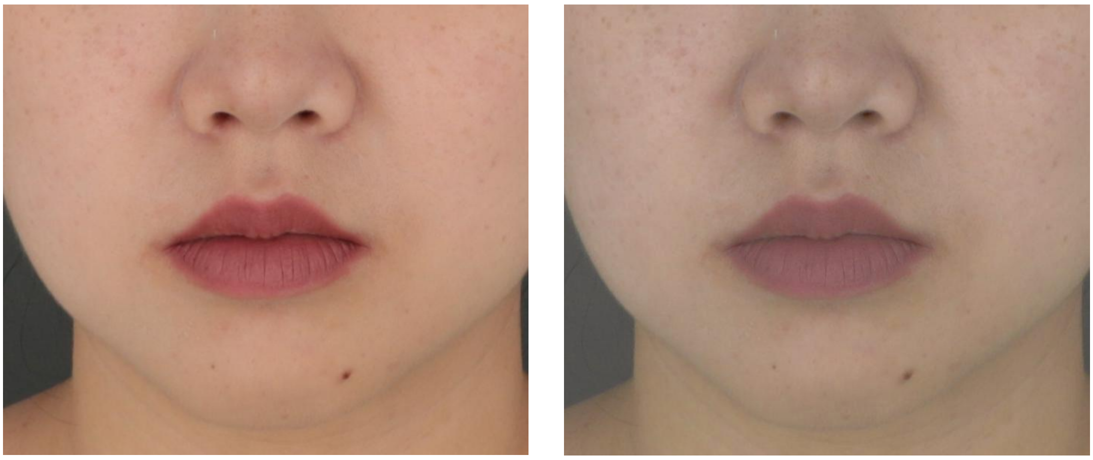


Figure 3.4 An example of colour characterisation, before and after.

3.3 Stage Two: Psychophysical Experiment

The 70 images collected from the previous stage were presented to 15 Chinese females (age range 23-36 years; mean 25.74) on a pre-characterised BenQ display. Images were set to a similar size as seen physically. The surrounding colour of the image was set to a mid-grey (R: G: B=128:128:128).

The Ishihara test was conducted on the same device before the experiment started. If qualified, the participant will be given an information sheet and consent form to explain the experiment. The participant was sitting in front of the BenQ monitor in a completely dark environment at a 40-centimetre distance from the screen. Sixty pictures were shown randomly to each observer to review. The interface of the experiment is shown in Figure 3.5.

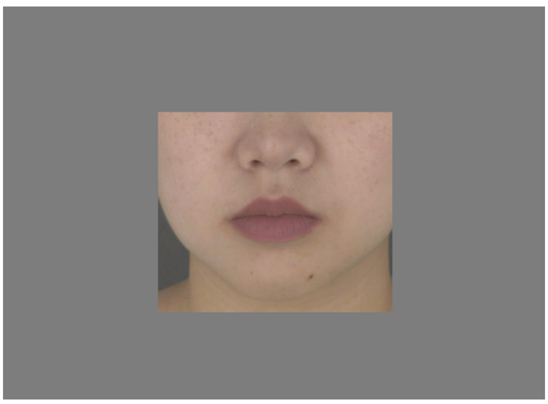


Figure 3.5 An example of experiment interface.

Observers were asked to give their judgements from 1 to 7 regarding four perceived attributes: lightness, yellowness, redness, and attractiveness. Four questions were asked for each image: from 1 being the least light/reddish/yellowish/attractive, and 7 being the most, how many points you would rate this image from the 4 attributes. Each observer experimented twice to ensure consistency and 2100 (=70*15**2) judgements were collected from the visual experiments.

3.4 Statistical Analysis

The statistical examination will be introduced to explain how the data collected can be analysed.

To investigate the differences in perceptual colour, change and the differences between each variable (lipstick), a set of statistical examinations is employed, including paired sample T-test and Cohen's d. Besides, Pearson's Correlation Coefficient (PCC) is also applied in this research to explore possible correlations between perceptual facial colour metrics and attractiveness.

3.4.1 Paired Sample T - Test

The Paired Sample T Test is utilised when comparing the means of two related groups to determine if their average difference is significantly different from zero (Manfei et al., 2017). This test is particularly suitable for studies where the same subjects are subjected to two conditions. It can be applied to sets of parameters that are normally distributed. In this study, with and without lipstick are the conditions given and will be compared.

The test calculates a t-statistic, which represents the ratio of the average difference between paired observations to the standard error of the difference. A significant t-value indicates that the mean difference between paired observations is unlikely to arise from random variation alone.

Key values that explain the differences are t-statistics, degree of freedom (df) and p-value. t-statistic measures the size of the difference relative to the variation in the sample data. The larger the t-value, the more significant the difference between the group means. Degrees of Freedom (df) reflects the number of values in the final calculation of a statistic that are free to vary. For the Paired Sample T Test, df is typically the number of pairs minus one. p-value assesses the probability of observing the calculated t-value, or one more extreme, under the null hypothesis that there is no difference between the groups. A p-value below a predetermined threshold (e.g., 0.05) indicates statistical significance. A significant t-test result suggests a meaningful difference in means between the paired groups, which, in this context, would imply a significant impact of lipstick application compared to the no-lipstick condition.

3.4.2 Cohen’s d

Cohen’s d is defined as the difference between two means divided by a standard deviation for the data (Gignac and Szodorai, 2016). In the context of a paired sample t-test, it's often calculated using the mean difference between the paired observations divided by the standard deviation of these differences. Cohen's d thus provides a standardised measure of the magnitude of the observed effect, independent of the sample size. It offers a practical significance adding on to the statistical significance provided by the t-test.

The equation for Cohen’s d is:

$$d = \frac{Mean\ Differences}{Standard\ Deviation\ of\ the\ Differences} \qquad \textbf{Equation 3.1}$$

According to Gignac and Szodorai (2016), when scaling the effect size, a Cohen's d between 0.2 is typically considered a "small" effect size, 0.5 refers to a "medium" effect size, and 0.8 or higher indicates a "large" effect size.

In this study, applying Cohen's d to the paired sample t-test results enables us to quantify the impact of lipstick application versus the no-lipstick condition beyond mere statistical significance. By doing so, the practical implications of our findings regarding how different lipstick colours alter perceived skin colour can be explained. This nuanced understanding is crucial for drawing comprehensive conclusions from our data analysis.

3.4.3 Pearson's Correlation Coefficient

Pearson's Correlation Coefficient (PCC), symbolises as r, measures the linear relationship between two variables, quantifying the strength and directions of two sets of data (Cohen et al, 2009). It is a statistical method showing how closely two sets of data correlate to one another. The range of r is between -1 (completely negative correlation) and 1 (completely positive correlation). The PCC value can be calculated with the formula below:

$$r = \frac{\sum(X - \hat{X})(Y - \hat{Y})}{\sqrt{\sum(X - \hat{X})^2}\sqrt{\sum(Y - \hat{Y})^2}} \qquad \textbf{Equation 3.2}$$

As mentioned before, objective 2 seeks to investigate the correlation between perceived facial colour changes and their impact on attractiveness levels. Given that our data is both quantitative and continuous, the Pearson Correlation Coefficient (PCC) is an apt choice for this analysis. Employing PCC enables us to elucidate the strength and directionality of the relationship between skin colour metrics and perceived attractiveness. The correlation coefficient, denoted by the symbol r, facilitates the comparison of relationships across various variables, allowing us to assess how correlations might vary among different ethnic groups. Moreover, PCC offers initial insights into the interplay between perceptual colour changes and attractiveness. These insights serve as a valuable foundation for future research, guiding subsequent investigations into these relationships.

3.5 Summary

In section introduced the experiment designed to fulfil the two research objectives and previous research gaps. Diverging from prior methodologies that relied heavily on computer-generated imagery (CGI), real human images were applied in the experiment, offering a more authentic examination of colour assimilation effects across diverse skin tones.

The methodology can be divided into two primary stages. The first stage focuses on capturing facial images under controlled lighting conditions and characterising these images for accurate colour representation. This involves the selection of six lipstick shades from the Maybelline Super-stay Ink Crayon Lipstick collection, applied to ten participants of two varying ethnic backgrounds. Detailed measurements are taken using the Konica Minolta Spectroradiometer CS-2000, with subsequent image processing conducted to ensure colour accuracy. This process entails calculating CIE XYZ tristimulus values, extracting RGB values from captured images, and employing a third-order polynomial regression technique to predict XYZ values from given RGB data.

Furthermore, the display is also characterised ensuring that the images viewed by observers are representative of true colours as perceived by the human eye. This involves the application of the CAT16 chromatic adaptation transform model and the Gain-Offset-Gamma (GOG) model to adjust the images for display on a BenQ colour professional display. These steps are vital for achieving a consistent colour appearance across different devices for the accurate assessment of colour assimilation effects.

The second stage of the methodology is devoted to gathering observer assessments. 15 Chinese females are enlisted to evaluate the perceived lightness, redness, yellowness, and overall attractiveness of the facial images. This evaluation process is carefully designed to minimise biases and ensure reliable data collection.

To quantitatively assess the effects of lipstick application and its impact on attractiveness, a robust statistical analysis framework is established. This includes the use of paired sample T-tests with Cohen’s d for effect size measurement, and Pearson’s Correlation Coefficient (PCC) to explore correlations between colour changes and attractiveness. The choice of statistical tests is guided by the data structure and specific research objectives, aiming to provide a nuanced understanding of how different lipstick shades influence perception.

The results of the experiments will be presented and analysed primarily in the following data analysis section.

Chapter 4. Results

4.1 Colour Measurement

The skin and lip colours measured from the 10 human participants are averaged for each group (CN: Chinese, CA: Caucasian) and detailed in the Table below. The "facial average" is calculated from the mean values of the measurements at facial points 1 and 2, as outlined in section 3.2.1.1. Similarly, measurements were averaged across two lip areas (points 5 and 6) to represent the colour of bare lips and with each lipstick colour applied.

	CN					CA				
Measured Points	L*	a*	b*	h*	C*	L*	a*	b*	h*	C*
face average	66.04	14.29	17.70	39.18	22.82	66.28	16.47	17.80	43.66	24.26
bare lips (BL)	52.30	22.63	15.45	55.57	27.43	42.67	33.83	9.87	71.59	35.81
light orange (LO)	45.66	29.34	10.81	69.56	31.38	49.69	26.24	12.52	58.28	29.41
light pink (LP)	45.64	30.96	8.50	74.35	32.23	46.44	31.05	10.82	61.56	33.02
dark pink (DP)	43.09	34.09	9.64	74.42	35.62	44.84	30.75	9.69	58.96	32.51
dark orange (DO)	43.05	33.22	13.65	67.35	36.12	43.22	35.49	8.57	62.81	36.74
Red (R)	38.78	39.16	19.39	63.65	43.70	41.01	36.75	15.61	59.76	40.17
Purple (P)	34.25	43.09	11.47	75.09	44.60	42.96	36.02	15.35	60.00	39.54

Table 4.1 Averaged skin and lip colour measurements for Chinese and Caucasian images.

4.1.1 Skin Colour

The measured skin colours of the 10 participants were illustrated in CIE Lab colour space, as shown in Figure 1, which reveals that the lightness level of both Chinese (CN) and Caucasian (CA) faces exhibits similarities. However, the CA group demonstrates higher a* values, indicative of redder skin tones. Additionally, the Chroma values for CA faces are comparatively richer than those of the CN group. These findings suggest that the skin colour of Caucasian females presents as more saturated and vibrant relative to their Chinese counterparts.

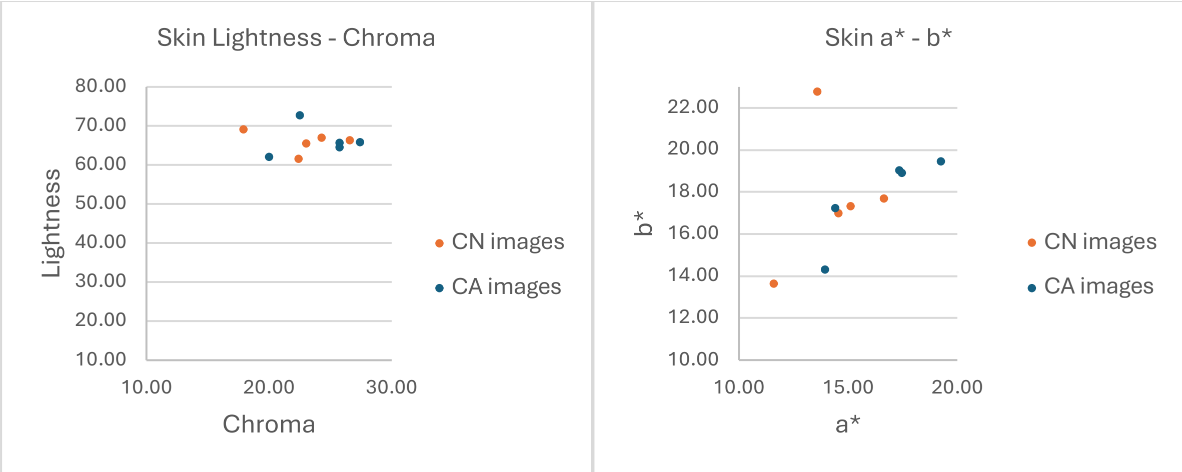


Figure 4.1 Individual skin colour measurement, lightness – chroma and a* - b*.

