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A study of preferred and natural memory colours across different ethnic groups

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Keywords: Memory colours; Visual appreciation; Ethnic group

Abstract

A psychophysical experiment method was used to study the preferred and natural memory colours of 24 familiar objects on mobile displays. 106 observers from 5 different ethnic groups participated. 49 colours for each object were rendered three-dimensionally to cover a large colour range in CIELAB space. The intra-observer and inter-observer variations were analyzed for each ethnicity group. Ellipsoid models were established to represent results in terms of memory colour centre and colour range in CIELAB space for each ethnic group. Natural and preferred memory colour centres were compared within each ethnic group and among different ethnic groups.

Key words: Memory colour centre, memory colour range, ethnic group difference

1. Introduction

The term 'memory colour' is the typical colour of an object through frequent visual experience. Memory colours were first introduced by Hering [1] in the late 19th century who associated it with the idea that knowledge about typical colours affects the perception of the actual colour of given objects. Memory colours are considered to be an individual's standard of recollection for familiar objects and the memory colours probably tend to be relatively stabilized. Although memory colours undoubtedly are related to one's particular interests, it seems logical that most people's memory colours for highly familiar objects may be typically more general in their characteristics [2,3]. It seems apparent that the mean memory colours for the familiar objects examined are not of the same colour specification as the original object-colour means.

Some studies investigated the memory colours of the real objects. Sanders[4] studied the memory colour of natural objects such as skin colour, tea, butter, raw steak and potato chips. A light box with variable colour light was used to change the colour of the test object. In this experiment, the background was limited to two chromaticities of CIE standard B light source and standard C light source. For each natural colour object, a set of qualified colours covering all acceptable ranges were provided. Then, a set of colours were presented to the observer in random order. The observers were asked to judge whether the colour reproduction is "good", "general to good", "general to dissatisfied" or "dissatisfied". The results showed that the preferred colour of butter is much lighter than that of the actual butter sample; The difference between the preferred colour and the actual colour of other objects is not significant. Smet *et al.*[5], while investigating colour appearance tolerances for familiar objects, nine familiar real objects were studied. LED lightings were projected to the object to render its colour. Observers were asked to rate the similarity of the perceived object's colour to their memory colour. They reported that similarity increases in saturation and shifts towards the dominant hue for most familiar objects. Vurro *et al.* [6] also investigated the memory colour of natural familiar objects. Their primary goal was to compare the memory colour of familiar natural objects by varying natural shape contour, natural chromatic texture, or three-dimensionality, and all combinations of these cues. They found hue shifts in memory colours of natural objects, but these were not systematically towards the dominant hue of the object and also found that hue shifts were reduced by increasing the naturalness of the stimuli.

Some investigations were conducted based on paper medium such as photos, print colour patches. Bartleson [7] designed a study to compare memory colour with colour preference and to determine whether sophistication in colour technology affects colour memory and preference. 931 Munsell colour blocks were placed on an observation platform and was judged by 50 observers. The walls of the observation room were painted in neutral grey with about 18% reflectivity, and the colour temperature is 2700K. About half of the observers are professionals related to the colour industry, and the other half are naïve observers. The experimenter gives an object or image name, and the observer looks at all colour samples and then points out the colour block that can represent the object colour best. The observers were allowed to interpolate between the available colour patches. Results indicated that, for hue and brightness, memory and preference were quite accurate for the objects tested; however, all subjects remembered and also preferred all items to be more highly saturated.

More recently, the memory colour studies were conducted on displays. Newhall *et al.* [8] found that saturation and brightness tended to increase in memory colours and that hue tended to shift towards the dominant hue within the object for some objects. Siple and Springer [9] confirmed the tendency of colour shift not only for saturation increase but also for good agreement on brightness and hue. In a study by Pérez-Carpinell *et al.*[10] memory saturation only increased for high purity objects, while it decreased or remained the same for mid-range or low purity objects. They also reported unsystematic hue shifts specific to the familiar object investigated. There is evidence of an increase in the saturation of the memory colours. In most cases, there are hue shifts with memory in the direction of what is probably the most impressive chromatic attribute of the object. Memory colour saturation was also higher for the familiar object – a yellow banana – in the study by Yendrikhovskij *et al.* [11,12].

Memory and preferred colours have also been used as an internal reference to perform colour appearance studiws under different illumination [13-15] and to investigate colour rendering of lighting quality [16-19].

The cultural influence of memory colour was also studied. Bodrogi *et al.* [20,21] established a methodology to study memory colours across different countries and cultures based on homogeneous colour patches. Results indicate that the inter-observer variability in the assessment of the memory colours is strongly context-dependent and twice as large as the inter-group variations. No significant differences in the overall assessment could be found between the Chinese and Germans. Smet *et al.* [22] investigated the effect of cross-cultural differences on colour appearance ratings and memory colours of familiar objects in seven different countries. They found that the differences between the average observers from different ethnic groups and the ALL average observer were found to be of the same magnitude or smaller than the typical within-region inter-observer variability. Zhu *et al.* [23] performed a study on long-term memory colours of 26 familiar objects using the asymmetric colour matching method among Chinese and German observers on a display. They found that the cultural effect has a significant impact on the assessment of memory colours when considering specific objects, such as blue sky, nectarine, or broccoli, but has a less significant impact on other colours, like the red rose, green apple, and strawberry.

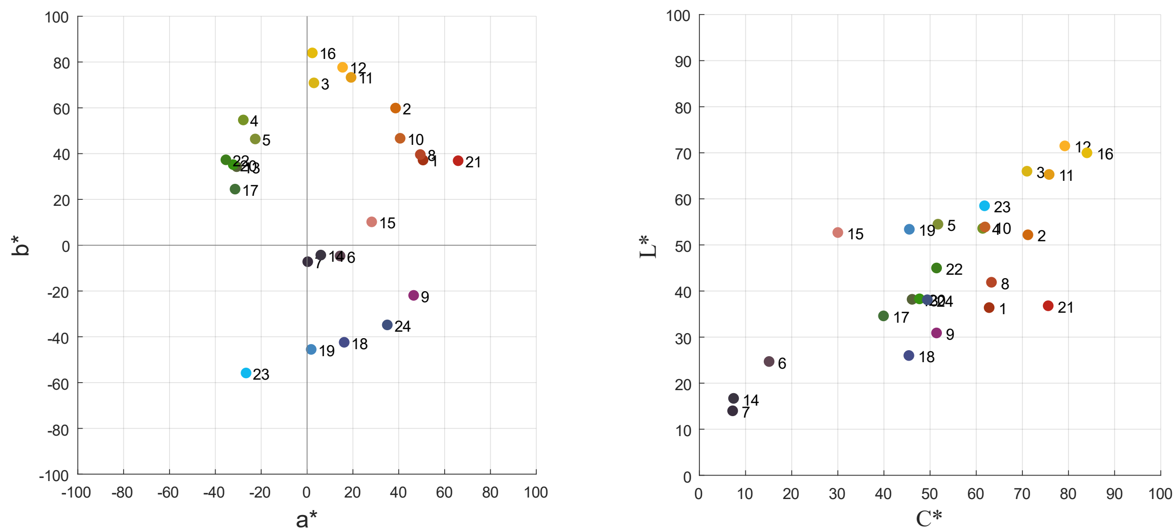
In addition, multifarious studies [20-22] have been conducted to find the parameters influencing memory colours, such as the cultural background, personality of the observers. Nowadays, mobile phones were used to shoot, display and transmit images every day. They are the most common medium for memory colour digital picture display. Although there are few studies [23] available to investigate the relationship between preference and naturalness on memory colour objects, they were not done on the mobile phone.

With the above in mind, the goals of this study are to explore the influence of preference and naturalness on the colour centre and range for each memory colour, and to compare the results between different ethnic groups of observers and between those from the earlier studies. A psychophysical experiment was carried out by threshold method to investigate memory colours on mobile displays. The 50% acceptability ellipses were derived for preference and naturalness from 5 different ethnic groups. The ellipse centre corresponds to memory colour. The memory colour study based on mobile display was comprehensive in terms of memory objects, observer ethnic groups and colour ranges.

2. Experimental Design

2.1 Memory objects Selection

The selection of memory colours was aimed to cover a wide range of hues. It was found difficult to find natural colours in the cyan region so artificial objects like Smurf, Pepsiwere included in this study. Finally, 24 objects were chosen, including 18 common indoor memory colour samples and 6 typical outdoor objects. The selected objects are mainly comprised of familiar vegetables and fruits, and important scenery objects (e.g., Summer grass, blue sky, etc.). Skin tones are also important memory colours, these were excluded because they were previously studied by the authors [24,25]. The 24 objects studied in the present experiment were selected partially from the familiar objects studied by other researchers [7,20-23]. Figure 1 shows those colours plotted in CIELAB a*b* and L*C*ab planes under D65 and 1964 standard colorimetric observer. . It can be clearly seen that there is a lack of memory colour from the green to blue region. Hence, the rest of objects used in the experiment were selected to cover this range.



(a) (b)

***Figure 1**. Colour distribution of the 24 test objects on CIELAB a) a^*b^* and $L^*C^*_{ab}$ planes.,*

2.2 Stimuli

In the image stimuli preparation, the physical memory objects were first collected. Each object was placed in the centre of an illumination cabinet with a grey background (L^* of 70 illuminated by a 1000 lux standard D65 simulator respectively. Each object was captured by a Nikon Z6 Digital Single Lens Reflex (SLR) camera having a high-resolution (6048 width × 4024 height pixels). And the camera parameters were set at conditions of ISO 200, aperture size F/5.6, shutter speed 1/60 second, and the white balance to 6500 K. An XRite Macbeth ColorChecker Chart (MCCC) including 24 colours were also captured at the same position by the same camera setting. Each colour was measured by a JETI-Specbos 1211 tele-spectroradiometer (denoted as TSR) under the same lighting condition. The polynomial model proposed by Hong *et al.* [27] was used to characterize the camera, and to transform RGB values to CIE tristimulus XYZ values. The MCCC colours were used to develop and test the camera model, where the CIEDE2000 (ΔE_{00}) values [28] were ranged from 0.53 to 4.03 and had a mean value of 1.95. The performance was considered to be satisfactory. For the objects that are not able to captured in the cabinet (such as blue sky, grass, rose, pine, Smurf, blue sky and lavender), images from the internet were chosen with a rule of thumb to have a prominent subject, simple background, appealing appearance, natural colour. Figure 2 shows all the original images used in the experiment.

