Chapter 14
Investigation of Memory Colors of Chinese Observers

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Abstract Long-term memory colors of familiar objects are of great significance in the applications such as imaging, lighting, and color reproduction. Previous studies of memory color were mainly conducted on the surface color samples under variable illuminations or images presented on displays. In this work, memory colors of Chinese observers with a set of 22 familiar objects have been investigated on a well-calibrated display. A specially developed psychophysical method and an operational program were applied for the observers to match the homogenous patch colors through object name descriptions with their memory colors on a self-luminous monitor in a given viewing situation. The results of inter-observer variability were analyzed in CIELAB color space by mean of color differences from the mean (MCDM) and tolerance ellipse. The two indexes were found to be consistent. Our aim is to establish a methodology both to study memory colors and to quantify the specific Chinese memory colors, which can benefit for further image enhancement.

Keywords Memory color · Long-term memory · Chinese colors · Tolerance ellipse

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14.1 Introduction

Memory colors have been extensively studied to achieve high-quality color reproduction [1]. The earlier studies mainly focused on three big parts: real objects, reflected color samples, and display-based images. Bartleson [2, 3] investigated the memory colors of skin, blue sky, and grass colors using Munsell color chips, which were the most important colors in color reproduction. Smet et al. [4] found saturation increased for memory colors and hue shifts toward the dominant hue compared to natural colors when investigating color appearance rating of familiar real objects. Similar results have been confirmed by many other researchers [5–8].

Tarczali et al. [9] compared the method of reproducing memory colors from a color name and from a grayscale photograph, of which the latter showed smaller variability. Moreover, they found a significant cultural difference between Hargarian and Korean. Smet et al. [10] carried out a project to investigate memory colors of eleven familiar objects across seven countries/regions by rating the similarity between the objects displayed on the calibrated monitor and that in reality. Although there was a significant difference between the regions, the effect of cultural difference was considered to be unimportant due to large inter-observer variability.

In our work, the long-term memory colors of Chinese people with a set of 22 familiar objects in different categories were studied. A homogenous color patch was manipulated by the observers to match their memory color on a calibrated display with large color gamut. This study provided quantitative data of Chinese memory colors to potentially support image reproduction and enhancement in the aspect of color.

14.2 Method

14.2.1 Selection of Objects

Twenty-two familiar objects were specially chosen for this experiment so as to cover the entire hue circle, except the green–blue quadrant, which was found to be lack of memory colors. The categories of these object colors were traditional Chinese colors, common natural colors, and vegetables and fruits colors, as given in the first column of Table 14.1. The main intention of the first category was to investigate the difference between memory colors and real historical colors in the work of museum conservation and relic restoration. Second and third categories were the most important memory colors associated with daily life for diverse applications.

Table 14.1 The memory color results of 22 familiar objects: L^*, $C^*_{ab,}$and h_{ab} values of color centers in CIELAB color space, detailed parameters of tolerance ellipses and chromatic MCDM

No.	Object name	L^*	C^*_{ab}	h_{ab}	Ellipse A	Ellipse A/B	Ellipse theta	Ellipse area	Chromatic MCDM
2	Caucasian face skin	73.8	13.0	33.3	6.4	2.0	43.4	64.0	6.2
2	African face skin	20.7	13.8	47.2	7.7	1.8	53.0	100.4	7.4
3	Nectarine	31.3	54.1	30.5	7.1	1.4	71.6	114.5	8.2
3	Red rose	34.6	69.1	35.9	6.8	2.5	83.6	57.6	9.4
3	Pink lotus	68.9	35.8	343.6	9.9	2.2	158.6	140.7	9.2
2	Oriental face skin	62.5	25.5	52.0	8.9	2.2	69.5	114.9	8.9
1	Dragon robe	77.4	77.3	84.7	9.0	1.5	8.3	166.2	10.2
3	Lavender	40.1	56.2	301.3	10.6	2.2	129.1	159.0	10.4
3	Aubergine	15.4	25.7	333.0	12.6	2.9	119.6	173.5	9.2
3	Banana	77.3	77.2	90.6	7.3	1.1	167.8	150.3	9.9
3	Strawberry	42.9	76.5	34.4	15.5	2.4	52.2	318.6	11.9
3	Lemon	81.6	78.6	97.3	8.9	1.2	7.4	206.5	11.0
2	Blue jean	29.6	27.0	274.3	9.3	1.8	104.9	151.8	10.0
3	Orange	64.1	75.4	64.3	10.1	2.0	12.9	164.9	11.6
1	Blue and white porcelain	34.7	46.7	283.1	10.8	2.0	123.6	186.3	10.7
1	Sausage	29.0	47.3	29.9	10.8	1.5	57.0	247.4	12.3
3	Pink lotus	62.8	71.4	125.1	12.1	1.3	0.8	348.9	12.9
4	Kiwi	68.4	68.1	115.7	11.0	1.2	120.0	321.5	13.1
3	Broccoli	41.2	49.1	141.8	12.1	1.4	5.9	341.1	14.1
3	Green apple	66.9	65.9	122.0	16.0	1.8	176.3	437.7	15.3
1	Chinese red	39.3	69.8	36.5	24.5	2.3	29.8	8066	16.4
2	Blue sky	49.1	64.3	284.9	14.6	1.7	121.0	394.0	19.3