4.1.2. Lipstick Colour

Figure 2, a scatter chart, presents the individual colour measurements of lips with lipstick applied. Despite the application of an identical quantity of lipstick across participants, the lipsticks manifested as lighter on the lips of the Caucasian female participants compared to those of the Chinese group. Furthermore, a* value for the CN (Chinese) group measured is higher, signifying a redder appearance of the lipstick application. This indicates a perceptible variation in how the lipstick colour interacts with the underlying lip colour between the two ethnic groups.

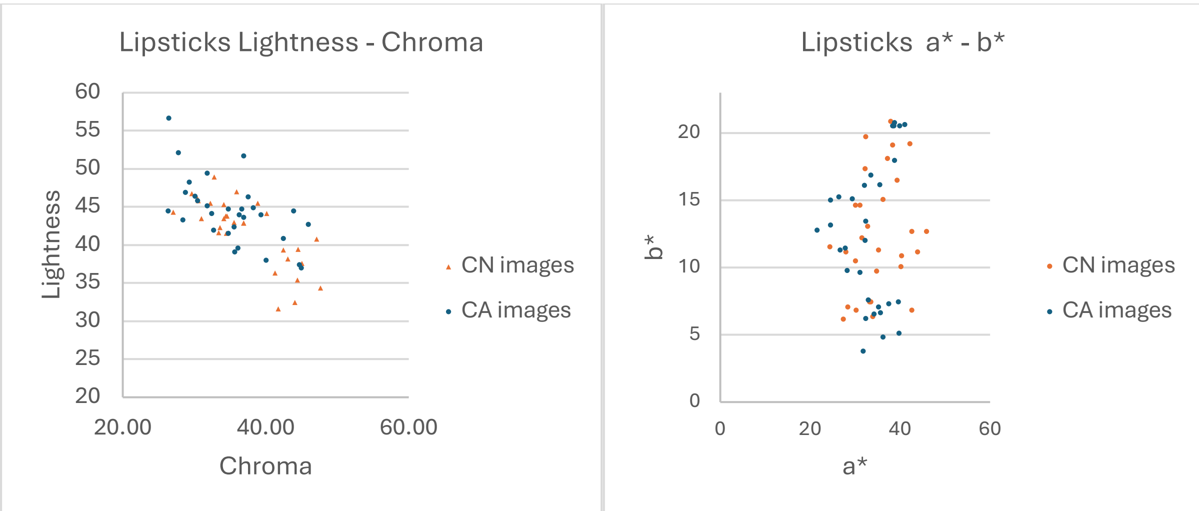


Figure 4.2 Individual lipstick colour measurement, lightness – chroma and a* - b*.

4.1.3 Colour Difference between Skin and Lipstick

Colour differences between the face and lips, measured in L, a, b*, and total colour difference, serve as critical indicators for assessing facial attractiveness. These metrics quantify colour differences from a measurement standpoint and can be analysed with the perceptual perspective together to investigate the relationship between face colour metric and attractiveness comprehensively.

According to the literature review sections 2.2.4 and 2.3.3.2, colour differences in the lightness, a*, b* axis and the total colour differences are important indicators while judging facial attractiveness and linking typical impressions towards certain lipstick. The lightness contrast will influence the perceptual attractiveness and charm of lipstick colour if combined with a*. Total colour difference, delta E, also plays an important role in classifying lipstick colours. The colour difference for each individual face is calculated by using the figure of lips minus the figure of the skin (Stephen and McKeegan, 2010), and then the average colour difference for each ethnical group is formed.

The heatmap demonstrated the average colour difference of each lipstick by using the lip measurement minus the skin and averaged by lipstick code and their absolute colour difference. Since the value is calculated by lip minus the skin. A negative L* indicates that the greater the absolute value is, the darker the lip is. The greater the a* value is, the redder the lips are compared to the skin. A positive b* value means the lips are yellower compared to the skin, and a negative indicates bluer. Delta E is the absolute colour difference that describes how much colour difference is in total between the two objects.

	CN images					CA images				
Lipstick ID		delta L*	delta a*	delta b*	delta E		delta L*	delta a*	delta b*	delta E
light orange (LO)		-20.37	15.05	-6.89	26.6		-17.09	11.18	-6.97	21.98
light pink (LP)		-20.39	16.68	-9.2	28.13		-20.23	16.11	-7.75	27.36
dark pink (DP)		-22.95	19.81	-8.06	31.82		-22.29	14.33	-6.05	27.61
dark orange (DO)		-22.98	18.93	-4.05	30.39		-22.84	19.46	-6.47	31.17
red (R)		-27.26	24.87	1.69	37.11		-25.56	22.08	-3.5	34.73
purple (P)		-31.79	28.8	-6.23	43.49		-32.79	25.69	-4.15	39.29

Table 4.2 Heatmap for average colour differences of Chinese and Caucasian images, lip minus skin.

Delta L*: The data reveals that all lipstick applications result in a darker appearance relative to the skin. Notably, lipstick LO exhibits the smallest difference in lightness across both groups, with this disparity more pronounced on Caucasian skin. Conversely, the purple shade shows the largest delta L* value for both groups, indicating a significant contrast to the skin.

Delta a*: Reflecting the redness dimension, all lipsticks register as redder than the skin. The lipstick LO remains consistently the least reddish for both ethnicities, while the purple lipstick stands out with the highest increase in redness, indicating a strong difference in both hue and chroma.

Delta b*: The analysis indicates that all lipstick shades impart a bluer hue compared to the face, except for the red lipstick on Chinese skin which adds a yellowish tint. For the Caucasian group, the red lipstick is observed to be the yellowest compared to other shades. The two pink lipsticks appear bluer on Chinese faces, whereas light pink is the most blue-tinged on Caucasian images.

Delta E*: Overall, the total colour difference, as measured by delta E, is greater for Chinese faces than for Caucasians. The shade purple generates the most substantial colour difference across all faces, asserting itself as the most transformative shade. In contrast, light orange lipstick showcases the least deviation from the skin's natural colour.

The objective measurement data presented in this section offer a foundational understanding of how skin and lipstick colour look like on Chinese and Caucasian group. By integrating these physical measurements with subjective evaluations from external observers, a more nuanced insight into the impact of lipstick on perceived skin colour and its subsequent influence on perceived attractiveness can be developed.

4.2 Experimental Results

This section reports collectively the responses of experiment stage 2. Each facial image stimulus was evaluated 15 times, and the visual assessments were averaged in Microsoft Excel. Descriptive statistics such as the mean, standard deviation, and standard error are detailed within the table.

A preliminary examination of the responses reveals a notable observation: the standard deviation for the CN (Chinese) group is larger than that for the CA (Caucasian) group. This discrepancy suggests that the responses from the CN group exhibit greater variability compared to those of the CA group, implying a more homogeneous consensus among Chinese observers regarding the other ethnic group than towards their own.

For a more granular analysis and to facilitate a clearer understanding of the responses, the results will be dissected across four rating scales: lightness, redness, yellowness, and attractiveness. Additionally, ethnic groups will be scrutinized as variables to investigate potential differences in colour assimilation effects between them. This detailed exploration aims to uncover nuanced insights into how perceptual evaluations of colour and attractiveness are influenced by ethnic background.

4.2.1 Intra- and Inter- Observer Variability

To ensure the reliability of the responses, participants in the second stage of the experiment were required to complete the evaluation twice to ascertain intra-variability. This term refers to the reliability of responses by assessing two sets of answers provided by the same observer at different times. Pearson's Correlation Coefficient was utilised to calculate this consistency. The correlations, calculated in Excel, yielded average values across the scales as follows: lightness (0.87), redness (0.86), yellowness (0.86), and attractiveness (0.85), indicating a good consistency between the two trials.

Inter-observer variability examines the uniformity of responses across different observers. Cronbach's Alpha (α), a statistical method that measures consistency in a multi-item bipolar scale (Vaske, Beaman, and Sponarski, 2017), was employed to assess this form of consistency. This method is apt for evaluating variability across different groups, whereas the Pearson correlation coefficient is more commonly used to assess the linear relationship and correlation between two sets of data. Therefore, when dealing with multiple observers or instruments, Cronbach's Alpha offers a more comprehensive assessment of consistency.

The process was completed in SPSS, resulting in alpha values for each scale as follows: lightness (0.88), redness (0.82), yellowness (0.81), and attractiveness (0.91), demonstrating good to excellent consistency. This suggests a common agreement among observers in evaluating the scales of images.

4.2.2 Visual Responses

4.2.2.1 Perceived Skin Lightness

After invalid responses are filtered, responses were collated from 15 external observers, detailing their lightness perception across various lipstick applications, including a no-lipstick control. The figure down below shows the average result of all responses, each bar represents 75 responses with 5 different faces in each group viewed 15 times.

As illustrated in the figure 4.3, the application of lipstick consistently resulted in a perceived increase in skin lightness across all samples. Notably, red lipstick yielded the most significant lightening effect for both Chinese (CN: 4.32) and Caucasian (CA: 4.37) groups, with the least lightening effect observed in CN with lipstick LP and in CA with LO. The depicted error bars signify the standard error, reflecting the response consistency; narrower bars suggest a higher agreement level amongst observers.

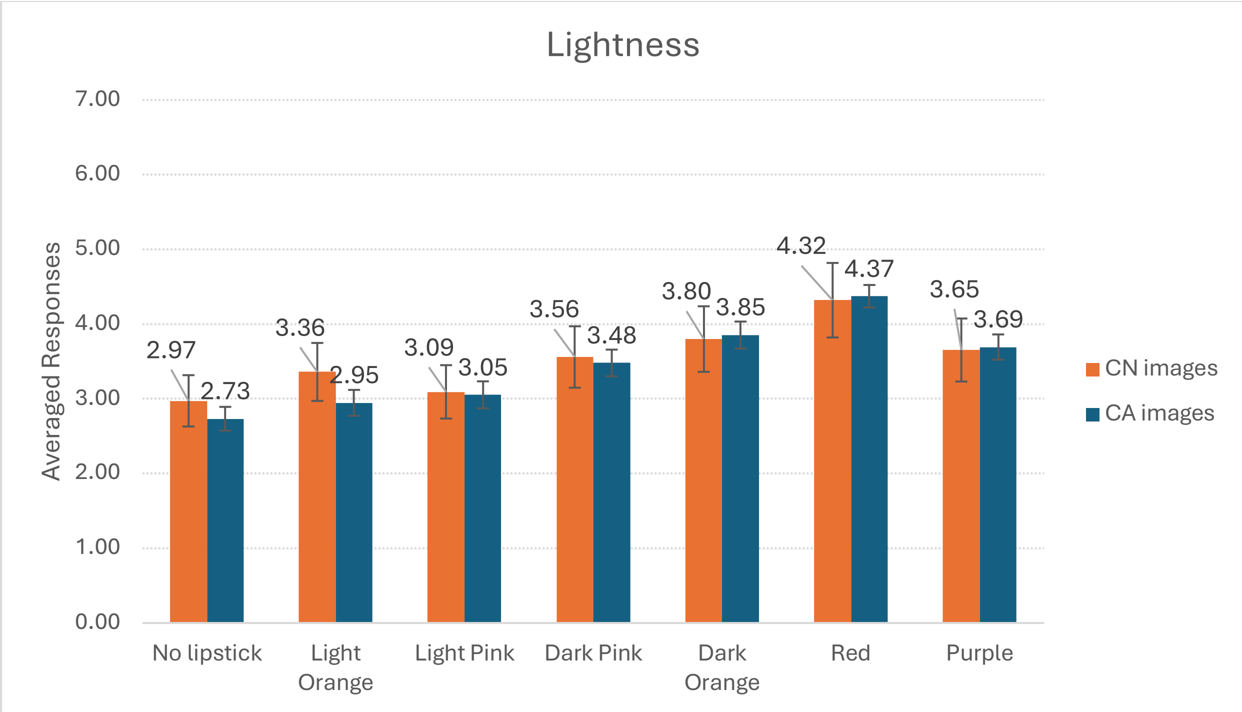
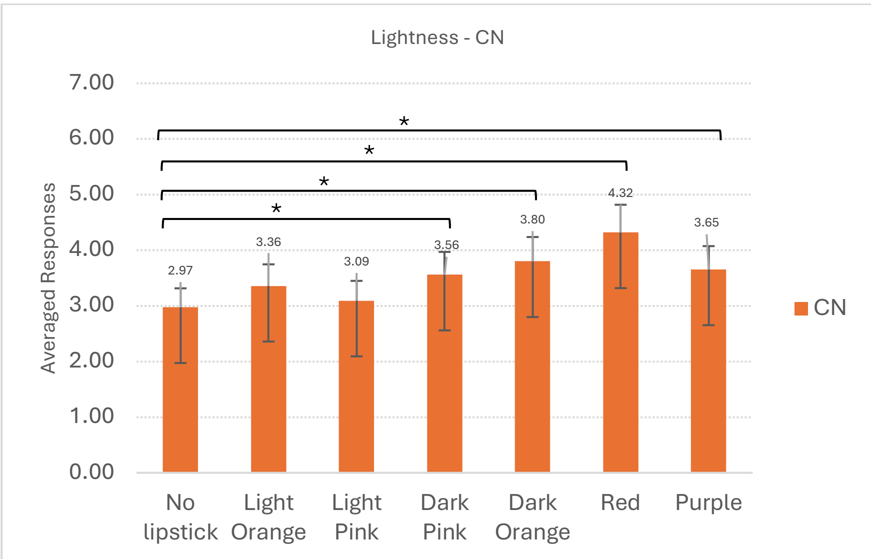


Figure 4.3 Averaged results of experiment stage 2, lightness for CN and CA images.