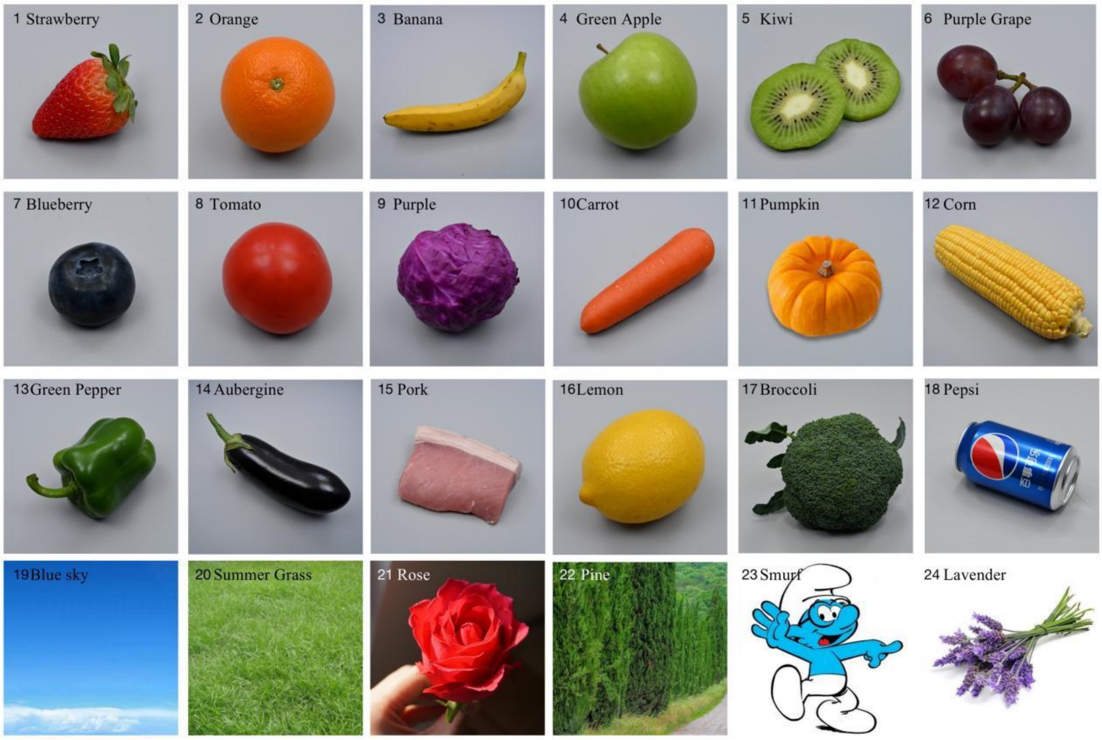


***Figure 2**. Images used in the experiment, (1-18) captured objects images, (19-24) images selected from the internet. The labels in all figures in this article after are correspond to the image labels here*

2.3 Image rendering

Each original image was rendered to have different colours. Each object was first separated from the original image. Its colour was then rendered from the original mean colour into 49 colour coordinates nearby in CIELAB colour space. Figure 3 shows the stages to modify the colour of memory colour. Firstly, the desired object (strawberry) was separated with the other colour such as leave. Subsequently, the strawberry colour was altered but the leave colour and texture were unchanged. Finally, the object and leaves were merged. These were then placed on a uniform grey background to have L* value of 60. As for the colour transformation, the RGB values of all pixels belonging to the region of interest were extracted, averaged and transformed into XYZ tristimulus values via the camera characterisation model, and then convert to CIELAB colour space. The $L^*a^*b^*$ values of each rendered image were used to represent the memory colour. According to the ellipse range and coordinate axis rotation data of memory colour in previous literature [22,23], colour coordinates were selected to form two layers of ellipses against the colour centre in a^*b^*, L^*a^*, L^*b^*, planes. Taking the sky image as an example, the long semi-axis of the outer ellipse is twice of the inner ellipse. There are points every 45° on each ellipse in each plane, as shown in Figure 4. Finally, a visual examination was taken by a few observers to view those images in the outer layer to cover a sufficiently large range with an aim to establish an ellipse boundary to define a threshold, 50% of observers recognise as the preferred or natura colour.

Additional to the original image a total of 49 stimuli images with different $L^*a^*b^*$ colour coordinates (8 points ×2 ellipses×3 planes+1 origin=49). The 49 coordinate points varied in a certain range in the direction of lightness, chroma and hue angle. Finally, 49 similar images were obtained from each initial image as shown in Figure 5.

The region of interest (ROI) in each original image was extracted using Photoshop image processing software to create a suitable mask. The color of the region of interest was morphed toward each of the 49 pre-determined centers to produce 49 versions of each image in which only the ROI color was different and the other colors in the image remained the same. The formula for the memory color transformation is:

$$\begin{aligned} L^*_{new} &= L^* + \left(L^*_c - L^*_m\right) \\ a^*_{new} &= a^* + \left(a^*_c - a^*_m\right) \\ b^*_{new} &= b^* + \left(b^*_c - b^*_m\right) \end{aligned} \quad (1)$$

where (L^*, a^*, b^*), (L_c^*, a_c^*, b_c^*) and (L_m^*, a_m^*, b_m^*) are the coordinates of the original, target and mean memory color of an original image, respectively. The mean memory color was obtained by averaging all the skin colors of the image. (L_{new}^*, a_{new}^*, b_{new}^*) are the adjusted memory color.

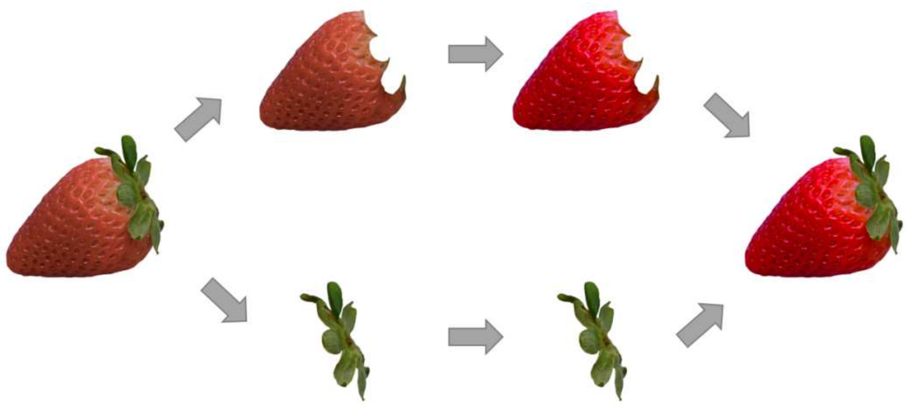


Figure 3. *Segmentation and colour adjustment process of memory colour image*

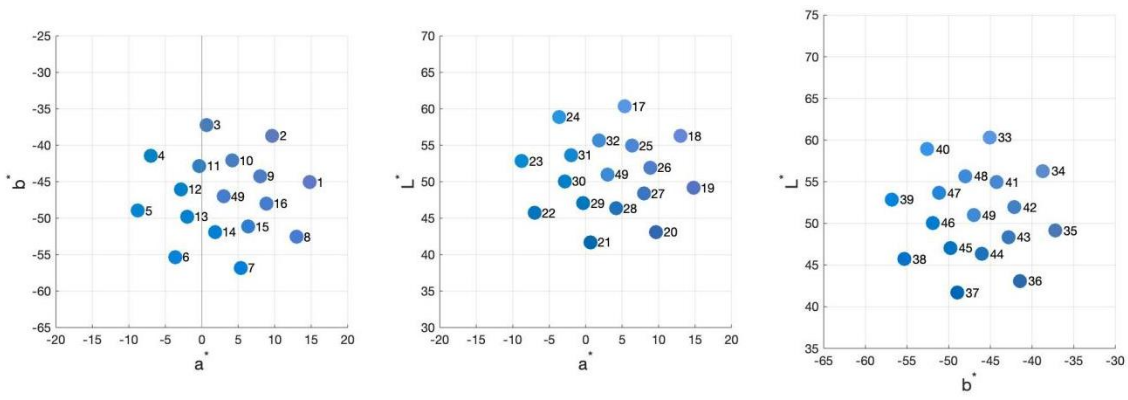


Figure 4. *selection of the image rendering point image rendering effect of 'sky'.*

***Figure 5**. image rendering effect of ‘sky’.*

2.4 Display model

Images were displayed respectively on five 6.1-inch Huawei P20 Pro mobile phone displays, which were organic lighting-emitting diode screens. The screen had a native resolution of 2240 × 1080 and a DCI-P3 colour gamut. All monitors were adjusted to achieve a peak luminance of 400 cd/m^2 and a white point at 6500K in CCT as measured by the TSR. The auto-brightness function of the smartphones was turned off. The 3D-Look-Up-Table (3D-LUT) display model [29] was used to characterize each display, including 729 colours ($9 \times 9 \times 9$). The five mobile phones were measured at 0 degrees perpendicular to the display plane at a distance of 30 cm in the dark condition. The mean colour differences of each smartphone between the predicted and measured results from the 24 MCCC colours were 1.51, 1.76, 1.37, 1.24 and 1.79, respectively. The mean colour difference between before and after working continuously for an hour on the 5 mobile phones was 0.28. The measurement of the same 24 colour patches was repeated at 24 hours intervals, the average colour difference was 0.36. This means these five displays had good temporal stability. Further investigation was conducted to compare the inter-display agreement, the mean colour difference between each smartphone and the other four smartphones was about 1.9. This means that the predictive accuracy from the 3D-LUT model was almost the same as the inter-display discrepancy among different displays, indicating a good agreement among the 5 mobile phones used.

2.5 Observers

Observers were divided into 5 ethnic groups: 20 native Chinese (CHZ), 31 South Asians in China (SA), 23 Chinese in UK (CHL), 21 native British Caucasians (CA) and eleven Africans living in UK (AF) . They were all the students at Zhejiang University or Leeds University. The CHL and SA observers were postgraduate students at Leeds and Zhejiang universities, respectively. The AF observers were the Leeds students invited according to their skin colour. There were 61 male and 45 female observers with a mean age of 29.7 years old. All observers passed the Ishihara colour vision test [30] and had normal colour visions. Table 1 summarises the observer information for each ethnic group.