The figure below shows the visualised results for perceptual lightness and the differences between each lipstick for both ethnicities with the result of the t-test and effect size evaluated using Cohen's d.



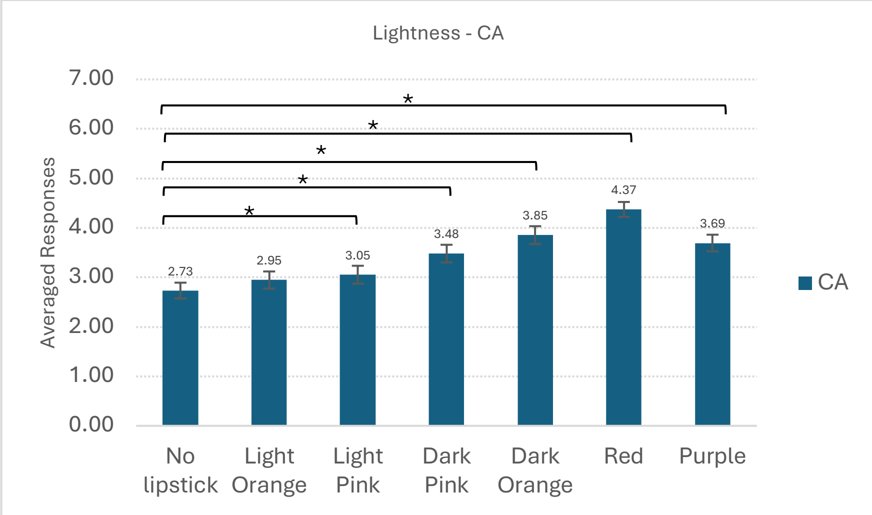


Figure 4.4 Visualised differences and significance of t-test, lightness.

For images featuring Chinese (CN) individuals, the illustrative data depicted above delineates that, with the exception of two lighter shades, all lipstick applications statistically enhance the perceived lightness of the skin relative to the no-makeup condition. When assessing the magnitude of these effects, it emerges that the two lighter hues and the dark pink shade exert a small influence, whereas dark orange and purple display medium effects. Notably, red lipstick has a pronounced large effect on perceived lightness. Turning attention to the images of Caucasian (CA) participants, it can be deduced that except for the light orange shade, all lipstick varieties contribute to a statistically significant elevation in skin lightness perception in comparison with the unadorned state.

In terms of effect size, as shown below, a parallel trend to that of the CN cohort is observed. The two lighter lipsticks and the dark pink shade present small effects; dark orange and purple manifest medium effects; and red asserts itself as the shade imparting a large effect on perceptual lightness.

Lightness			Effect Size	
	Group		CN	CA
	BL - LO	Cohen's d	-0.329	-0.248
	BL - LP	Cohen's d	-0.246	-0.303
	BL - DP	Cohen's d	-0.42	-0.47
	BL - DO	Cohen's d	-0.591	-0.663
	BL - R	Cohen's d	-0.9	-0.927
	BL - P	Cohen's d	-0.579	-0.606

Table 4.3 Effect size for Chinese and Caucasian images, perceptual lightness.

This congruency in trends between CN and CA images reinforces the notion that lipstick not only universally augments lightness perception but also does so to varying extents dependent on the specific shade, underscoring the role of colour intensity in cosmetic influence.

4.2.2.2 Perceived Skin Redness

The data illustrated in the corresponding figure suggests that all lipsticks tend to enhance the redness to varying degrees. Notably, red lipstick is associated with the highest increase in perceived redness for both ethnicities, registering average scores of 4.32 for Chinese (CN) and 4.37 for Caucasian (CA) individuals. Interestingly, the lowest redness enhancement is observed with lipstick LO in both groups, hinting at subtle but distinct variations in how lipstick hues manifest across ethnicities.

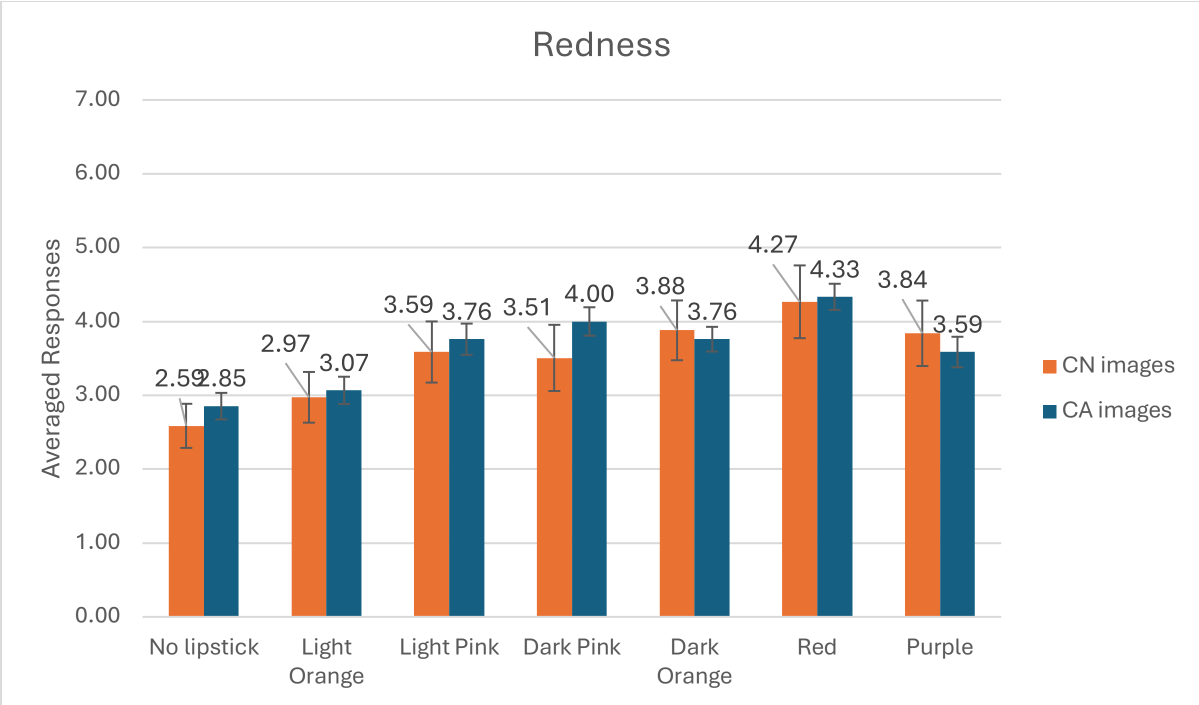
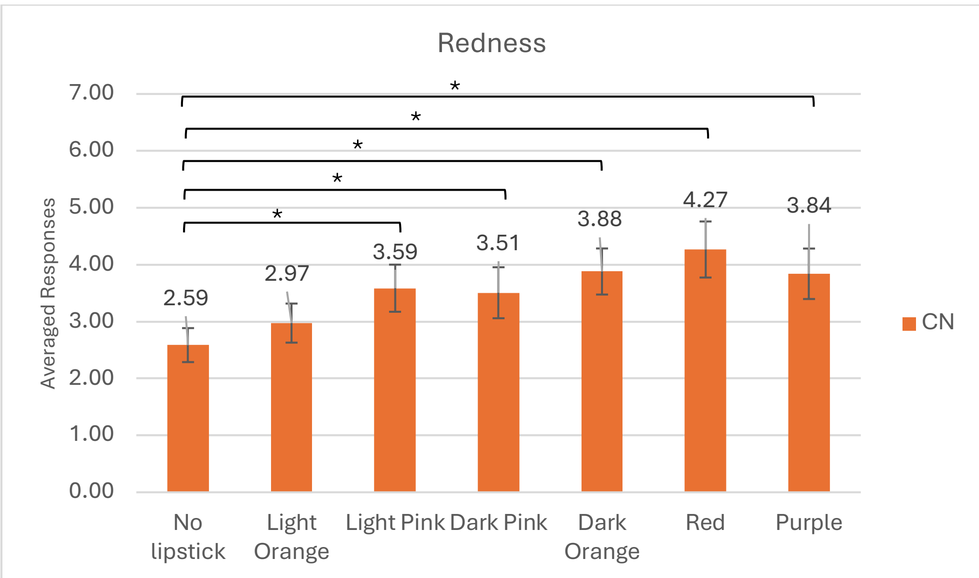


Figure 4.6 Averaged results of experiment stage 2, redness for CN and CA images.

The figure and table below reveal the responses of Chinese external observers regarding how lipstick influences the perceptual redness of the face with the result of the t-test and effect size evaluated using Cohen's d.



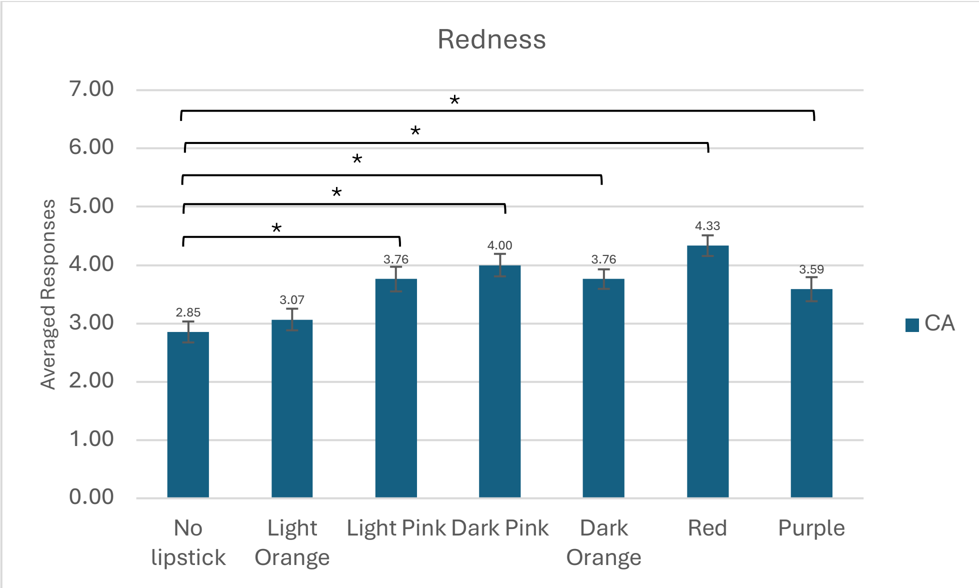


Figure 4.7 Visualised differences and significance of t-test, redness.

Redness			Effect Size	
	Group		CN	CA
	BL - LO	Cohen's d	-0.245	-0.027
	BL - LP	Cohen's d	-0.56	-0.345
	BL - DP	Cohen's d	-0.473	-0.403
	BL - DO	Cohen's d	-0.691	-0.355
	BL - R	Cohen's d	-0.854	-0.588
	BL - P	Cohen's d	-0.711	-0.266

Table 4.4 Effect size for Chinese and Caucasian images, perceptual redness.

The synthesis of information from the graph and accompanying table elucidates that, with the notable exception of light orange, all lipstick shades exert a significant influence on the perceived redness of the skin, transcending ethnic boundaries. In the case of Chinese (CN) images, it is observed that, except light orange (LO), the remaining shades elicit a medium to large effect in terms of redness assimilation, with the shade red leading the charge in enhancing red hues. Contrastingly, for Caucasian (CA) images, the effect size is comparatively subdued, with only the shade red demonstrating a medium level of assimilation effect under the standard of Cohen's d mentioned in section 3.4.2.

This suggests that while the impact of lipstick on enhancing skin redness is a universal phenomenon, the magnitude of this effect varies between ethnic groups, especially for DO and P. Specifically, Chinese individuals tend to perceive a more substantial shift towards redness across a broader spectrum of shades, Caucasian individuals exhibit a more restrained response, with significant assimilation predominantly attributed to the red lipstick alone when observed by Chinese females.

4.2.2.3 Perceived Skin Yellowness

As depicted, the perceptual yellowness scores indicate a relatively consistent increase across lipstick shades compared to the no lipstick baseline. The trend appears homogenous between the ethnic groups, with no single lipstick shade markedly altering the yellowness perception compared to others. This uniformity points towards a collective tendency in the perception of yellowness irrespective of ethnic background.