Table 1 Observer information for each ethnic group

Observers	*Number*	*Male*	*Female*	*Mean age*	*SD age*
CHZ	20	10	10	23.2	1.7
SA	31	31	0	30.9	3.3
CHL	23	6	17	31.4	10.4
CA	21	9	12	28.8	7.6
AF	11	5	6	34.1	13.1
ALL	106	61	45	29.7	8.4

2.6 Experimental procedure

First of all, observers had to pass the Ishihara test to make sure that they had normal colour visions. Next, they were trained to understand the basic notion of perceptual colour attributes: preference and naturalness. After reading and understanding the experimental instructions properly, they were led into a dark room to sit at a distance of 40 cm away from the mobile display. Observers were asked to sit in front of a table covered with a grey table cloth. A bracket was placed to support the smartphone to ensure the 45°:0° geometry. They were allowed to practice on a pre-experimental program to familiarize the experimental software. Each day, the mobile phone had been warming up for at least 20 min. Prior to the experiment, each observer took a 2-min adaptation to the dark environment with the screens off.

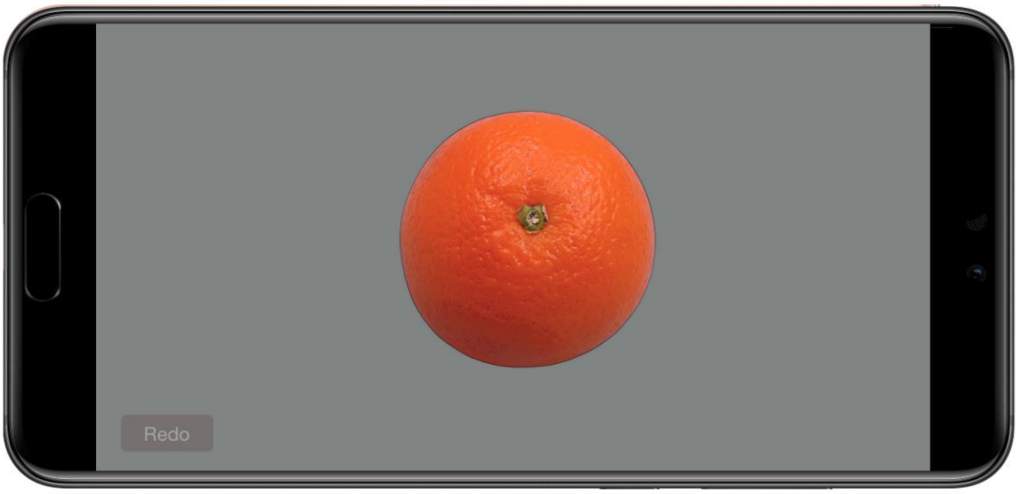


Figure 6. *Experimental software interface.*

Figure 6 shows the experimental software interface. Observers were asked to sit around a table covered with grey cloth and sit in front of a smartphone to experiment. The size of each object in the image was controlled at about 3.5° field of view. The evaluation had a threshold method to judge 2 attributes of the memory colour in the image (either ‘like’ or ‘dislike’, and either ‘natural’ or ‘unnatural’), one at a time. They click on the left side of the grey background to give a positive result. Otherwise, click the right side of the grey background to give a negative result. After clicking, the system will automatically record the result and display the next picture. If the subjects regret the choice, they can click the "Redo" button in the lower-left corner of the screen to redo the previous image. Observers received a short training section prior to the experiment to manipulate the experimental software. The subjects were asked to evaluate 49 consecutive renderings of each image, and their order was randomly arranged. The display order of 24 kinds of memory colour images and 4 repeat images were also randomly disrupted to avoid the influence of image display order on memory colour perception. In total, 290,864 judgments were obtained in the experiment: 28 (24 images + 4 repeats) × 49 (rendering)× 2 (attributes)×106 (observers). The order of stimuli was randomized. The whole experiment lasted for approximately 120 minutes for each observer. They were asked to finish the experiment in two sessions, for assessing preference or naturalness, respectively.

3. Data analysis

The results were reported in the form of 'yes' and 'no'. They were arranged in the form of preferred rate *Yes%*, which was calculated by the number of the yes decisions divided by the total number of observers multiplyied by 100.

3.1 Observer variations

Each observer assessed 49 renderings of a memory object image. The $L^*a^*b^*$ values of each 'preferred' or 'natural' image were the weighted mean to represent each observer's results for this image. The mean results represent the panel results. The mean-colour-difference from-mean (MCDM) [31] was used in this experiment to assess the observer variability between two sets of visual results. The intra-observer variation reflects the accuracy of the observer's cognition of memory colour. The intra-observer variation reflects the degree of unity of memory colour cognition among different observers.

The MCDM value measures the inter-observer variation through colour difference in CIELAB colour space in such a way that a smaller value corresponds to better repeatability, as shown in Equation (1).

$$MCDM = \frac{\sum_{i=1}^{n} \Delta E^*_{abi}}{n} \tag{1}$$

where

$$\begin{aligned} \Delta E^*_{abi} &= \sqrt{\left(L^*_i - L^*_{mean}\right)^2 + \left(a^*_i - a^*_{mean}\right)^2 + \left(b^*_i - b^*_{mean}\right)^2} \\ L^*_{mean} &= \frac{\sum_{i=1}^{n} L^*_i}{n} \\ a^*_{mean} &= \frac{\sum_{i=1}^{n} a^*_i}{n} \\ b^*_{mean} &= \frac{\sum_{i=1}^{n} b^*_i}{n} \end{aligned} \tag{2}$$

and

$$\begin{aligned} L^*_i &= \frac{\sum_{j=1}^{49} L^*_j \times w_j}{m} \\ a^*_i &= \frac{\sum_{j=1}^{49} a^*_j \times w_j}{m} \\ b^*_i &= \frac{\sum_{j=1}^{49} b^*_j \times w_j}{m} \end{aligned} \tag{3}$$

where n is the number of observers; m is the number of 'preferred' or 'natural' images in 25 rendered images of each skin type; (L_i^*, a_i^*, b_i^*) values are the weighted mean colour centre for each observer where w_j was the preferred weight of each image: w_j was 1 when the rendered image was judged as 'preferred' or 'natural', w_j was 0 when the rendered image was judged as 'not preferred' or 'unnatural' ; (L_j^*, a_j^*, b_j^*) is the colour coordinates of the representative skin tone of each rendered image; and (L_{mean}^*, a_{mean}^*, b_{mean}^*) is the average colour centre for all observers.

A similar method was used to calculate MCDM to represent the intra-observer variation between each observer's two repeats, as shown in Equation (4).

$$\Delta E_{abi}^* = \sqrt{(L_{i1}^* - L_{i2}^*)^2 + (a_{i1}^* - a_{i2}^*)^2 + (b_{i1}^* - b_{i2}^*)^2} \quad (4)$$

where (L_{i1}^*, a_{i1}^*, b_{i1}^*) and (L_{i2}^*, a_{i2}^*, b_{i2}^*) are the weighted mean colour centre of "preferred" images in the first and the second judgements for each observer. The ΔE_{abi}^* was replaced by ΔE_{00} calculation eqution[26] in this study for comparing with ethnic group rsesluts easily. Finally, the average inter-observer and intra-observer variability (MCDM in ΔE_{00}) of the whole panel of observers was obtained by calculating the mean value of all memory colour images in terms of memory colour attributes as listed in Table 2 for each ethnic group and the combined data (ALL). The average inter-observer variability values of naturalness and preference were 1.41, 1.32 units, respectively, while those of intra-observer variability were 1.07 and 1.00 units, respectively. Intra-observer variation was found to be about half of the magnitude of inter-observer variation. This result indicates the current data to be reliable.

It can be found in Table 2 that the CA and CHZ observers performed the least consistent and the other three groups gave similar performance for assessing naturalness and preference. Also, intra-observer variations are more consistent than inter-observer variation. However, the overall MCDM ΔE_{00} values are very small, i.e. 1.41 and 1.32 for naturalness and preference, respectively.

Table 2. *Observer variations in MCDM in ΔE_{00} units*

Observers	*Inter-MCDM*		*Intra-MCDM*	
	Naturalness	*Preference*	*Naturalness*	*Preference*
CHZ	1.46	1.39	1.30	1.19
SA	1.29	1.31	0.79	0.72
CHL	1.29	1.21	0.96	1.05
CA	1.56	1.57	1.43	1.10
AF	1.24	1.07	0.94	0.95
ALL	1.41	1.32	1.07	1.00

Figure 7 and Figure 8 show the Inter-observer MCDM of preference and naturalness result of each memory object, respectively. It can be observed that there is an agreement of the most inconsistent objects between the preference and naturalness results, i.e. observers judged Blueberry, Green pepper, Aubergine, Summer grass and Pine least consistent. Results indicate that the inter-observer variability in the assessment of the memory colours was strongly context-dependent and larger than the inter-group variations

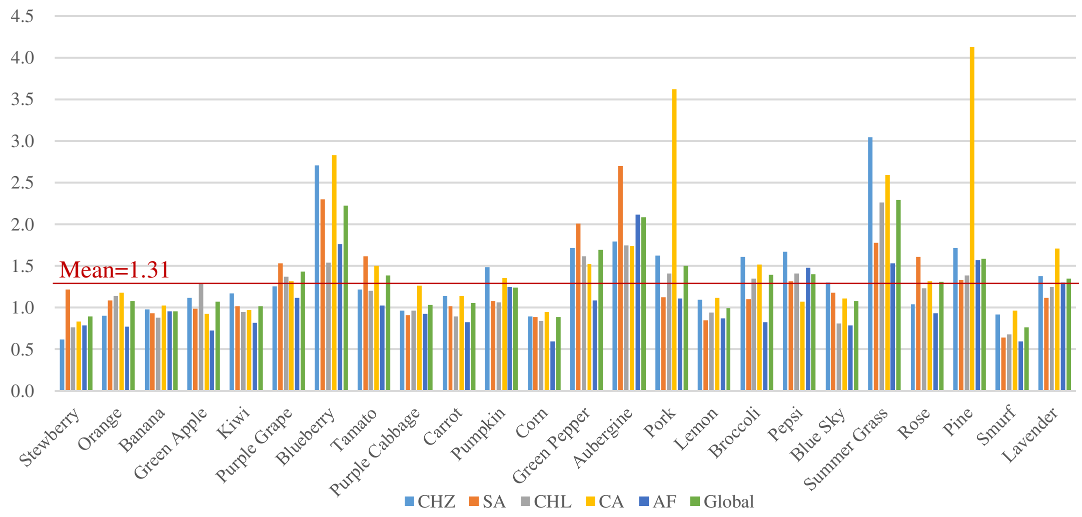


Figure 7. *Inter-observer MCDM of preference result in* ΔE_{00} *units*

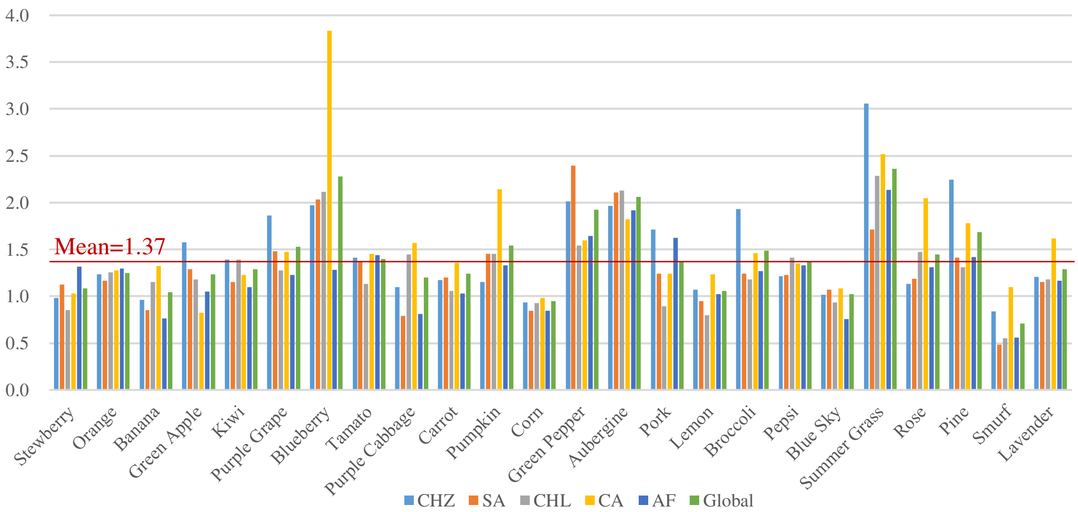


Figure 8. *Inter-observer MCDM of naturalness result in* ΔE_{00} *units*

3.2 Memory colour acceptance ellipsoid model

From the earlier studies, the memory colour centres were described as ellipsoids in CIELAB colour space. The ellipsoid model was derived in a matrix form and a polynomial form. Each observer's 'Yes decision' images were recorded. The results were in the form of 'Yes' and 'No'. They were arranged in the form of yes decisions rate Pv, which was calculated by the number of the yes decisions divided by the total number of observers multiplying by 100. These values for each image were used to fit the tolerance ellipsoids under each ambient lighting. Equation (2) shows a logistic function to transform between the model predicted probability (P_p) and calculated from an ellipsoid equation in CIELAB space. The ellipsoid equation defined the boundary corresponding to P_p equals 50%, i.e. half of the observers affirm the stimulus and the other half deny it. There is one method to build the ellipsoid model. As shown in Equation (4), it simulates an ellipsoid model with a skew angle in CIELAB space. An optimization process was established to obtain the coefficients, i.e. k_1, k_2, k_3, k_4, k_5, k_6, L_0, a_0, b_0 and α by maximizing the correlation coefficient between the P_p and P_v, which is the yes decision percentage from the visual results. Note that α is the colour difference calculated from the ellipsoid equation corresponding to the 50% ellipsoid boundary.

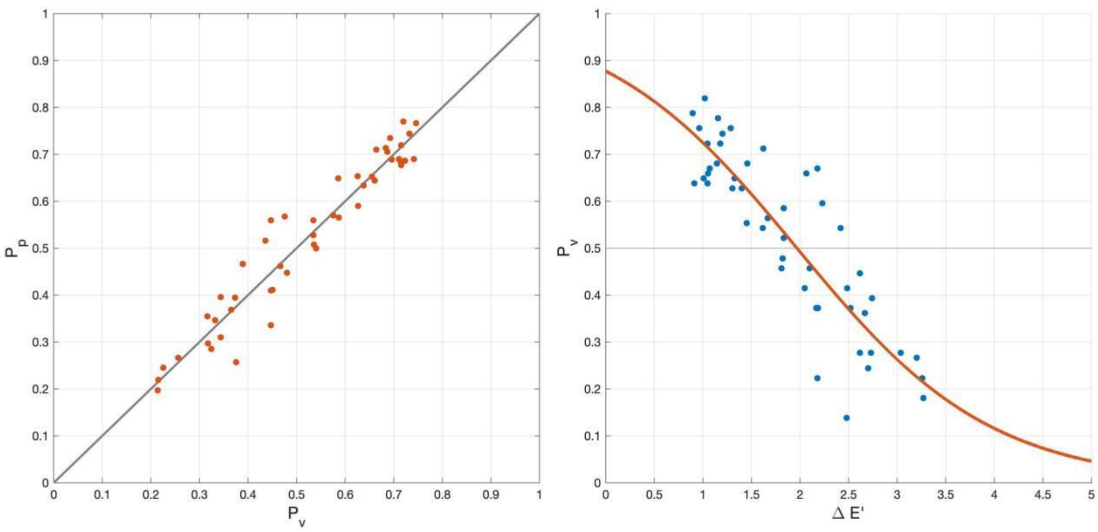
$$P_P = \frac{1}{1+e^{(\Delta E'-\alpha)}} \quad (3)$$

$$\Delta E' = \left(k_1(L^* - L_0^*)^2 + k_2(a^* - a_0^*)^2 + k_3(b^* - b_0^*)^2 + k_4(a^* - a_0^*)(b^* - b_0^*) + k_5(L^* - L_0^*)(a^* - a_0^*) + k_6(L^* - L_0^*)(b^* - b_0^*)\right)^{0.5} \quad (4)$$

where $[L^*_0, a^*_0, b^*_0]$ is the colour centre of the ellipsoid. Taking an example, Figure 9 is plotted respectively to the distribution of the original data is reasonable. Figure 10(a) shows a significant positive correlation between the preference percentage calculated from the experimental data and the preference percentage predicted by the model. Figure 10(b) shows the model's predictions and experimental data had an excellent agreement.

The mean correlation coefficient (r) between the preference visual percentage (P_p) and the model predicted preference percentage (P_v) was 0.83. The mean correlation coefficients predicted by the preference memory colour model in the CHZ, SA, CHL, CA, AF and ALL groups were 0.72, 0.87, 0.89, 0.77, 0.81 and 0.93, respectively. Overall, the high correlation coefficients indicate the ellipsoid model can fit the data well. The typical predictive correlation coefficient of the preference memory colour model was about 0.8. Only the correlation coefficients of blueberry and sky images were significantly lower, which were 0.73 and 0.68 respectively.

The mean correlation coefficient (r) between the naturalness visual percentage and the model predicted naturalness percentage was 0.84. The mean correlation coefficients predicted by the naturalness memory colour model in the CHZ, SA, CHL, CA, AF and ALL groups were 0.76, 0.86, 0.88, 0.82, 0.78 and 0.93, respectively. The correlation coefficients of model prediction in ALL and SA groups were high too. The typical predictive correlation coefficient of the preference memory colour model was about 0.8. Only the correlation coefficients of the sky and lavender images were significantly lower, which were 0.67 and 0.73 respectively. This was also found by [13] that sky colour could vary greatly according to different personal experiences in different territories.



(a) (b)

Figure 9. *Plot of the preferred model predicted results (Pp) and (a) the experimental visual results (Pv), and (b) ΔE' results from equation (4).*

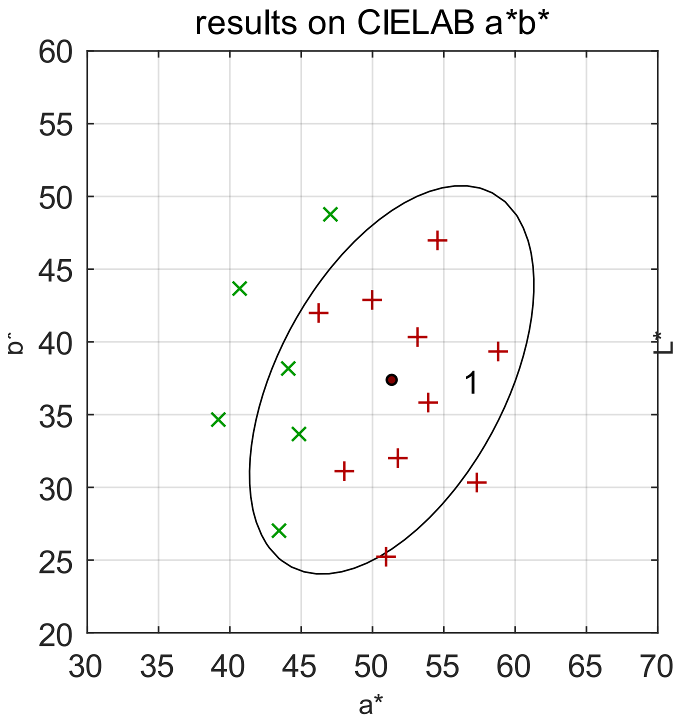


Figure 10. *'Yes' (red plus) and 'No' (green cross) choice result distribution and the model predicted memory colour ellipse.*

Figure 10 shows the distribution of the fitted ellipsoid model and data points on CIELAB a^*b^* plane. The ellipse equation defined the boundary corresponding to P_p of 50%, i.e. half of the observers preferred the stimulus and the other half not preferred. The red plus and the green cross sign indicate the data points with a preferred rate of more than 50% and less than 50%, respectively. It can be seen that almost all red data points were inside the ellipse, while green data points were outside the ellipse.

3.3 Memory colour results

Figure 11 and Figure 12 plot the naturalness and preference memory colour ellipses of CHZ, SA, CHL, CA, AF in a^*b^* plane. The colour of the ellipse in the figures is consistent with the memory colour centres of the corresponding object. It can be seen that there are variations in the size and shape of ellipses between the neighbouring colour regions such as the yellow region for CHZ, SA groups. Also, there were differences between ellipses from different ethnic groups. The most obvious one was the AF group ellipses were larger than those from the other groups. The variation of the natural memory colours across different ethnic groups (Fig. 12) was smaller than those of ellipses (Fig. 11). This indicates that people judged naturalness more consistently than judged preference. The most marked difference for objects was the Smurf object. This can be attributed to the familiarity of this cartoon character with different groups. The centre and range of preference ellipsoid and naturalness ellipsoid are also different. The impact of different ethnic backgrounds and the relationship between preference and naturalness will be discussed in following sections.