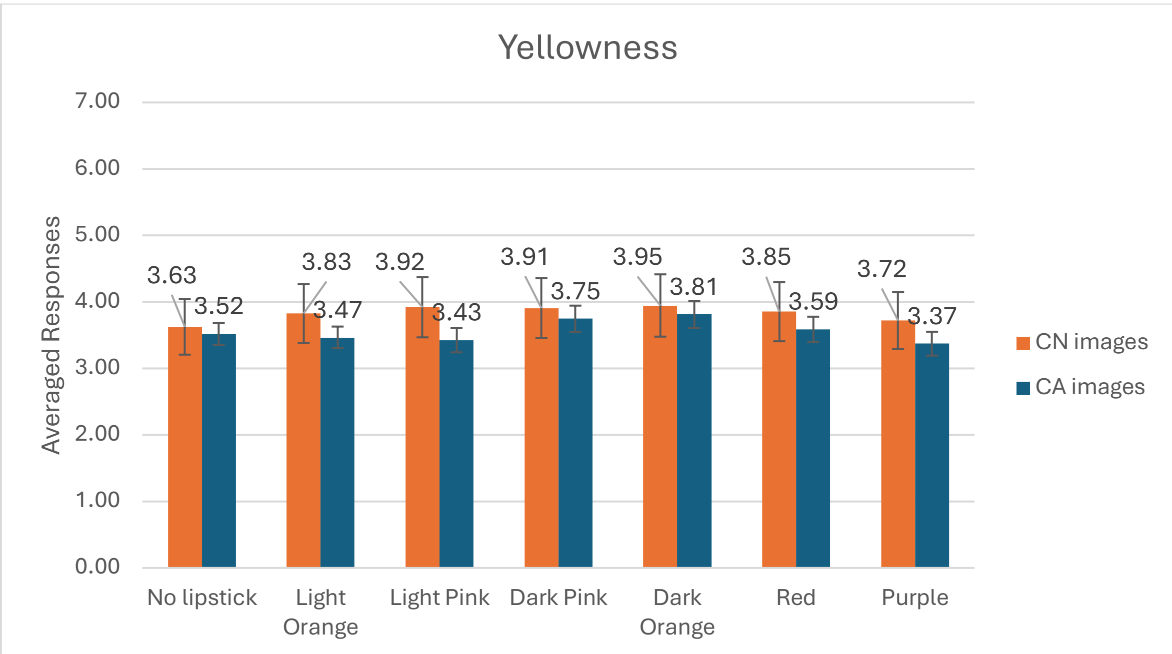


Figure 4.8 Averaged results of experiment stage 2, yellowness for CN and CA images, yellowness.

The figure below shows the visualised results for perceptual yellowness with the result of the t-test and effect size evaluated using Cohen's d.

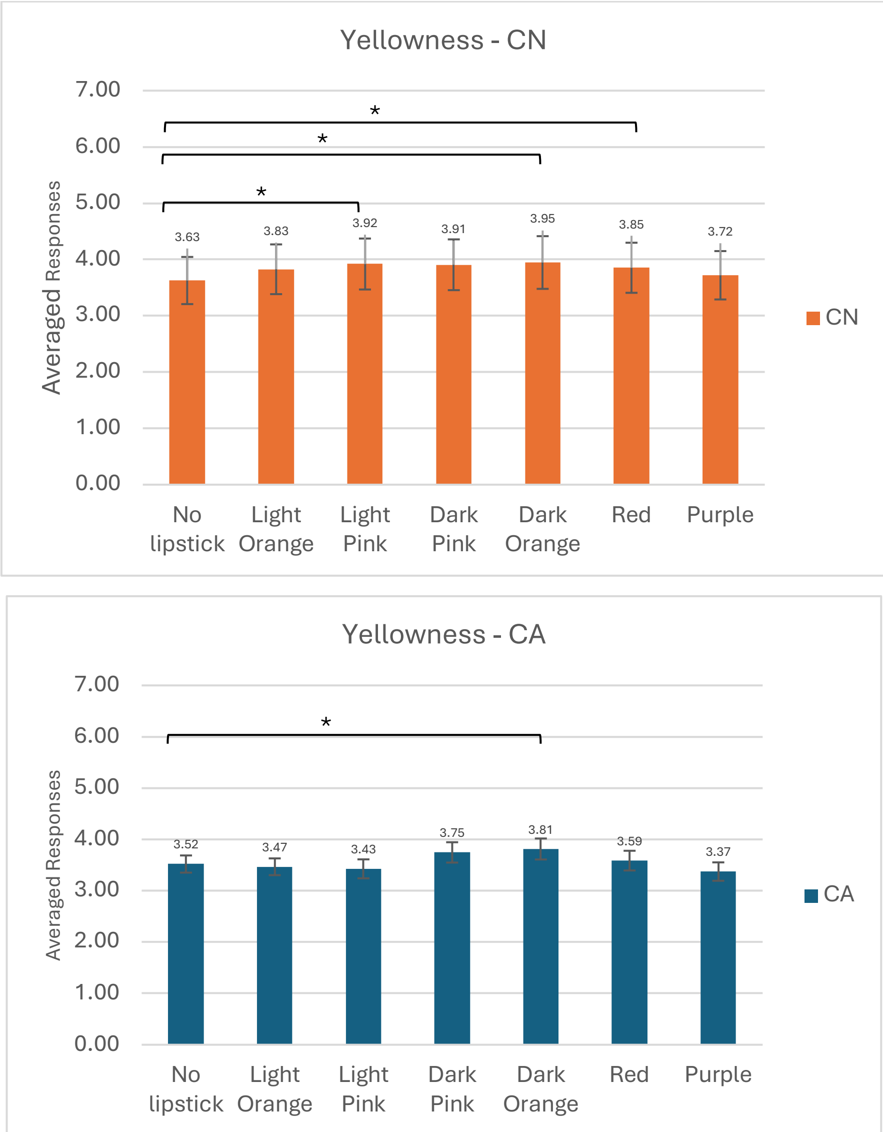


Figure 4.9 Visualised differences and significance of t-test, yellowness.

The analytical data portrayed in both the figure and table elucidates that changes in perceptual yellowness are less pronounced when compared to the perceptual shifts observed in the other colour scales. For Chinese (CN) images, a discernible colour assimilation effect in terms of yellowness is evident in the application of light pink (LP), dark orange with the biggest effect size (DO), and red lipsticks. However, in the case of Caucasian (CA) images, only dark orange (DO) lipstick manifests a noticeable change in yellowness perception.

When quantified using Cohen’s d, the intensity of these changes is consistently minor across all instances. This uniformity in small effect sizes, regardless of the ethnicity or colour scale under consideration, indicates a more nuanced impact of lipstick on the perception of yellowness. Such findings suggest that, while lipstick can alter the perception of skin colour, its influence on yellowness is considerably subtle and less variable compared to lightness and redness.

Yellowness			Effect Size	
	Group		CN	CA
	BL - LO	Cohen's d	-0.181	0.108
	BL - LP	Cohen's d	-0.273	0.08
	BL - DP	Cohen's d	-0.244	-0.039
	BL - DO	Cohen's d	-0.301	-0.097
	BL - R	Cohen's d	-0.291	-0.058
	BL - P	Cohen's d	-0.236	0.048

Table 4.5 Effect size for Chinese and Caucasian images, perceptual yellowness.

Notably, the effect sizes for these differences, as measured by Cohen's d, were found to be small. This indicates that while the statistical tests are sensitive enough to detect subtle variations, the practical significance of these differences in terms of perceptual yellowness may be minimal. Consequently, the observed significant differences, albeit small, are reported and discussed in the context of their potential implications for consumer perceptions and cosmetic industry practices.

4.2.2.4 Perceived Skin Attractiveness

The assessment of attractiveness reveals a differential impact of lipstick application. Lipstick shades such as Red are perceived to notably elevate attractiveness for both groups, achieving average scores of 4.51 for CN and 4.07 for CA, respectively. The least increase in attractiveness is observed with the no lipstick condition for both ethnic groups. This suggests that the application of lipsticks, particularly those with vivid hues, may significantly contribute to the enhancement of facial attractiveness.

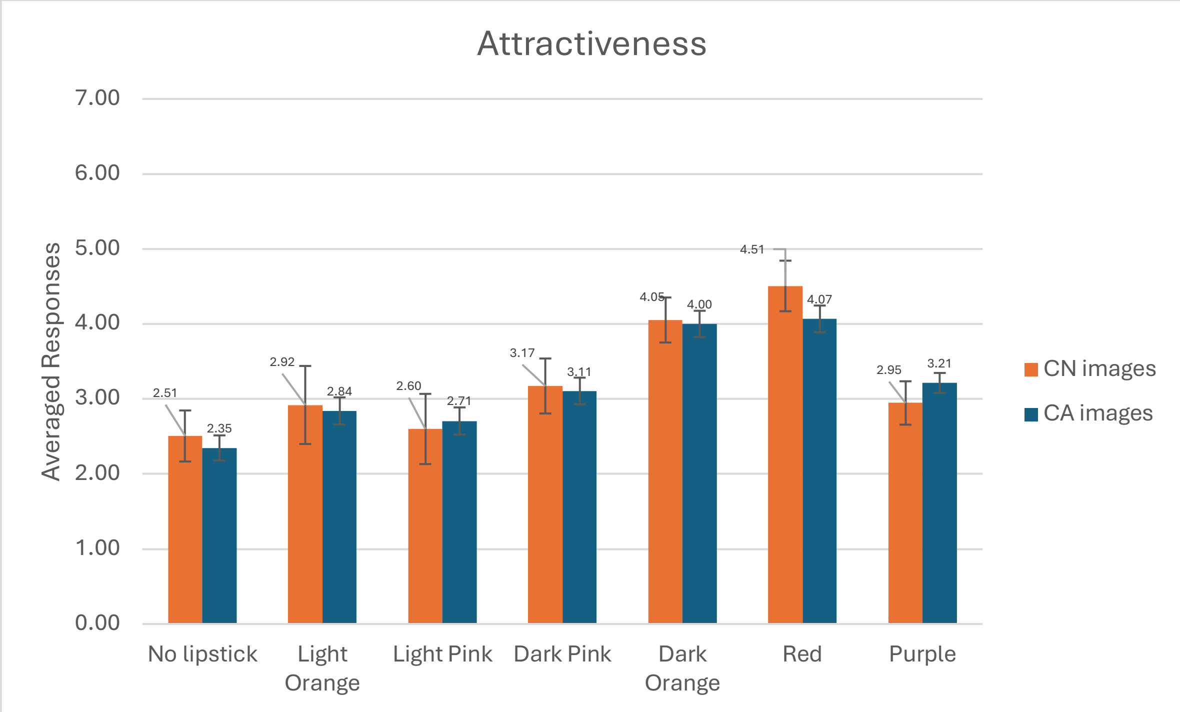
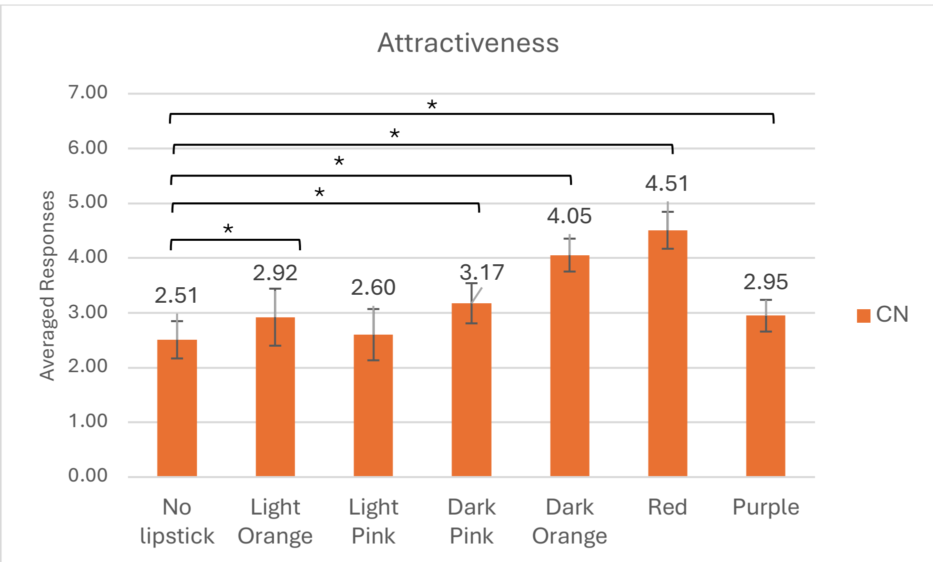


Figure 4.10 Averaged results of experiment stage 2, attractiveness for CN and CA images.

Specific shades such as red, dark orange and dark pink have a uniform effect in attractiveness, highlighting an intriguing aspect of colour perception that crosses ethnic lines.

The figure below shows the visualised results for perceptual attractiveness.



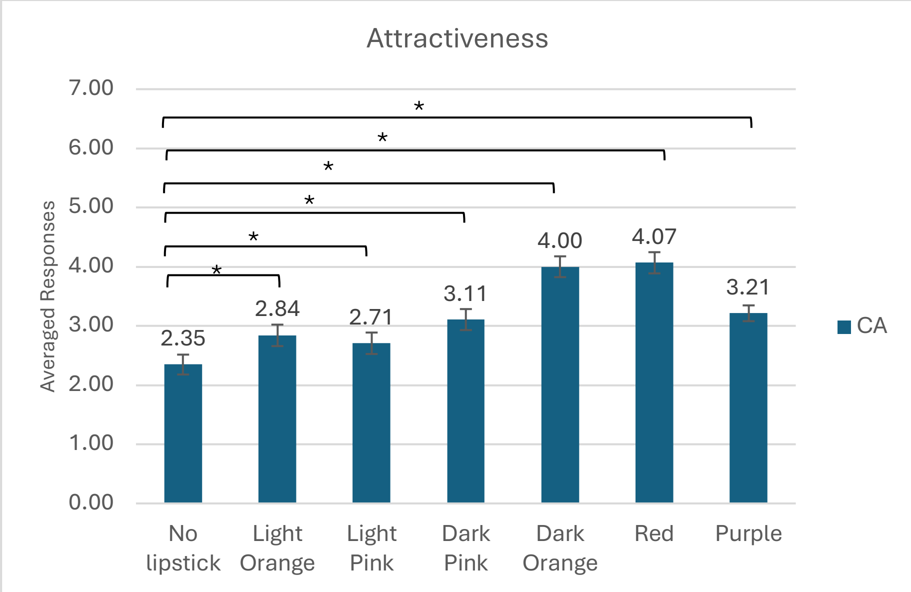


Figure 4.11 Visualised differences and significance of t-test, attractiveness.

Upon reviewing the Chinese (CN) image data, it is evident that all lipstick shades, except light pink (LP), significantly enhance perceived attractiveness in contrast to the no-lipstick baseline. Specifically, light orange (LO), dark pink (DP), and purple (P) are associated with a modest, small effect, whereas dark orange (DO) and red (R) are characterised by a substantial, large effect.

In the context of Caucasian (CA) images, each lipstick shade achieved statistical significance in terms of augmenting perceptual attractiveness. Nevertheless, when evaluated using Cohen's d (Table 4.6), the observed effect sizes are not as pronounced as those seen in the CN cohort. Consistent with the findings for Chinese faces, the shades of red (R) and dark orange (DO) yield the most notable enhancement in attractiveness among CA individuals, registering as a medium effect. In comparison, light orange (LO), light pink (LP), and dark pink (DP) display the least pronounced effects.

Attractiveness			Effect Size	
			CN	CA
	NL - LO	Cohen's d	-0.294	-0.15
	NL - LP	Cohen's d	-0.209	-0.146
	NL - DP	Cohen's d	-0.42	-0.267
	NL - DO	Cohen's d	-0.819	-0.676
	NL - R	Cohen's d	-0.964	-0.726
	NL - P	Cohen's d	-0.386	-0.4

Table 4.6 Effect size for Chinese and Caucasian images, perceptual attractiveness.

These observational insights into perceptual changes across the redness, yellowness, and attractiveness scales provide a comprehensive understanding of how cosmetic application influences aesthetic perception. Moreover, they serve as a prelude to further statistical analysis that seeks to quantify these perceptual differences and examine their significance in the context of perceptual attractiveness.

4.3 Relationship between Perceptual Colour Metrics and Attractiveness

In order to explore the dynamic interplay between perceptual colour changes on skin attractiveness due to lipstick application and identify which colour cue could serve as an indicator, the Pearson Correlation Coefficient (PCC) was employed to quantify the relationship between perceptual lightness, redness, yellowness, and attractiveness. This statistical approach will illuminate the degree to which these variables correlate, underpinning the findings with a linear interpretative framework.

To encapsulate the relationship between colour metrics and perceived attractiveness, a series of scatter plots were created in Microsoft Excel. These plots include linear trend lines derived through the least-squares method, which serve to succinctly illustrate the correlation between each colour metric and attractiveness.

The scatter plots are created using the average value of each stimulus, uniformly exhibiting that lightness and redness share a positive correlation with perceived attractiveness across different facial groups. Conversely, yellowness appears to have a negative association with attractiveness, particularly pronounced in the Chinese (CN) group compared to the Caucasian (CA) group. This trend suggests that while increases in lightness and redness generally enhance the perception of attractiveness, yellowness does not follow this pattern and is, in fact, inversely related, especially within the CN sample.

These visual insights suggest a cross-cultural preference for increased lightness and redness as contributors to attractiveness, while perceptions regarding yellowness may be more complex and racially nuanced.

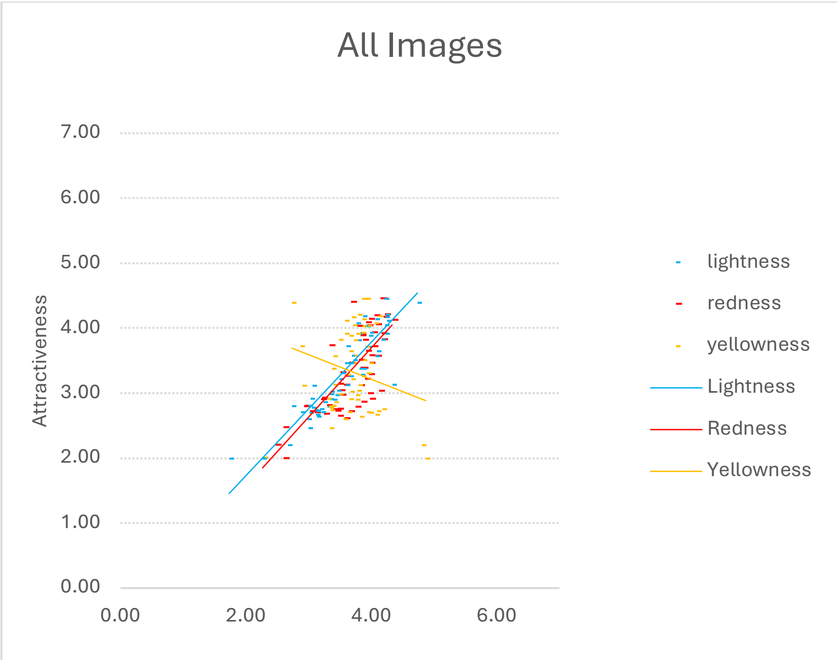


Figure 4.12 Correlation of perceptual lightness, redness and yellowness with attractiveness, in all images.

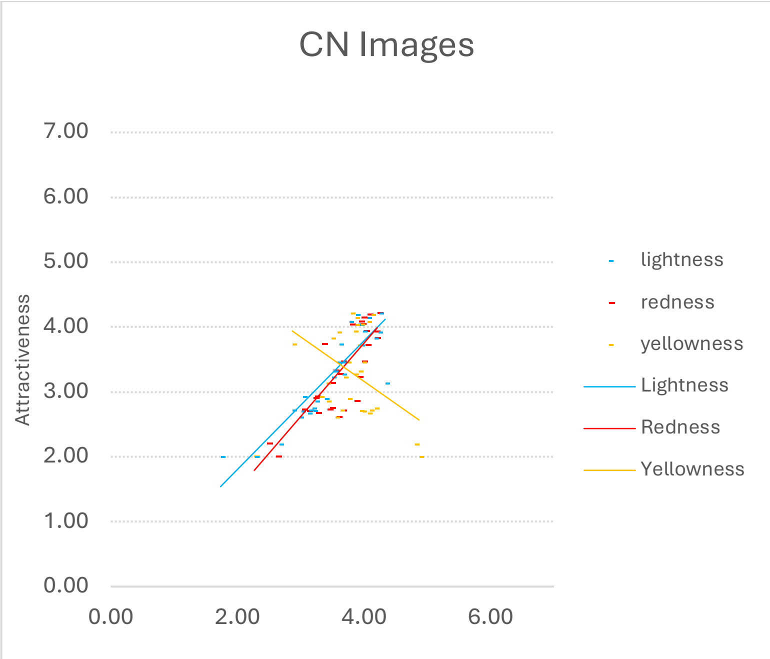


Figure 4.13 Correlation of perceptual lightness, redness and yellowness with attractiveness, in Chinese images.

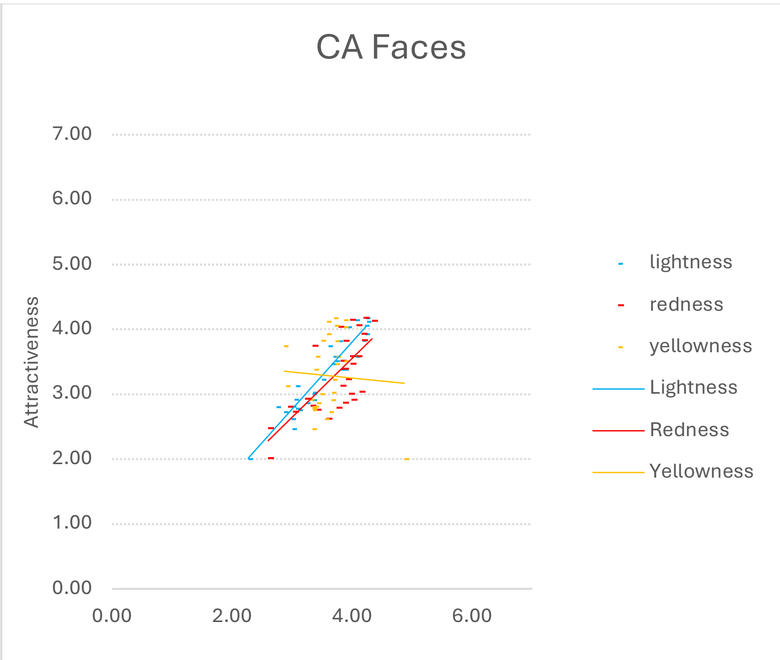


Figure 4.14 Correlation of perceptual lightness, redness, and yellowness with attractiveness, in Caucasian images.

4.4.1 Correlation between Perceptual Lightness, Redness, Yellowness, and Attractiveness

Pearson's correlation coefficient (PCC) has been utilised to quantify the linear relationships between perceptual attributes and attractiveness. As displayed in the table below, a consistent positive correlation exists between both lightness and redness with attractiveness across all images, with lightness demonstrating a strong correlation and redness a moderate one by the PCC general standards.

Intriguingly, the correlation between yellowness and attractiveness diverges from the patterns observed with lightness and redness. The data indicates a negligible correlation for all faces combined and specifically for Caucasian (CA) images. This suggests that the perceived changes in yellowness caused by applying lipsticks have a very limited impact on attractiveness within these groups. For Chinese (CN) images, the relationship between yellowness and attractiveness is weak and negative, echoing the results generated by the least-squares trend analysis.

These findings indicate that while lightness and redness significantly contribute to perceptions of attractiveness, the influence of yellowness is minimal and varies between ethnic groups. Such nuances highlight the complex interplay of colour perception and aesthetic valuation in different racial appearance contexts.

Pearson Correlation			
Perceptual	All images	CN images	CA images
Attractiveness-Lightness	0.674**	0.685**	0.662**
Attractiveness-Redness	0.393**	0.394**	0.391**
Attractiveness-Yellowness	0.009	-0.051	0.075

Table 4.7 Pearson's Correlation Coefficient of perceptual attractiveness and colour metrics.

4.4.2 Correlation between Perceptual Responses and Physical Colour Measurements

To discern the underlying which facial cues were utilised in judging colour metrics and aesthetic appeal, a comprehensive set of Pearson Correlation Coefficient (PCC) analyses was performed. These analyses probe the connection between the perceived colour scales—lightness, redness, and yellowness—and their corresponding objective values in the CIE Lab colour space (L*, a*, and b*). Given the complex nature of the CIE Lab colour space, where hue and chroma are derived from L*, a*, and b* values, the correlation between these dimensions and perceived colour metrics warrants a thorough exploration. The result will be described according to the four experiment scales.

Perceptual / Physical	All images	CN images	CA images
Lightness-delta L*	-0.084	-0.108	-0.16*
Lightness-Hue	0.081	0.156*	-0.127
Lightness-Chroma	0.047	0.017	0.182**
Redness-delta a*	0.157**	0.086	0.161*
Redness-Hue	0.007	-0.036	-0.166*
Redness-Chroma	0.141*	0.061	0.216**
Yellowness-delta b*	0.106*	0.156*	0.06
Yellowness-Hue	-0.101*	-0.19*	0.026
Yellowness-Chroma	0.037	0.04	0.091
Attractivenes-delta E	0.084	0.181*	0.074
Attractivenes-Hue	0.136*	0.175*	-0.095
Attractivenes-Chroma	0.54*	0.55*	0.163*

Table 4.8 Pearson's Correlation Coefficient of perceptual responses and facial colour cues.

Lightness Perception: Perceived lightness shows a negative correlation with delta L. This is because the delta L is calculated by lip measurement minus skin, while the perception is how light the observer perceives the skin. Yet, no strong correlation with the delta L* values across all images, suggesting that other factors may influence the perceptual assessment of lightness. However, for CN images, hue presents a significant positive correlation, indicating that hue variations might inform lightness perception. As for CA images, chroma shows an impact on skin lightness perception.

Redness Perception: Delta a* values have demonstrated a consistent positive correlation with perceived redness across all groups, confirming delta a* as a reliable physical indicator of redness. Interestingly, full-face chroma also correlates with perceived redness, especially for CA images, which points to the chroma's role in enhancing the perception of redness.

Yellowness Perception: The perceptual assessment of yellowness is linked with delta b* values, more so in CN images, but this relationship does not hold as strongly for CA images. The negative correlation of hue with yellowness in CA images suggests a complex relationship where hue variations might inversely affect the perception of yellowness.

Attractiveness Assessment: Across all images and particularly in CN images, chroma shows a moderate positive correlation with perceived attractiveness. This implies that more saturated colours are generally perceived as more attractive. For CN images, attractiveness also has a notable positive relationship with hue, suggesting a nuanced interplay between colour saturation and attractiveness.