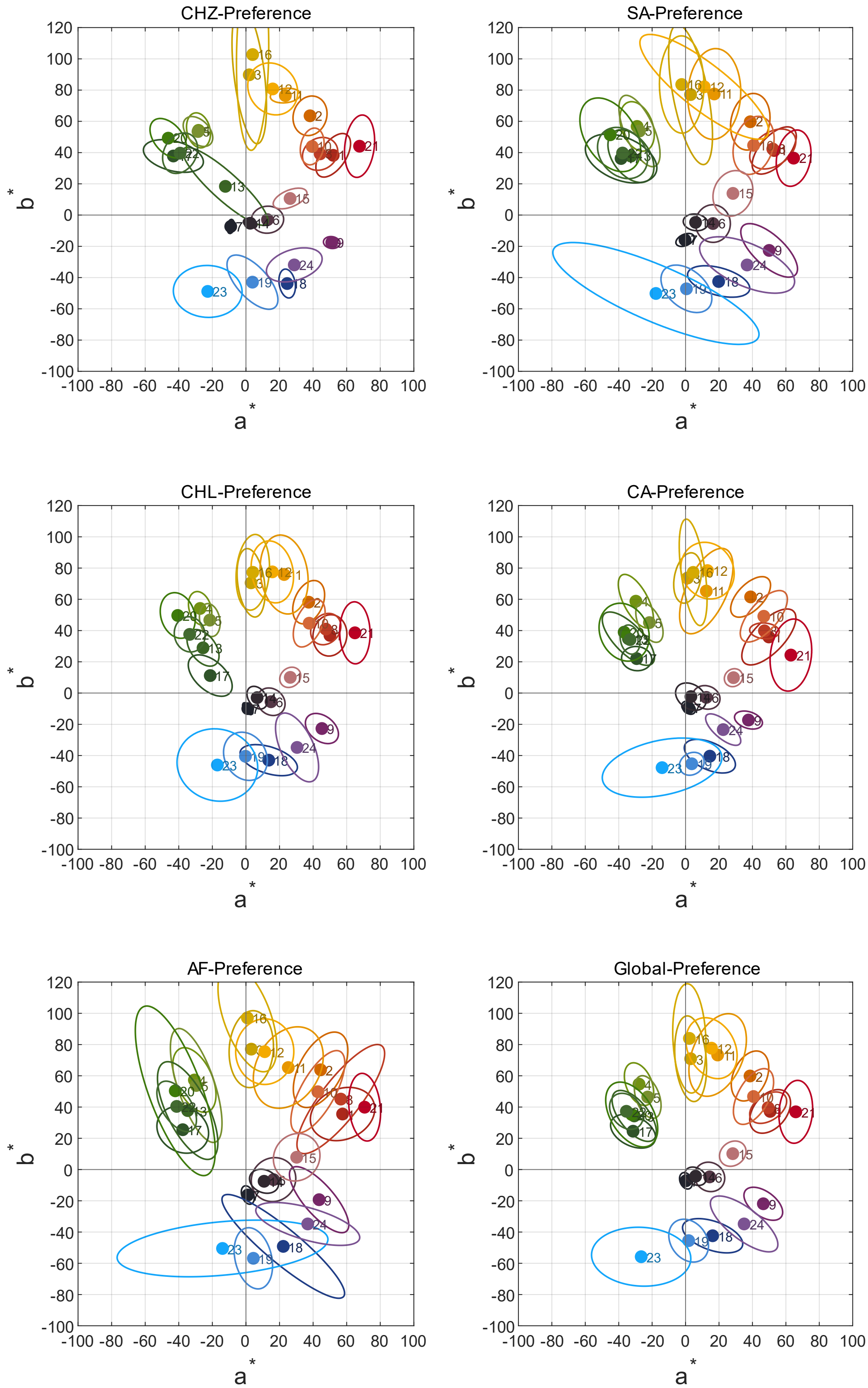


Figure 11. *Predicted preferred memory colour centre and ellipses of each ethnic group*

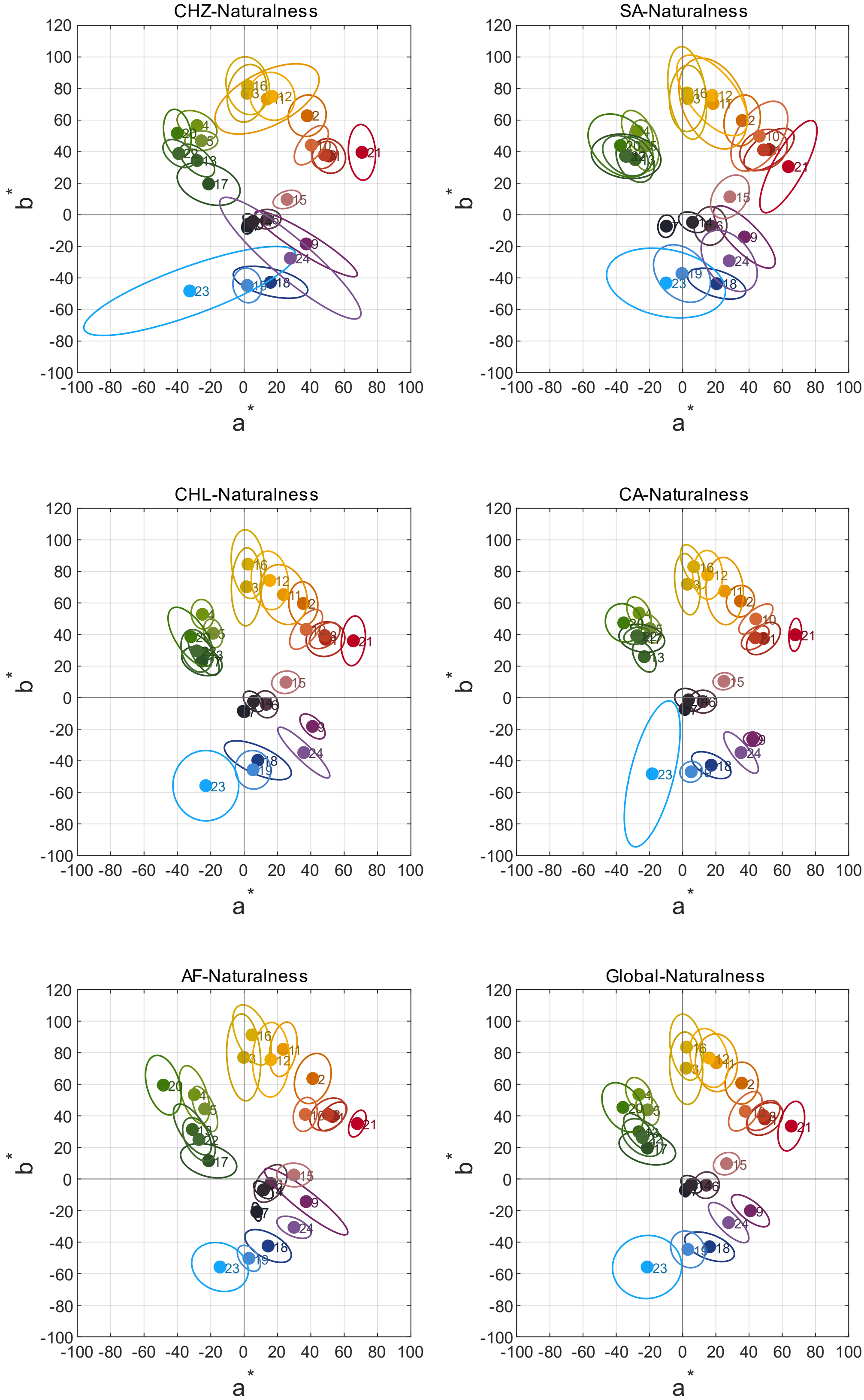


Figure 12. *Predicted natural memory colour centre and ellipses of each ethnic group*

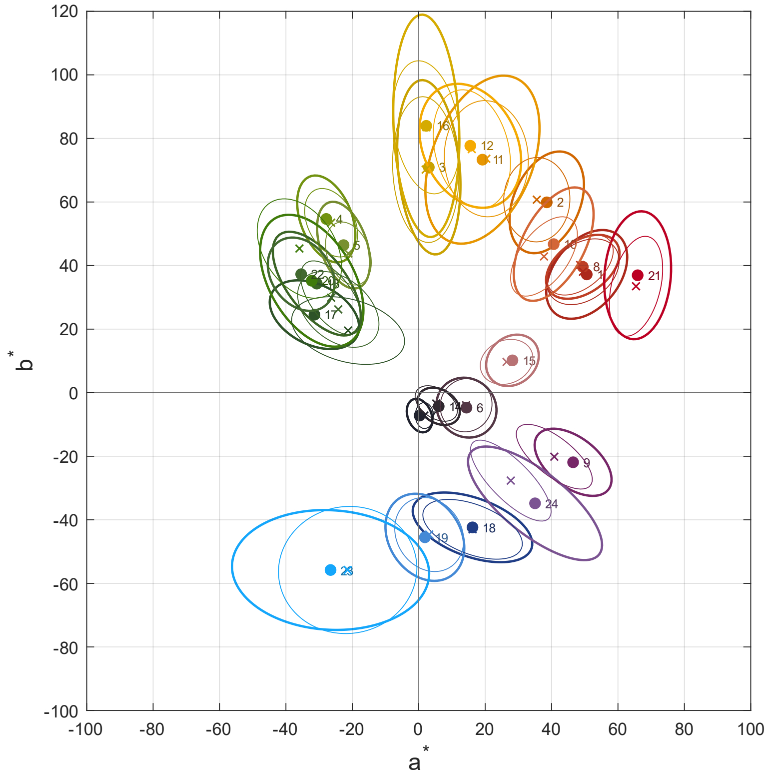


***Figure 13.** Preference and naturalness ellipsoids in a^*b^* plane*

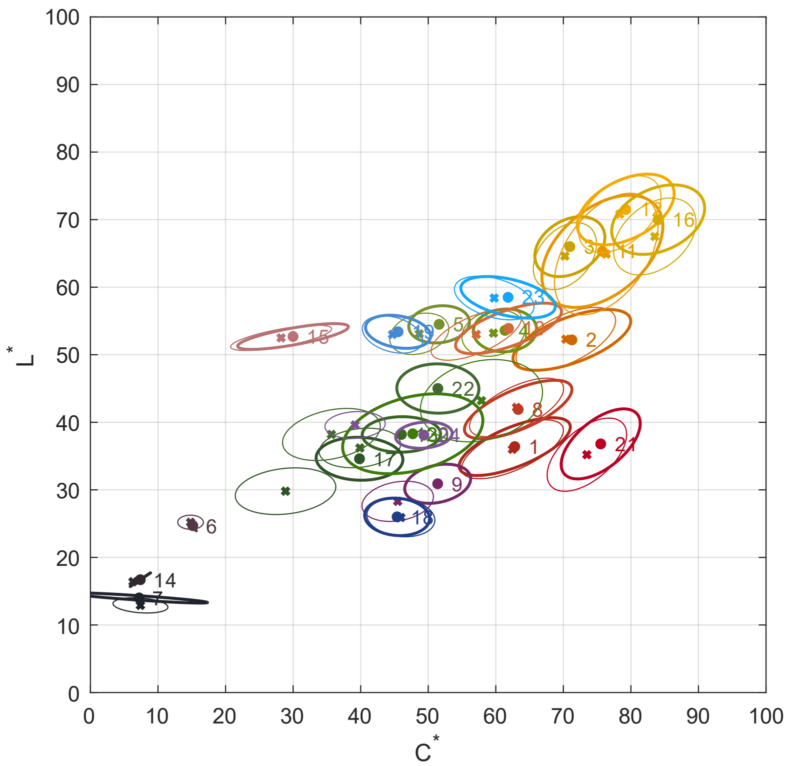


***Figure 14.** Preference and naturalness ellipsoids in $L^*C^*_{ab}$ plane*

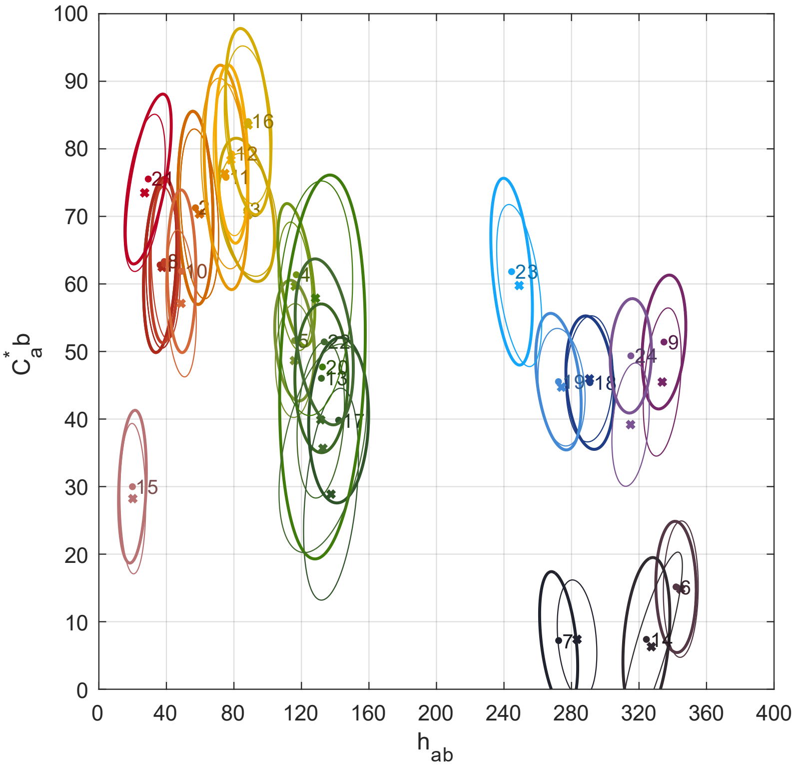


***Figure 15.** Preference and naturalness ellipsoids in C^*_{ab} h_{ab} plane*

Figures 13, 14 and 15, show the preference (thick line) and naturalness (thin line) ellipses calculated from all of the observers plotted in a^*b^*, $L^*C^*_{ab}$, $C^*_{ab}h_{ab}$ planes respectively, where the colour drawn for each ellipse in the figures is the same as that of the memory colour centre. The solid and cross dots represent preferred and natural colour centres respectively. The ellipses number and object name can be found in Figure 2. Figure 14 shows the preference and naturalness ellipses in $L^*C^*_{ab}$ plane. It can be seen that all ellipses orientated alone the direction of the 'vividness' scale [32,33] and their sizes increase when vividness increases. Note vividness is a two-dimensional colour appearance scale, with an origin at [0,0], the black point. The scale reflects the appearance of an object illuminated by light, i.e. the higher intensity of light would make the object appear brighter and more colourful. Figure 15 shows the preference and naturalness ellipses in $C^*_{ab}h_{ab}$ diagram. As it can be seen, all semi-axes of ellipses in hue angle are shorter than those in chroma direction, This indicates that observers were more sensitive in hue direction. Comparing the preference and Naturalness ellipses, there is little difference in the colour coordinates of the memory colour centre preferred by observers from different ethnic groups, but a trend can be found for each ellipse to point to the origin of a^*b^* plane. This implies memory or natural perception of the familiar objects to be hue consistent as also found by Zhu et al. [22] and Camgöz [34].

4. Results and Discussion

4.1 Preferred and natural result comparison

The results from the naturalness and preferences were first compared. By plotting both datasets, it was found very high correlation between them, i.e. an average correlation coefficient of 0.89. The worst agreement objects were purple cabbage and orange with correlation coefficients of 0.78 and 0.79.

Table 3 *The colour difference calculated between the colour centres of the preference and naturalness ellipses*

	ΔL^*	ΔC^*_{ab}	ΔH^*_{ab}	ΔA	$\Delta A/B$	$\Delta\theta$	ΔE_{00}[26]
CHZ	2.4	3.2	-2.7	1.6	0.2	-3.4	3.8
SA	0.3	4.3	3.2	-1.7	-0.2	-3.5	5.6
CHL	1.3	1.2	0.6	0.6	-0.1	2.0	3.1
CA	0.4	-1.3	1.0	4.7	0.9	-11.6	3.9
AF	1.2	3.8	-1.3	-5.8	-0.6	7.5	2.1
ALL	0.9	2.5	-0.5	1.9	0.3	0.3	5.2
mean	1.1	2.3	0.0	0.2	0.1	-1.5	4.0

Table 3 shows the difference of colour centres (ΔL^*, ΔC^*_{ab}, ΔH^*_{ab}, ΔE_{00}) and ellipse parameters (ΔA, $\Delta A/B$, ΔE) between preference memory colour and natural memory colour. It can find a systematic trend that the preferred centres to be more vivid (higher lightness and chroma) than that of the natural centres. Regardless of the ethnic groups, the overall lightness and chroma values of the preferred memory colour were consistently higher than that of the natural memory colour, with a mean of 1.1 and 2.3 units, respectively. This more or less agreed with the pattern in Figure. 14.

Detailed inspection can be found the CHZ observers to give much brighter preferred colours than natural colours amongst all ethnic groups. Also, all ethnic groups gave more colourful preferred colours than natural colours except the CA group to give a less colourful colour for the preferred colour.

4.2 Ethnic group differences

To compare the ethnic group difference, the colour difference between every two ethnic groups was calculated, as shown in Table 4 together with their mean values. For preferred memory colours, the ethnic group difference is the largest between CHZ and AF and the smallest between CHL and ALL. CHZ and CHL had the largest and the smallest difference from other ethnic groups. For natural memory colours, the ethnic group difference is the largest between SA and AF and the smallest between CHL and ALL. AF and CHL have the largest and the smallest difference comparing to other ethnic groups, respectively.

Table 4. *Colour difference (ΔE_{00}) between each two ethnic groups*

Preferred (ΔE_{00})	CHZ	SA	CHL	CA	AF	ALL	mean
CHZ		4.9	5.1	6.1	**6.8**	5.0	5.6
SA			4.6	5.4	5.1	3.8	4.8
CHL				3.8	5.3	2.7	4.3
CA					5.1	3.4	4.8
AF						5.2	5.5
ALL							4.0

Naturalness (ΔE_{00})	CHZ	SA	CHL	CA	AF	ALL	Mean
CHZ		4.3	3.4	3.9	5.2	2.4	3.8
SA			5.0	4.2	**6.3**	4.1	4.8
CHL				3.1	5.1	2.0	3.7
CA					6.1	3.1	4.1
AF						4.2	5.4
ALL							3.2

Furthermore, Figures 16 and 17 show the colour difference of five ethnic groups against the ALL results to reveal the ethnic group difference for individual objects, for preference and naturalness respectively. It can be seen that large ethnic group difference can be found for Summer grass, Smurf, Blueberry, Blue sky, Kiwi, the for preference results. But smaller discrepancy was found for the naturalness results, i.e. Broccoli, Smurf, Pine, Blueberry, Summer grass. .