In summary, the PCC analysis reveals that while delta a* and chroma are consistently influential in assessing redness and attractiveness, the perceptual assessment of lightness and yellowness seems less straightforward, influenced by a combination of physical colour measurements. These findings underscore the multifaceted nature of colour perception and its implications for aesthetic judgements.

4.5 Summary

To summarise this section, the comprehensive data analysis conducted in this study reveals a series of intricate relationships between the application of different lipstick shades and their perceptual impact on facial colour metrics and attractiveness. Through the utilisation of paired sample T-tests, the study has identified statistically significant differences in how lipstick shades alter the perception of lightness and redness across all images, with yellowness showing a more minor and complex pattern of perception, particularly within the Chinese (CN) cohort.

Pearson Correlation Coefficient (PCC) analyses further interpret these findings, demonstrating that while lightness and redness are consistently related to increased perceptions of attractiveness, the influence of yellowness remains minimal and varies between ethnicities. Specifically, redness and lightness in facial images were positively correlated with attractiveness, and these attributes were significantly influenced by the richness and saturation of the lipstick colours applied, as indicated by the chroma measurements in the CIE Lab colour space.

The study's findings suggest that observers rely on a spectrum of facial colour cues to assess attractiveness and colour metrics. These cues include but are not limited to, the delta a* and chroma for evaluating redness and the delta b* for assessing yellowness. Chinese female observers displayed a propensity to base their judgements on these physical colour attributes, although this varied slightly when evaluating faces from another ethnic group.

Overall, the data analysis underscores the critical role that colour plays in the perception of human attractiveness and how such perceptions are influenced by both physical and perceptual colour metrics. This cross-cultural exploration into the perceptual effects of cosmetics extends our understanding of aesthetic valuation, highlighting the interplay between cosmetic colour application and ethnic variations in colour perception.

Chapter 5. Discussion

5.1 Overview

This research aims to investigate the colour illusion induced by different lipsticks on the skin and the relationship between colour metrics with perceptual attractiveness. Two objectives are listed to break down the research question, including quantifying the perceptual colour differences of the skin induced by lip colours as well as how each colour metric interacts with perceptual attractiveness.

5.2 Effects of Lipstick Colours on Skin Colour Perception, Lightness

Prior studies have noted a colour assimilation effect induced by lipstick colours, where lighter lip shades relative to the skin can make the complexion appear brighter (Kobayashi et al., 2017). Since none of the lipstick colours chosen in this research is lighter than the skin colour, the illusion of perceptual lightness increase is not induced by lightness assimilation but by contrast. Apart from light orange and light pink for Chinese images, and light orange for Caucasian images as shown in figure 4.4, all groups demonstrate a statistically significant difference of perceptual lightness of the skin compared to bare lips.

5.2.1 Lightness Differences

Echoing Kiritani et al. (2017), this thesis also finds that lipstick application enhances skin lightness perception compared to bare lips, as depicted in Figure 4.3. The lipsticks, being darker than the skin, could create an illusion of lighter skin by contrast. This observation could align with von Bezold’s simultaneous contrast effect described in Section 2.3, where greater lightness differences should intensify the contrast effect. Nevertheless, this effect appears not to strictly apply to the human face and lips as previous literature stated.

The perceptual lightness of the skin is not coherent with the relative lightness difference between the lipstick and the face. The hue purple showed the largest lightness difference (delta L*) against facial skin in both ethnic groups (CN: -31.79, CA: -32.79), yet red and dark orange shades are perceived to increase skin lightness more than bare lips. This indicates that perceptual lightness is affected by more than just the absolute lightness contrast between lips and skin.

Consistent with Kiritani et al. (2017), the red hue markedly boosts perceptual lightness across all skin tones and ethnicities and purple has the least lightening effect, even though the delta L* is the greatest. Contrarily, unlike the referenced literature, pink shades in this study did not show a significant increase in perceptual lightness. This divergence could be due to variations in the pink shades used. In the cited study, the average pink across four skin tones was L*, a*, b*, h*, C* = 63.8, 54.3, 10.07, 79.52, 55.96. Combined with our data in Table 4.1, we deduce that despite minor hue angle differences, especially for Chinese images, between light and dark pink in our study versus the previous one, our pink shades are darker in lightness and less chromatically saturated. As all pink shades are darker compared to the face, the theory of lightness assimilation may not be sensible. Similarly, the purple used in the previous study, was significantly darker than the skin and other lip colours yet performed the least effectively in enhancing skin lightness. This suggests that lightness difference might not be the only influence in the perception of facial skin lightness. Hue and Chroma of the lip colours might also impact on perceptual lightness of the face.

In exploring the interplay between chroma or hue and perceptual lightness, the Pearson correlation coefficient was employed. Data from Table 4.8 reveal that a statistically significant correlation in perceptual lightness with delta L* is present only in the representation of Caucasian faces (-0.16), with a more pronounced correlation noted with chroma (0.182). For Chinese subjects, a significant correlation was observed solely with hue (0.156). These findings suggest a heightened detectability of relative lightness differences in Caucasian representations as assessed by young Chinese female observers. The evaluative process for perceptual lightness in Chinese representations seems to accord greater importance to the hue of lipsticks, indicating a heightened sensitivity to the applied colour before forming judgments of lightness. This might offer insight into why red lipstick creates a stronger illusion of lighter skin than purple. When it comes to assessments of Caucasian images, saturation of the lip colour appears to be the predominant factor influencing judgments of light appearance.

The absence of direct precedents in existing literature for these results prompts an examination of the colour measurement outcomes for the lipsticks. As delineated in

Table 4.1, the hue angle is found to be more significant on Chinese faces than on Caucasian faces upon lipstick application. This suggests a more noticeable variance in hue perception for lipsticks on Chinese representations, potentially elucidating the observed reliance on this visual cue. Nonetheless, the chroma values for both ethnic groups with applied lipstick display considerable similarity, implying that factors other than simple colour metrics may influence the judgement of perceptual lightness of Caucasian skin tones by Chinese observers.

5.2.2 Perceptual Lightness and Attractiveness

Table 4.7 shows the result of the correlation between perceptual lightness and attractiveness. The overall correlation is positive (0.674), while CN images (0.685) are slightly stronger than CA (0.662). As discovered in previous literature, perceptual lightness has a positive correlation with attractiveness regardless of whether the stimulus is monochromatic or coloured (Russell, 2010; Kiritani et, al., 2017; Kobayashi et, al., 2017; Kiritani et, al., 2021). Similarly, perceptual lightness has a positive correlation with attractiveness and Caucasian images used in this experiment have expanded the context beyond Japanese and Chinese faces, implying this effect can be commonly observed in the races with a relatively lighter skin appearance.

The correlation between perceptual lightness and attractiveness supports previous findings that increasing lightness contrast would make female faces more attractive (Russell, 2003; Lu et, al., 2022) which is possible due to the increase in sexual dimorphism (Russell, 2009; Nestor and Tarr, 2008; Stephen et al., 2009; Jones et al., 2015). However, the increase in sexual typicality cannot explain why dark orange and purple received similar scores in perceptual lightness, but the attractiveness perception differs, especially in Chinese images. Compared with bare lips, the effect size for the lightness perception for both colours are around 0.58 for Chinese images and 0.6 for Caucasians. As for the attractiveness of dark orange and purple compared to bare lips, the figure for the CN group is DO:P = 0.819: 0.386, and for the CA is 0.676:0.4, indicating that Chinese observers prefer the orange hue colour much more than the purple hue especially when they are applied on Chinese faces, even though the perceptual lightness level is similar. This implies that perceptual lightness change induced by lipsticks does not solely determine the perceptual attractiveness of the lipstick-skin combo.

Conclusively, perceptual skin lightness has a positive correlation with attractiveness especially viewed by Chinese observers. Since the previous study discovered that facial colour cues used to judge attractiveness levels vary by cultural background, together with the Chinese's preference for lighter skin (Chen and Jablonski, 2021), the preference for lightness might be codefined from both biological and cultural sides. However, the attractiveness cannot be simply determined solely from the lightness difference point of view regarding the result of the colour purple. It could be because of the impression induced by the colour that is often related to vicious, dominant and not natural enough in Eastern Asian cultures (Kiritani et, al., 2021; Gong et, al., 2024; Zhang, 2019).

5.3 Effects of Lipstick Colours on Skin Colour Perception, Redness

Redness assimilation of the skin can be induced by red lips (Kobayashi et al., 2017). In this thesis, all lipsticks make skin appear redder compared to no makeup as Figure 4.6 demonstrates. The constant positive delta a* might be able to explain the result. Concerning Table 4.2, all lipsticks have a greater a* value compared to the skin. A positive a* value indicates a shift to red on the red-green axis.

5.3.1 Perceptual Redness Difference

In general, the perceptual differences in redness observed by Chinese participants varied significantly between the two groups. This variation might be attributed to differences in skin colour, with the Caucasian group showing an average a* value that is greater by 2.18 than that of the Chinese group, indicating a naturally redder skin tone, as shown in Table 4.1. This pattern is corroborated by Figure 4.6, showing the redness differences of skin with bare lips.

Further analysis combining data from Table 4.2 and Figure 4.7 reveals that, except dark pink and purple, all lipstick shades induce greater redness assimilation in Caucasian skin compared to Chinese skin. Similar to findings related to perceptual lightness, where purple has the largest delta L* but is not perceived as the most light-enhancing lipstick, purple also exhibits the highest delta a* value yet does not induce the strongest redness assimilation. Instead, the colour red is found to be most effective in enhancing redness across both ethnic groups, aligning with findings from Kiritani et al. (2017).

Given that hue is determined by both a* and b* values, the reason purple does not result in the reddest skin tone, despite having the largest a* of all samples, may be attributed to its negative b* value. This suggests that relative to the skin, the lipstick shades lean closer to blue on the yellow-blue axis, as the colour difference is calculated by using the measurement of lips minus the skin. Excluding the red on Chinese faces, all lipsticks exhibit less yellow compared to the skin, as indicated in Table 4.2. Referring back to Table 4.1, which displays hue values of the colour red, the figure stands at 63.65 (CN) and 59.76 (CA). Although no clear pattern emerges between perceptual redness and hue values, it can be concluded that, aside from red, purple shows the most significant redness assimilation. When lightness remains constant, dark orange imparts a redder appearance compared to dark pink for all groups, based on effect size. Meanwhile, light pink and orange induce only minor changes towards redder appearances in Caucasian faces, with light orange having a slightly more pronounced effect on Chinese faces than light pink.

According to Table 4.8, which explores the correlation of delta a*, hue, and chroma with redness, no statistically significant results were found for the Chinese group, indicating that redness change is difficult to perceive on Chinese faces. In contrast, all related measures for the Caucasian group show significant correlations as this group has a greater average a* value compared to the other. Delta a* between the lip and skin positively correlates with perceptual redness (0.161), partially explaining the redness differences across various lipsticks, excluding the colour red. Chroma of the lip exhibits the strongest correlation (0.216) when Chinese females assess facial redness in Caucasian images. As the hue angle for Caucasians ranges from 58.28 to 62.81, with red positioned at 59.76, it seems plausible to suggest that perceptual redness increases as the hue angle approaches that of the red if the chroma is growing richer at the same time.

In conclusion, redness is more readily perceived on yellower faces, which contradicts the previous study only tested redness assimilation on redder faces (Kiritani et, al., 2017). However, given the complexity of variables, it is challenging to definitively determine how each factor influences perceptual redness, especially with limited related studies available for reference.

5.3.2 Perceptual Redness and Attractiveness

As demonstrated in Table 4.7, the relationship between perceptual redness and attractiveness is positively correlated for all faces (0.393), with CN (0.394) and CA (0.391). These findings support that facial redness is an indicator of attractiveness when observed by Chinese females of both Caucasian and Chinese ethnicity (Lu, et, al., 2022), and the mechanism of why reddish skin is preferred is possibly due to sexual dimorphism (Sforza et al., 2010; Elliot and Niesta, 2008; Jones et al., 2015;). Apart from facial attractiveness, redder skin is also an indicator of perceptual healthiness and youthfulness (Lu et, al., 2022). This might further support red is considered the most attractive colour among all faces by Chinese observers. However, similar to perceptual lightness differences, the perceptual redness differences between the colours dark orange and dark purple are not significant (CN: CA = 0.04:0.17) compared to the attractiveness differences (CN: CA = 1.1: 0.79). This finding can offer another evidence that the reason why orange is favoured by Chinese observers is not simply just related to perceptual skin colour change.

Besides, a reddish skin appearance also indicates health conditions, such as sensitive skin, allergies, acne blemishes, or even mental health issues across ethnicities (Taylor, 2002; Habif et,al., 2011). It would be interesting to further investigate how red assimilation induced by lipstick might influence perceptual healthiness and the threshold of perceptual attractiveness, especially when blushes join as a variable.

5.4 Effects of Lipstick Colours on Skin Colour Perception, Yellowness

The application of lipstick can induce perceptual differences in yellowness compared to bare lips, although the effect is minor. Perceptual yellowness shows the least significant variations between different lipsticks in the two ethnic groups when compared to other colour metrics, as indicated by results from Tables 4.3, 4.4, and 4.5.