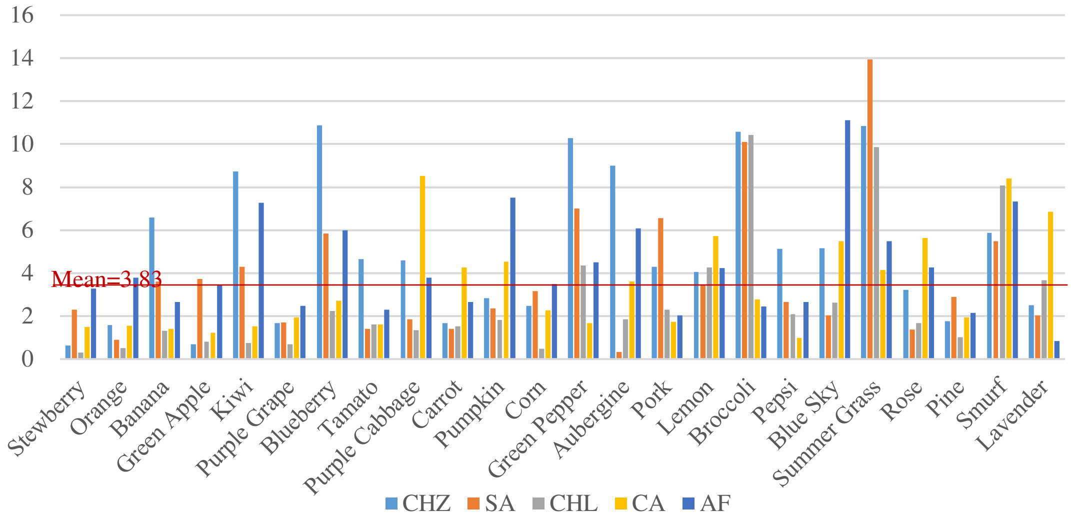


Figure 16. *Preference results of each ethnic group compared with ALL results*

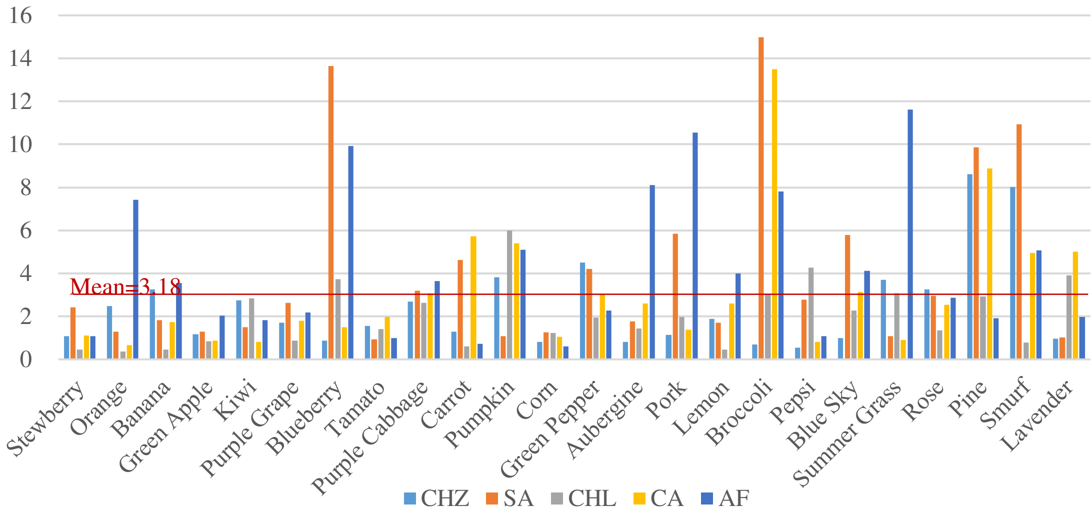


Figure 17. *Naturalness results of each ethnic group compared with ALL results*

Table 5 lists the MCDM values (ΔE_{00}) of the preferred and natural ellipsoid centre of each memory colour image among five observer groups from different ethnic groups. The average MCDM value between groups with different ethnic groups is 2.68 and 3.00 ΔE_{00} for natural and preferred ellipsoid centres respectively. In the naturalness experiment, the MCDM values among different cultural background groups of blueberry, pumpkin, broccoli, Summer grass, pine and smurf are larger than the average value, which means that the cultural backgrounds of these memory colour images are quite different in naturalness. In the preference experiment, the MCDM values among different cultural background groups of kiwi, blueberry, purple cabbage, pumpkin, green pepper, aubergine, lemon, broccoli, blue sky and Summer grass are larger than the average value, which means that the cultural backgrounds of these memory colour images are quite different in preference. The average value of broccoli is the largest, reaching 6.89 and 6.24 ΔE_{00} among natural and preferred ellipsoid centres respectively. In addition, there are few differences among different cultural background groups of other memory colour images.

Table 5. *MCDM (ΔE_{00}) among 5 groups. Those in red represent the larger discrepancy objects..*

No	objects	Preference	Naturalness
1	Strawberry	**1.45**	**1.05**
2	Orange	**1.47**	**2.26**
3	Banana	**2.31**	**1.43**
4	Green Apple	**1.63**	**1.07**
5	Kiwi	**4.07**	**1.65**
6	Purple Grape	**1.44**	**1.56**
7	Blueberry	**4.43**	**5.44**
8	Tomato	**1.95**	**1.16**
9	Purple Cabbage	**3.50**	**2.48**
10	Carrot	**2.04**	**2.51**
11	Pumpkin	**3.28**	**3.65**
12	Corn	**1.88**	**0.82**
13	Green Pepper	**4.84**	**2.77**
14	Aubergine	**3.56**	**2.79**
15	Pork	**2.87**	**3.98**
16	Lemon	**3.66**	**1.88**
17	Broccoli	**6.24**	**6.89**
18	Pepsi	**2.31**	**1.62**
19	Blue Sky	**4.43**	**2.63**
20	Summer Grass	**4.76**	**3.71**
21	Rose	**2.72**	**1.72**
22	Pine	**1.66**	**4.39**
23	Smurf	**2.77**	**4.96**
24	Lavender	**2.69**	**1.94**
	mean	**3.00**	**2.68**

Table 5, in general, shows a good agreement for the worst and best agreement objects between the ethnic groups on preference and naturalness. The best-agreed objects are strawberry, green apple, tomato, corn, purple grape, and the wort agreed objects are blueberry, broccoli, smurf, green pepper and blue sky.

4.3 Statistical test

To test whether the difference between the sample average and the overall average of each cultural background group on each colour attribute is significant, the t-test was used to investigate the significance of pairwise comparison differences among six groups: CHZ, SA, CHL, CA, AF and ALL. Here the paired sample test method of the double population test T-test was used to verify whether the difference between the average of the two relevant samples is significant.

Table 6 and Table 7 show the t-test results on two colour attributes (lightness L^* and chroma C^*_{ab}) for the memory colour centres between groups with different cultural backgrounds in the experiment of naturalness and preference, respectively. Hue angle results were also tested. However, it was found no significant difference for all inter-comparisons. So, they were not listed here.

Table 6. *T-test difference significance test results between groups with different cultural backgrounds in naturalness experiment, where '1' and '0' represent statistically significant and insignificant differences respectively.*

L^*	***CHZ***	***SA***	***CHL***	***CA***	***AF***	***ALL***	***Total No. of significant***
CHZ		0	1	0	1	1	3
SA			1	1	1	1	4
CHL				1	0	0	2
CA					0	0	2
AF						0	2
ALL							2
C^*_{ab}	***CHZ***	***SA***	***CHL***	***CA***	***AF***	***ALL***	***Total No. of significant***
CHZ		0	0	0	0	0	0
SA			0	0	0	0	0
CHL				0	1	0	1
CA					0	0	0
AF						1	2
ALL							1

Table 7. *T-test difference significance test results between groups with different cultural backgrounds in preference experiment , where '1' and '0' represent statistically significant and insignificant differences respectively.*

L^*	***CHZ***	***SA***	***CHL***	***CA***	***AF***	***ALL***	***Total No. of significant***
CHZ		0	1	1	1	1	4
SA			0	0	1	1	2
CHL				0	0	0	1
CA					0	0	1
AF						0	2
ALL							2
C^*_{ab}	***CHZ***	***SA***	***CHL***	***CA***	***AF***	***ALL***	***Total No. of significant***
CHZ		0	1	1	0	0	2
SA			1	1	0	1	3
CHL				0	1	0	3
CA					1	0	3
AF						1	2
ALL							2

The results showed that The SA and CHZ observers had more significant difference from other groups in the lightness of the natural centre. The CHZ observers have more significant differences from other groups in the lightness of the preferred centre. For the chroma of the natural centre, there are only significant differences between AF and CHL, and between AF and ALL.

4.4 Comparison with previous datasets

In order to verify whether the experimental results of this model were reasonable, the preference data obtained in this experiment were compared with the experimental results of several groups of predecessors, including Zhu et al.[22] and Smet et al.[21]. Smet et al. Studied 11 common memory colours of 7 groups of observers from different countries and regions and asked the observers to score the similarity between 100 colour transformations and memory colours in the image. Finally, the memory colour coordinates of observers with different cultural backgrounds were gathered. Zhu et al. asked Chinese and German observers to match the black-and-white images of 26 common memory colour objects on the display with the memory colour.. There were 6 memory colour objects of the same kind studied in all three experiments. Only those memory colours of the three experiments are drawn in a^*b^* plane, as shown in Figure 18, in which the solid points represent the memory colour results of this study, the circular and diamond points represent the preference and naturalness results respectively; ellipse represents the projection of the preferred acceptance ellipsoid obtained in this study; the open triangular points represent the memory colour results of Smet et al's; the open square points represent the Zhu's memory colour research results. It can be observed that the Smet's and Zhu's results are not all distributed in the preferred ellipse of this study, which confirms that memory colour is not completely equal to preferred colour. This conclusion is particularly obvious in the images of strawberry, green apple and lavender. The mean colour differences of the six memory colours between the present study and the results of Smet and between the present study and the results of Zhu were 5.09 and 11.60ΔE_{00}, respectively. The mean colour difference of 6 memory colours between Smet's and Zhu's results was 10.76ΔE_{00}. The mean colour difference of the three groups of memory colour results was 9.15ΔE_{00}, the largest of which was 11.33ΔE_{00} (lemon).

The difference found here was mainly due to different experimental techniques used such as matching and estimation, and different image sizes. The Smet et al. and Zhu et al used the large size displays comparing with the present mobile phone size. The Zhu et al's experiment adopted matching method comparing with the present and the Smet's estimation method. So, we can conclude about 5 ΔE_{00} units between different studies caused by the image size effect.

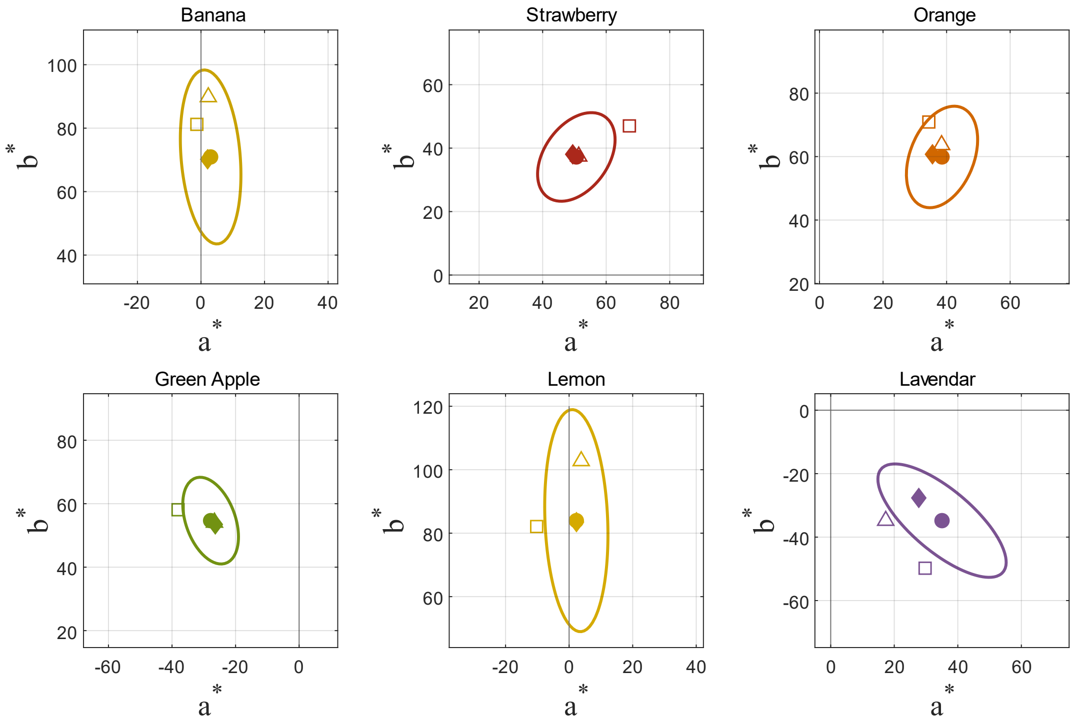


Figure 18. *Comparison of research results of memory colour*

5. Conclusion

In this study, a comprehensive experiment was carried out to investigate the memory colours across ethnic groups. In total, 24 object colours were assessed by 106 observers from 4 ethnic groups using mobile phones. The experiment was carried out in China and UK over a 2-years period. Psychophysical experiments were conducted using the threshold method. The results were analysed in terms of inter- and intra- observer variability. 50% acceptance ellipsoids were established to represent the colour centre and range for the preference and naturalness for each memory object. Some conclusions are drawn below.