5.4.1 Perceptual Yellowness Differences

As demonstrated in Table 4.5, similar to perceptual redness which is more noticeable on reddish faces (Caucasian), the effect size of perceptual yellowness differences for Chinese images is greater (min: max= -0.191: -0.301) compared to Caucasian images (min: max= -0.097:0.108). One possible explanation for this result might be that the lipstick colours selected for the research do not contain sufficient yellowness.

Reflecting on the colour orange used previously (Kiritani et al., 2017), although the colour difference of a* to the skin is akin to the two orange shades employed in this thesis, the delta b* value is always positive and estimated at 20 compared to the skin. In this research, the only positive delta b* is observed in the colour red in Chinese images, with a mere 1.69. Considering that the orange-red hue is favoured by Chinese consumers (Chanel Beauty, 2023), a broader range of orange hue colours should be explored to investigate whether changes in perceptual yellowness induced by lipstick colours are indicators of perceptual attractiveness from the perspective of Chinese females.

However, unlike the responses for the Chinese stimuli, where all lipsticks made the face appear yellower than bare lips, the shades light orange, light pink, and purple make Caucasian skin appear less yellow than before. Contrary to previous research (Kiritani et al., 2017), where only orange and red resulted in yellower-looking skin, all lipstick shades make skin appear yellower in Chinese faces, with light pink, dark orange, and red showing statistical significance. A statistically significant result indicates that the outcome is not merely coincidental, even though the value is small. However, since light pink, dark orange and red are situated in different hues, it cannot be concluded that all changes in yellowness perception are due to assimilation rather than contrast.

The results on Caucasian faces align with the cited research; shades of pink and purple make the face appear less yellowish, albeit without statistical significance. Whether the reduction in perceptual yellowness is induced by assimilation to blue, hence a contrast to yellow remains unclear.

5.4.2 Perceptual Yellowness and Attractiveness

The correlation between perceptual yellowness and attractiveness is also the weakest compared to other colour metrics for both CN (-0.051) and CA (0.075) images with no statistical significance. This finding is consistent with previous research that perceptual yellowness is not a significant factor used to judge facial attractiveness (Kiritani et, al., 2017), even though the observers are Japanese females instead of Chinese. Although perceptual facial yellowness is a clue indicating health conditions (Stephen, Coetzee, and Perrett, 2011), it might not be a clue used to judge perceptual attractiveness for

Chinese and Japanese observers as this thesis and previous literature discovered (Kiritani et, al., 2017). In contrast, facial yellowness is often utilised by Western observers while judging attractiveness of the skin (Lu, et al., 2021; Lu et, al., 2022).

The weak correlation between perceptual yellowness and attractiveness cannot explain why orange-red hue and red hue are favoured by Chinese consumers from an attractiveness point of view. One potential interpretation can be that the colour red, and orange red is culturally favoured by Eastern Asian consumers. Previous studies on Chinese females discovered that lipstick with a relatively high value of L* and a higher value of b* is preferred by Chinese females (Kiritani et, al., 2017; Kiritani et, al., 2021; Zhang, 2019; Hong et, al., 2024). Another assumption could be that yellow-red hue lip colours can induce a perceptual colour change in lightness, even though the mechanism behind them remains unclear. Therefore, orange-red and red hue colours are favoured by Chinese observers as lighter skin is preferred in this culture (Chen and Jablonski, 2021).

5.5 Effects of Lipstick Colours on Skin Colour Perception, Attractiveness

The differences in perceptual facial colour metrics, such as lightness and redness, correspond to perceptual attractiveness from the perspective of Chinese females. Having already discussed the relationship between perceptual colour metrics and attractiveness in the previous section, this section will focus on identifying which facial colour cues correlate with perceptual attractiveness and explaining why certain colours are favoured when they induce similar perceptual effects on the skin.

5.5.1 Facial Colour Cues and Perceptual Attractiveness

For Chinese images, as shown in Table 4.8, the total colour difference (delta E) between the lip and the skin, along with the hue and chroma of the lipsticks, all positively correlate with perceptual attractiveness, with significant statistical evidence. Among these indicators, chroma demonstrates the strongest correlation, at 0.55, suggesting that saturated colours are particularly preferred by Chinese females on Chinese faces. This preference partially explains why the colour red is most favoured ($C^*=43.70$) and light orange and pink is favoured the least ($C^*_{LO}= 31.38$, $C^*_{LP}=32.23$). However, although rich in chroma ($C^*=44.60$), the colour purple is not as favoured by observers. In terms of delta E (correlation=0.181), which indeed acts as an indicator of attractiveness judgement for Chinese females evaluating their own ethnic group (Lu et al., 2022), purple, despite having the highest delta E value (43.49), is not seen as attractive as dark orange, which has a delta E of 30.39. The positive correlation between attractiveness and hue (0.175) does not justify the preference for orange hues over purple, especially considering the chroma and delta E values.

When assessing Caucasian female faces, chroma is the only factor that shows a statistically significant correlation with perceptual attractiveness, albeit at a relatively weak level of 0.163. It is noteworthy that the average chroma for the bare lips of Caucasian faces is richer compared to those of light orange, light pink, and dark pink; yet, observers still perceive faces with lipstick as more attractive. This observation, combined with the correlation of perceptual lightness and redness with chroma, suggests that the differences in perceptual colour metrics might trigger the increase in attractiveness.

5.5.2 Culture Implication

It is unsurprising that Chinese females view red as the most attractive colour in Chinese images when cultural influences are considered. According to both the report of Chanel Beauty (2023) and CBN data (2021), the best-selling shade of lipstick in mainland China is intense red. Historically, red has always been considered the most emblematic colour of Chinese culture, symbolising good luck, happiness, marriage, prosperity, authority, romance, and passion in traditional Chinese colour psychology (Wu et al., 2018). Red hues are also extensively used in cosmetics, adhering to the traditional Chinese beauty aesthetic. The colour “胭脂红” (NCS S1580-Y90R), which means literally and verbally as rouge for lipsticks and blush, embodies this tradition (Huang, 2020).

In contrast, the colour purple performs best when Chinese females wish to convey power and dominance (Zhang, 2019). Yet, it is the least consumed colour in the Asian market, including mainland China (Chanel Beauty, 2023). Although research shows a positive correlation between purple hue lipsticks and the perceptual charm factor of the face (Hong et al., 2024), the colour itself is still considered less attractive. Conversely, orange hues consistently display a level of attractiveness similar to red (Zhang, 2019; Kiritani et al., 2017; Kiritani et al., 2021) and are even viewed as more attractive than red under certain lighting conditions (Hong et al., 2024). The orange hue is deemed particularly attractive to yellowish skin because it appears more natural (Zhang, 2019). This assertion is supported by the experiment results. The total colour difference for dark orange, which is 30.39 (CN) and 31.17 (CA). The effect size of attractiveness is -0.819 (CN) and -0.676 (CA), indicating that Chinese observers regard the colour dark orange as more attractive on Chinese faces compared to Caucasian faces. These findings indicate that the preference for the colour orange on Chinese female faces viewed by Chinese observers is complex and cannot be fully explained by an investigation into perceptual colour changes alone. Further qualitative research into the impressions and reasons for this preference may be necessary for a deeper understanding.

Given the similarity in the correlation of perceptual colour metrics between the two stimuli from different ethnicities, it seems sensible to assume that when making judgements on faces from another racial group, cultural factors are less considered, while the perceptual colour changes induced by the lipstick colours themselves are given more emphasis.

Chapter 6. Conclusion

6.1 Overview

This thesis has explored the nuanced interplay between lipstick colours and their perceptual effects on skin colour, particularly focusing on Chinese females. The aim was to decipher the colour assimilation effects induced by various lipstick hues and understand how these changes correlate with perceived attractiveness. This exploration was anchored around two primary objectives: investigating the changes in skin colour perception prompted by different lipstick colours and exploring the correlation between these perceptual colour changes and attractiveness.

The research findings have illuminated several critical insights. Firstly, lipstick does influence skin colour perception in terms of lightness, redness, and attractiveness, with varying effects across Chinese and Caucasian ethnic groups. The lightness perception induced are similar across different ethnicities while redness is easier to be observed on Chinese skin. As for attractiveness, the general trend of colour preferred between the two stimuli are similar, but the effect size varies, especially for the colour red on Chinese faces. This might indicate that Chinese observers have a sensitive perception in skin colourfulness in their own race compared to Caucasians. Notably, perceptual differences in yellowness induced by the lipsticks showed no significant statistical correlation with attractiveness, which was the weakest among the colour metrics examined. This outcome underscores the complex dynamics of colour perception and its impact on attractiveness, which does not uniformly translate across different colour metrics.

Moreover, the study revealed that Chinese observers utilise distinct facial colour cues when assessing the attractiveness of Chinese and Caucasian faces. This suggests that cultural and ethnic backgrounds significantly influence perceptual judgments, highlighting the importance of cultural context in colour perception studies.

Another significant finding was the distinct preference for saturated colours, particularly the colour red, among Chinese observers, which aligns with traditional cultural affiliations with the colour in Chinese society. However, despite high chroma and delta E values, the colour purple was not as favoured, indicating that factors other than colour metrics per se, such as cultural connotations and personal biases, play critical roles in defining colour attractiveness.

In conclusion, this thesis has demonstrated that lipstick colours significantly influence perceptions of skin colour and attractiveness, particularly among Chinese females. The study confirms that lipstick shades notably affect perceptions of lightness and redness, with redness being more observable on Caucasian skin. It also shows a cultural preference for saturated red among Chinese observers. Notably, yellowness induced by lipsticks showed no significant correlation with attractiveness, emphasizing the complex and varied nature of colour perception. Additionally, the changes in skin lightness induced by red-toned lipsticks also merit attention. These findings highlight the importance of cultural and ethnic contexts in colour perception studies, revealing that cultural affiliations and personal biases significantly influence attractiveness judgments

6.2 Limitations

6.2.1 Lipstick Colour Selection

As highlighted in the discussion on perceptual yellowness, a significant limitation of this study lies in the selection of lipstick colours, particularly in the orange and orange-red hues. These colours are overwhelmingly popular and frequently purchased by Chinese consumers, which suggests a deeply rooted cultural or possibly biological preference. This study, however, did not extensively explore the underlying mechanisms that drive the attractiveness of these specific lip colours. Future research could benefit from a broader investigation into whether these preferences stem from inherent biological responses to these colours or from culturally conditioned perceptions. Such research could involve a comparative analysis across different cultures or an examination of the biological responses to colour stimuli using physiological measures.

6.2.2 Sample Size

Another limitation concerns the sample size. The study involved only 15 Leeds-based Chinese females, which may not adequately represent the broader population of Chinese females, particularly those residing in different geographical locations or within different socio-cultural contexts. The small sample size also limits the generalizability of the findings and increases the likelihood of type II errors, where true effects in the population might not be detected. Additionally, the homogeneous nature of the sample, focusing solely on Chinese females in Leeds, might overlook the nuanced variations in colour preferences that could exist among Chinese females internationally or in other demographic groups.

6.2.3 Methodological Considerations

The methodological approach primarily focused on quantitative measures, which, while providing valuable statistical insights, might not capture the depth of personal and cultural nuances that qualitative methods could offer. Qualitative approaches such as interviews or focus groups could provide deeper insights into the personal experiences and cultural meanings associated with lipstick colour choices among Chinese females. Such methods could uncover layers of cultural significance or personal associations that influence colour preferences, which are not easily captured through quantitative metrics alone.

6.3 Future Directions

To address these limitations, future studies should consider expanding the sample size and including participants from diverse backgrounds to enhance the representativeness and generalizability of the findings. Additionally, incorporating a mixed-methods approach could enrich the understanding of the complex interplay between colour perception and cultural influences. By integrating both qualitative and quantitative data, researchers could provide a more comprehensive analysis of how cultural, biological, and psychological factors converge to shape colour preferences in cosmetics.

Future studies should consider expanding the sample size and including diverse participant profiles to enhance the representativeness of the findings. Further, integrating qualitative methods could offer deeper insights into the personal and cultural nuances influencing colour preferences, which are not entirely capturable through quantitative measures.

6.4 Summary

In conclusion, this thesis not only sheds light on the specific effects of lipstick colours on perceptual attractiveness but also opens new avenues for understanding how deeply ingrained cultural influences and colour perceptions are intertwined with the aesthetics of beauty. The findings from this study could help cosmetic brands tailor their products more effectively to meet the culturally specific needs of diverse consumer bases, ultimately enhancing user satisfaction and engagement.

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List of Abbreviations

BL Bare Lips

CA Caucasian

CAM Colour Appearance Model

CIE Commission Internationale de L' Éclairage (International Commission on Illumination)

CN Chinese

DO Dark Orange

DP Dark Pink

GOG Gamma Offset Gain

ISO International Organization for Standardization

LCD Liquid Crystal Display

LO Light Orange

LP Light Pink

P Purple

R Red

RGB Red Green Blue

Appendix

Appendix 1. Colour Measurement Result by Individual

Chinese	CN1						Caucasian	CA1				
Data Name	L*	a*	b*	h*	C*			L*	a*	b*	h*	C*
face ave	65.64	16.61	17.69	43.20	24.27		face ave	62.21	13.92	14.34	44.16	19.98
LO	43.74	32.77	10.49	72.24	34.41		LO	52.06	24.50	13.13	61.82	27.80
LP	45.82	28.40	11.29	68.33	30.56		LP	43.26	26.67	9.76	69.90	28.40
DP	42.27	32.19	9.70	73.23	33.62		DP	41.95	32.46	3.75	83.41	32.67
DO	42.84	33.07	16.47	63.53	36.94		DO	39.02	35.29	4.80	82.26	35.61
R	39.31	37.87	19.21	63.11	42.46		R	41.54	32.05	13.41	67.29	34.74
P	35.33	42.63	12.66	73.46	44.47		P	40.80	38.44	17.95	64.96	42.42
BL	52.32	24.07	15.81	56.70	28.79		BL	33.92	42.38	10.91	75.56	43.76
	CN2							CA2				
	L*	a*	b*	h*	C*			L*	a*	b*	h*	C*
face ave	69.26	13.59	22.80	30.80	26.54		face ave	72.85	14.40	17.23	39.89	22.46
LO	45.41	31.51	6.81	77.81	32.24		LO	48.22	26.34	12.74	64.19	29.27
LP	46.71	27.44	11.15	67.88	29.61		LP	45.10	31.10	6.64	77.96	31.80
DP	43.43	33.30	7.41	77.45	34.11		DP	42.35	32.18	15.10	64.86	35.55
DO	43.81	31.15	15.03	64.24	34.58		DO	43.92	35.48	7.59	77.92	36.28
R	38.15	38.31	19.70	62.78	43.08		R	37.41	39.72	20.52	62.67	44.70
P	37.59	43.93	10.03	77.14	45.06		P	54.67	23.28	12.41	61.94	26.38
BL	52.01	18.96	14.70	52.21	23.99		BL	52.03	22.31	14.22	57.48	26.46
	CN3							CA3				
	L*	a*	b*	h*	C*			L*	a*	b*	h*	C*
face ave	61.74	14.54	17.00	40.53	22.37		face ave	65.87	19.24	19.48	44.65	27.38
LO	44.27	24.46	11.51	64.80	27.03		LO	44.73	34.18	6.51	79.21	34.79
LP	43.41	30.23	6.80	77.31	30.98		LP	46.32	33.53	16.84	63.33	37.52
DP	41.49	33.94	6.32	79.46	34.52		DP	46.41	27.87	11.41	67.74	30.12
DO	41.58	30.06	14.62	64.05	33.43		DO	44.88	37.52	7.29	79.01	38.22
R	36.29	37.17	18.07	64.08	41.33		R	42.64	41.04	20.62	63.32	45.93
P	31.60	40.32	10.85	74.95	41.76		P	37.96	39.75	5.12	82.66	40.08
BL	46.72	23.08	14.60	57.68	27.31		BL	55.08	23.38	13.63	59.77	27.06
	CN4							CA4				
	L*	a*	b*	h*	C*			L*	a*	b*	h*	C*
face ave	67.06	11.59	13.66	40.31	17.91		face ave	65.79	17.32	19.05	42.28	25.75
LO	46.00	27.91	12.21	66.37	30.46		LO	56.59	21.57	15.22	54.79	26.40
LP	45.32	33.54	6.17	79.57	34.10		LP	51.69	35.63	9.60	74.91	36.90
DP	42.85	36.20	7.42	78.41	36.95		DP	49.38	29.42	12.01	67.80	31.77
DO	42.93	32.41	14.60	65.75	35.55		DO	44.70	32.92	16.14	63.87	36.66
R	39.43	40.23	19.11	64.59	44.54		R	43.91	38.64	7.44	79.11	39.35
P	32.39	42.61	11.15	75.33	44.04		P	36.95	39.89	20.75	62.52	44.96
BL	53.49	22.44	16.94	52.95	28.12		BL	34.59	39.37	4.81	83.04	39.66
	CN5							CA5				
	L*	a*	b*	h*	C*			L*	a*	b*	h*	C*
face ave	66.47	15.11	17.34	41.06	23.00		face ave	64.69	17.45	18.92	47.31	25.74
LO	48.90	30.04	13.03	66.55	32.75		LO	46.85	24.58	14.99	31.37	28.79
LP	46.96	35.20	7.07	78.64	35.91		LP	45.81	28.31	11.27	21.71	30.47
DP	45.41	34.84	17.34	63.55	38.92		DP	44.10	31.85	6.18	10.98	32.44
DO	44.10	39.40	7.52	79.20	40.11		DO	43.59	36.24	7.04	10.99	36.92
R	40.71	42.23	20.85	63.72	47.10		R	39.53	32.33	16.07	26.43	36.11
P	34.33	45.96	12.67	74.58	47.68		P	44.41	38.75	20.52	27.90	43.85
BL	56.97	24.62	15.20	58.32	28.93		BL	37.72	41.69	5.78	82.11	42.09

The table above has demonstrated the colour measurement of each individual stimulus. Data from this figure is used to generate table 4.1 and 4.2.

Appendix 2. Experimental Results

2.1 Visual Assessment

			CN			CA		
LipID	Responses (perceptual)	N	Mean	Standard Devination	stand. Err	Mean	Standard Devination	stand. Err
No lipsticks	lightness	75.00	2.97	1.83	0.21	2.73	1.38	0.16
	redness	75.00	2.59	1.64	0.19	2.85	1.56	0.18
	yellowness	75.00	3.63	1.99	0.23	3.52	1.55	0.18
	attractiveness	75.00	2.51	1.49	0.17	2.35	1.16	0.13
Light Orange	lightness	75.00	3.36	1.89	0.22	2.95	1.50	0.17
	redness	75.00	2.97	1.55	0.18	3.07	1.61	0.19
	yellowness	75.00	3.83	1.97	0.23	3.47	1.66	0.19
	attractiveness	75.00	2.92	1.66	0.19	2.84	1.55	0.18
Light Pink	lightness	75.00	3.09	1.69	0.20	3.05	1.57	0.18
	redness	75.00	3.59	1.76	0.20	3.76	1.83	0.21
	yellowness	75.00	3.92	1.92	0.22	3.43	1.77	0.20
	attractiveness	75.00	2.60	1.52	0.18	2.71	1.52	0.18
Dark Pink	lightness	75.00	3.56	1.76	0.20	3.48	1.55	0.18
	redness	75.00	3.51	1.74	0.20	4.00	1.67	0.19
	yellowness	75.00	3.91	1.76	0.20	3.75	1.72	0.20
	attractiveness	75.00	3.17	1.64	0.19	3.11	1.54	0.18
Dark Orange	lightness	75.00	3.80	1.53	0.18	3.85	1.57	0.18
	redness	75.00	3.88	1.46	0.17	3.76	1.45	0.17
	yellowness	75.00	3.95	1.58	0.18	3.81	1.60	0.18
	attractiveness	75.00	4.05	1.63	0.19	4.00	1.57	0.18
Red	lightness	75.00	4.32	1.71	0.20	4.37	1.30	0.15
	redness	75.00	4.27	1.67	0.19	4.33	1.54	0.18
	yellowness	75.00	3.85	1.83	0.21	3.59	1.42	0.16
	attractiveness	75.00	4.51	1.61	0.19	4.07	1.57	0.18
Purple	lightness	75.00	3.65	1.53	0.18	3.69	1.46	0.17
	redness	75.00	3.84	1.55	0.18	3.59	1.79	0.21
	yellowness	75.00	3.72	1.46	0.17	3.37	1.45	0.17
	attractiveness	75.00	2.95	1.35	0.16	3.21	1.45	0.17

This table demonstrates the results of experiment stage two with the average of the stimuli. The sample size (N), mean, standard deviation and standard error are included in this table. Figure 4. 4-4.14 are generated based on this table.

2.2 Paired Sample T-test, NL=No lipsticks=Bare Lips (BL)

This table demonstrates the results of experiment stage two using the paired sample t-test with 96% confidence interval. The sample size (N), mean, standard deviation and standard error are included in this table. The significance in figure 4. 4-4.14 are generated based on this table.

					95% Confidence Interval of the Difference				Significance	
Group	Pair	Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	One-Sided p	Two-Sided p
CN_lightness										
	NL - LO	-0.92	2.79	0.40	-1.73	-0.11	-2.28	47	0.014	0.027
	NL - LP	-0.69	2.79	0.40	-1.50	0.12	-1.71	47	0.047	0.095
	NL - DP	-1.21	2.88	0.42	-2.04	-0.37	-2.91	47	0.003	0.006
	NL - DO	-1.42	2.40	0.35	-2.11	-0.72	-4.10	47	<.001	<.001
	NL - R	-1.44	1.60	0.23	-1.90	-0.97	-6.24	47	<.001	<.001
	NL - P	-0.88	1.51	0.22	-1.31	-0.44	-4.01	47	<.001	<.001
CN_redness										
	NL - LO	-0.39	1.58	0.18	-0.75	-0.02	-2.13	74	0.018	0.037
	NL - LP	-1.00	1.79	0.21	-1.41	-0.59	-4.85	74	<.001	<.001
	NL - DP	-0.92	1.94	0.22	-1.37	-0.47	-4.10	74	<.001	<.001
	NL - DO	-1.29	1.87	0.22	-1.72	-0.86	-5.98	74	<.001	<.001
	NL - R	-1.68	1.97	0.23	-2.13	-1.23	-7.40	74	<.001	<.001
	NL - P	-1.25	1.76	0.20	-1.66	-0.85	-6.15	74	<.001	<.001
CN_yellowness										
	NL - LO	-0.31	1.73	0.17	-0.65	0.03	-1.83	101	0.035	0.07
	NL - LP	-0.48	1.76	0.17	-0.83	-0.13	-2.75	101	0.003	0.007
	NL - DP	-0.46	1.89	0.19	-0.83	-0.09	-2.47	101	0.008	0.015
	NL - DO	-0.57	1.89	0.19	-0.94	-0.20	-3.04	101	0.002	0.003
	NL - R	-0.62	2.12	0.21	-1.03	-0.20	-2.94	101	0.002	0.004
	NL - P	-0.45	1.91	0.19	-0.83	-0.08	-2.38	101	0.01	0.019
CN_attractiveness										
	NL - LO	-0.47	1.60	0.16	-0.79	-0.16	-2.97	101	0.002	0.004
	NL - LP	-0.33	1.59	0.16	-0.65	-0.02	-2.11	101	0.019	0.037
	NL - DP	-0.75	1.77	0.18	-1.09	-0.40	-4.25	101	<.001	<.001
	NL - DO	-1.47	1.79	0.18	-1.82	-1.12	-8.27	101	<.001	<.001
	NL - R	-1.92	1.99	0.20	-2.31	-1.53	-9.74	101	<.001	<.001
	NL - P	-0.71	1.83	0.18	-1.06	-0.35	-3.90	101	<.001	<.001
CA_lightness										
	NL - LO	-0.32	1.31	0.13	-0.58	-0.07	-2.50	101	0.007	0.014
	NL - LP	-0.50	1.65	0.16	-0.82	-0.18	-3.06	101	0.001	0.003
	NL - DP	-0.80	1.71	0.17	-1.14	-0.47	-4.74	101	<.001	<.001
	NL - DO	-1.16	1.74	0.17	-1.50	-0.81	-6.70	101	<.001	<.001
	NL - R	-1.66	1.79	0.18	-2.01	-1.31	-9.36	101	<.001	<.001
	NL - P	-1.09	1.80	0.18	-1.44	-0.74	-6.12	101	<.001	<.001
CA_redness										
	NL - LO	-0.32	1.44	0.14	-0.61	-0.04	-2.26	101	0.013	0.026
	NL - LP	-0.93	1.68	0.17	-1.26	-0.60	-5.60	101	<.001	<.001
	NL - DP	-1.10	1.78	0.18	-1.45	-0.75	-6.22	101	<.001	<.001
	NL - DO	-1.00	1.77	0.18	-1.35	-0.65	-5.71	101	<.001	<.001
	NL - R	-1.54	1.89	0.19	-1.91	-1.17	-8.22	101	<.001	<.001
	NL - P	-0.92	1.95	0.19	-1.31	-0.54	-4.77	101	<.001	<.001
CA_yellowness										
	NL - LO	-0.13	1.47	0.15	-0.42	0.16	-0.88	101	0.191	0.382
	NL - LP	-0.20	1.70	0.17	-0.53	0.14	-1.17	101	0.123	0.247
	NL - DP	-0.42	1.78	0.18	-0.77	-0.07	-2.39	101	0.009	0.019
	NL - DO	-0.55	1.85	0.18	-0.91	-0.18	-2.99	101	0.002	0.004
	NL - R	-0.50	1.95	0.19	-0.88	-0.12	-2.59	101	0.006	0.011
	NL - P	-0.27	1.87	0.18	-0.64	0.09	-1.48	101	0.07	0.141
CA_attractiveness										
	NL - LO	-0.53	1.51	0.15	-0.83	-0.23	-3.55	101	<.001	<.001
	NL - LP	-0.53	1.53	0.15	-0.83	-0.23	-3.50	101	<.001	<.001
	NL - DP	-0.81	1.72	0.17	-1.15	-0.48	-4.77	101	<.001	<.001
	NL - DO	-1.55	1.70	0.17	-1.88	-1.21	-9.18	101	<.001	<.001
	NL - R	-1.72	1.78	0.18	-2.07	-1.37	-9.72	101	<.001	<.001
	NL - P	-1.02	1.66	0.16	-1.35	-0.69	-6.19	101	<.001	<.001