- The intra- and inter-observer variations in the experiment were small, i.e. 1.07 and 1.41, and 1.00 and 1.32 $\Delta E00$ units for naturalness and preference, respectively. This suggests similar observer consistency for scaling preference and naturalness. All observer groups judged the objects of blueberry, green pepper, aubergine, summer grass inconsistently.

- Comparing the preference and naturalness results, a consistent pattern of both sets of ellipsoids can be found. All ellipses in a*b* plane point towards neutral point except two blue ellipses, and all ellipses in L*C*ab plane point towards black point. Both sets were larger in ellipse size for high chroma regions. In addition, the preferred colours in general had a higher chroma and lightness than the naturalness colours, i.e. preference colour appearing more vivid than naturalness colour. Also, preference ellipses are larger than naturalness ellipses, indicating the former ellipses had a larger range than the latter ellipses.

- The typical colour difference between different ethnic groups is about 3 CIELAB units for both preference and naturalness. The objects of blueberry, broccoli, green pepper, blue sky and summer grass were particularly inconsistent.

- Compared with the previous research results, the results of memory colour had somewhat larger difference. This could be caused by the different experimental techniques and screen size.

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Compliance with ethical standards

Conflict of interest: *The authors stated that they had no conflict of interest with the experimental subjects.*

Ethical Approval: *All the procedures carried out in the research involving human participants were in line with the Academic Rules of Engineering Graduates of Zhejiang University and the 1964 Helsinki declaration and its subsequent revisions or similar ethical standards.*

Informed consent: *All individual participants included in the experiment were informed and agreed that the results of this study were used for academic research and publication of the paper.*

Appendix

CHZ	Naturalness ellipsoid					Preference ellipsoid				
	L^*	a^*	b^*	C^*_{ab}	h_{ab}	L^*	a^*	b^*	C^*_{ab}	h_{ab}
1	35.2	50.8	37.3	63.0	36.3	36.9	52.0	38.3	64.5	36.4
2	54.7	37.8	62.8	73.3	58.9	51.8	38.2	63.6	74.1	59.0
3	68.1	1.7	77.0	77.0	88.7	72.5	2.0	89.8	89.8	88.7
4	52.5	-28.2	56.6	63.2	116.5	53.0	-28.3	54.2	61.2	117.5
5	55.0	-25.7	46.9	53.5	118.7	63.8	-28.6	53.5	60.6	118.1
6	27.2	13.7	-2.8	14.0	348.6	25.3	12.8	-3.0	13.2	347.0
7	13.7	2.2	-7.2	7.5	287.3	18.1	-9.1	-7.3	11.6	218.8
8	40.9	48.2	37.9	61.3	38.2	46.3	44.2	39.2	59.1	41.6
9	31.3	37.2	-18.4	41.5	333.6	35.4	51.1	-17.6	54.0	341.0
10	52.2	40.3	44.1	59.7	47.6	52.5	39.5	43.9	59.0	48.1
11	64.7	13.8	73.4	74.7	79.4	63.1	23.5	76.5	80.0	72.9
12	70.5	16.9	75.1	77.0	77.3	74.7	15.9	80.8	82.3	78.8
13	41.0	-28.2	34.4	44.5	129.3	35.1	-12.2	18.4	22.1	123.7
14	16.0	5.2	-4.3	6.7	320.7	27.8	2.5	-5.2	5.8	295.9
15	53.6	25.8	9.7	27.5	20.7	57.1	26.3	10.6	28.4	22.0
16	65.2	2.1	81.8	81.8	88.5	72.3	4.0	102.8	102.8	87.8
17	30.7	-21.3	19.6	28.9	137.3	44.8	-43.2	37.8	57.4	138.8
18	25.2	15.8	-42.7	45.6	290.3	23.9	24.6	-43.8	50.2	299.3
19	52.7	1.9	-44.7	44.8	272.5	58.3	3.9	-42.9	43.1	275.2
20	46.5	-40.0	51.7	65.4	127.8	48.4	-46.3	49.2	67.6	133.2
21	38.0	70.7	39.6	81.0	29.3	35.2	67.7	44.1	80.8	33.1
22	44.5	-39.2	38.8	55.2	135.3	43.8	-39.2	39.6	55.7	134.7
23	65.0	-32.6	-48.3	58.2	236.0	64.8	-22.8	-48.9	53.9	245.0
24	40.7	27.7	-27.5	39.0	315.2	38.3	28.8	-31.9	43.0	312.1

SA	Naturalness ellipsoid					Preference ellipsoid				
	L^*	a^*	b^*	C^*_{ab}	h_{ab}	L^*	a^*	b^*	C^*_{ab}	h_{ab}
1	38.5	52.0	41.3	66.5	38.5	38.4	53.0	41.3	67.2	37.9
2	51.1	35.9	59.8	69.7	59.0	51.3	38.7	59.7	71.2	57.1
3	66.5	3.0	73.7	73.8	87.7	70.2	3.0	77.1	77.2	87.8
4	54.4	-27.3	53.0	59.6	117.2	57.5	-29.0	56.7	63.7	117.1
5	54.2	-23.2	43.9	49.7	117.8	58.2	-27.6	53.8	60.5	117.1
6	26.4	16.7	-7.0	18.1	337.2	25.9	16.4	-5.4	17.2	341.7
7	18.5	-9.8	-7.2	12.2	216.3	14.6	-0.3	-15.9	15.9	268.8
8	43.1	48.7	41.1	63.8	40.2	43.0	52.2	42.3	67.2	39.0
9	26.7	37.2	-14.0	39.8	339.3	32.8	50.0	-22.6	54.9	335.7
10	56.7	46.2	49.8	67.9	47.1	52.9	40.7	44.6	60.4	47.6
11	64.7	18.3	70.5	72.9	75.4	67.0	17.2	77.5	79.4	77.5
12	70.3	17.8	75.7	77.7	76.8	72.7	11.2	82.1	82.8	82.2
13	40.5	-28.6	35.0	45.2	129.3	45.8	-32.7	37.8	49.9	130.9
14	18.3	6.0	-4.7	7.6	321.5	16.8	6.0	-4.7	7.6	322.1
15	46.8	28.5	11.4	30.7	21.8	46.6	28.3	13.9	31.6	26.1
16	68.7	2.7	77.2	77.3	88.0	67.1	-2.3	83.6	83.6	91.6
17	44.8	-34.0	37.0	50.3	132.6	44.8	-38.6	36.2	52.9	136.8
18	27.2	20.5	-43.6	48.2	295.1	27.6	19.8	-42.5	46.9	295.0
19	59.0	-0.4	-37.2	37.2	269.4	51.9	0.5	-47.2	47.2	270.6
20	43.6	-37.4	43.9	57.7	130.5	51.7	-45.1	51.4	68.3	131.2
21	38.4	63.7	30.5	70.7	25.6	35.2	64.6	36.4	74.2	29.4
22	47.4	-34.4	37.4	50.9	132.6	47.8	-37.7	39.7	54.8	133.5
23	68.4	-10.0	-43.2	44.4	257.0	62.6	-17.7	-50.2	53.2	250.5
24	38.8	28.0	-29.2	40.5	313.9	37.8	36.8	-31.9	48.7	319.1

CHL	Naturalness ellipsoid					Preference ellipsoid				
	L^*	a^*	b^*	C^*_{ab}	h_{ab}	L^*	a^*	b^*	C^*_{ab}	h_{ab}
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	51.9	34.8	61.1	70.4	60.3	53.7	38.9	61.5	72.8	57.7
3	66.6	2.9	71.9	72.0	87.7	66.7	1.2	73.6	73.7	89.1
4	52.3	-26.3	53.6	59.7	116.1	53.2	-29.7	58.8	65.9	116.8
5	53.3	-19.7	43.7	48.0	114.3	53.0	-21.6	45.1	50.0	115.6
6	24.8	12.3	-2.5	12.5	348.3	24.5	12.4	-2.8	12.7	347.4
7	15.1	1.4	-7.2	7.3	281.1	15.6	1.8	-9.4	9.6	280.7
8	41.0	43.7	37.9	57.9	41.0	40.5	47.2	39.8	61.7	40.2
9	29.9	42.2	-26.3	49.7	328.1	20.2	37.6	-17.3	41.4	335.3
10	58.5	44.1	49.8	66.5	48.5	57.7	46.8	49.1	67.9	46.4
11	60.8	25.3	67.5	72.1	69.5	62.2	12.4	65.3	66.5	79.2
12	71.8	15.0	77.8	79.2	79.1	73.8	13.1	78.4	79.5	80.5
13	33.4	-23.1	25.9	34.7	131.7	37.2	-34.2	34.8	48.8	134.5
14	16.8	3.5	-1.4	3.8	338.4	15.1	3.2	-2.3	3.9	324.3
15	51.6	24.9	10.4	26.9	22.6	51.0	28.7	9.8	30.3	18.9
16	68.3	6.7	83.0	83.3	85.4	77.2	4.5	77.3	77.4	86.6
17	42.8	-24.6	37.6	44.9	123.2	31.5	-29.3	22.1	36.6	143.0
18	26.2	17.2	-42.8	46.1	291.9	25.0	14.5	-40.4	42.9	289.8
19	49.9	5.1	-47.0	47.3	276.2	59.1	3.7	-45.3	45.4	274.7
20	43.6	-35.5	47.4	59.2	126.8	42.5	-36.8	39.0	53.6	133.3
21	35.2	67.8	39.8	78.6	30.4	35.9	63.0	24.3	67.5	21.1
22	46.1	-27.7	39.2	48.0	125.2	46.6	-33.2	34.2	47.7	134.1
23	63.4	-18.3	-48.3	51.7	249.2	65.1	-14.0	-47.7	49.8	253.6
24	35.3	35.2	-34.8	49.5	315.3	42.0	22.5	-23.4	32.4	313.9