14.2.2 Display

The color matching experiment was operated on a calibrated LED-backlighting EIZO display with correlated color temperature (CCT) of 6556 K, luminance level around 111 cd/m^2, and the x, y chromaticity coordinates of [0.311, 0.330]. The monitor characterization was implemented utilizing GoG model with a prediction of less than 0.6 ΔE^*_{ab} unit averaged from eighteen gray scales [11]. The observers' memory color matching results were saved as trichannel RGB values, which were device dependent. They were redisplayed on the monitor, and device-independent CIEXYZ tristimulus values were then measured by a JETI Specbos 1211 UV tele-spectroradiometer (TSR).

14.2.3 Test Procedure

Twenty-five normal color vision Chinese observers, comprising fifteen males and ten females, participated in this experiment with an average age of 24 years old. After a training of experimental instruction and related color notion, they were asked to match the colors of the objects with respect to their memory by using a MATLAB program specially developed for the experiment.

Figure 14.1 illustrates the operational interface. Taking an example of 'Imperial robe', the descriptive name of the testing object was placed at the top of the interface with a sequence number. The observers reproduced their memory color on the 2 cm by 2 cm homogenous patch in the center. The original digital RGB signal values of the color patches were obtained from internet images of a representative region of the objects and set as starting points in the matching experiment. This size

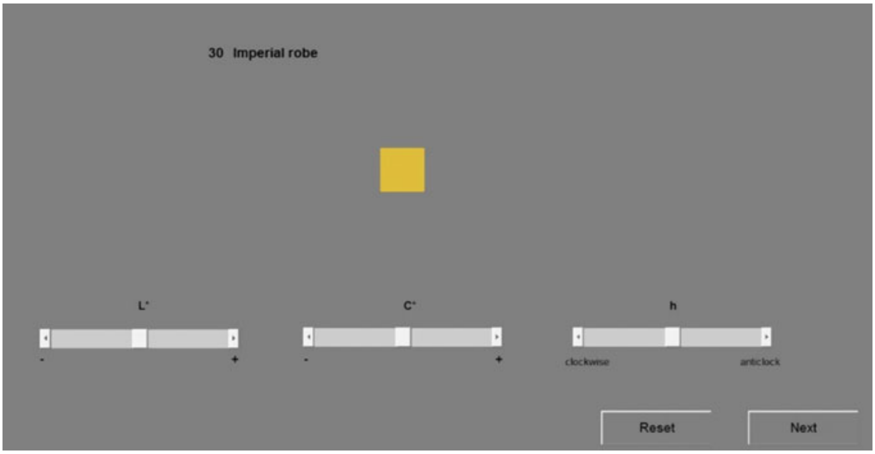

Fig. 14.1 Operational interface

resulted in a 2° of visual field from a viewing distance about 50 cm. The matching color was manipulated by continuously controlling the bars of lightness (L^*), chroma (C^*_{ab}), and hue angle (h_{ab}) in three dimensions, which were defined in the CIELAB color space. There were a 'reset' and a 'next' buttons in the bottom corner. The first button can cancel the manipulation and return to the starting point. The latter was set to continue matching after satisfactorily completing the present color patch until completing all the 22 objects.

14.3 Results and Discussions

The memory color data was first obtained from observers' matching results and stored in RGB digital values. Then they were redisplayed on the monitor and device-independent CIEXYZ values were measured by the TSR. In order to obtain the representative memory colors, the averaged results of the group were transformed from CIEXYZ into L^*, C^*_{ab}, and h_{ab} in CIELAB uniform color space (also given in Table 14.1). These data quantitatively represented the Chinese memory colors of the 22 familiar objects in the experiment.

Inter-observer variability was evaluated both by MCDM and by tolerance ellipse. It is clear that the smaller MCDM corresponds to better agreement within the observers' data. From the last column in Table 14.1, it can be seen that the largest MCDM and smallest MCDM are blue sky (19.26) and Caucasian face skin (6.23), respectively. This reveals that Chinese memory color of blue sky differs greatly from individual to individual, while Caucasian face skin stays close to each other.

The other methods employed here are tolerance ellipse [12] in the a^*b^* diagram (ellipse parameters listed in Table 14.1). The tolerance ellipse gives an elliptical boundary statistically based on the distribution of individual data with a preset confidence level. In general, a larger ellipse area indicates greater inter-observer variability. Figure 14.2 shows the 22 tolerance ellipses in the a^*b^* diagram. Their sizes and orientations vary individually. The smallest ellipse is Caucasian face skin, while the largest one is blue sky. However, it is observed that larger ellipses are located in higher chroma area. This can be ascribed to the poor uniformity of CIELAB color space. It is worth pointing out that some colors are hue direction orientated, whereas some are chroma direction orientated.

These two indexes show to be in great accordance with correlated coefficient equal to 0.92. It means a bigger MCDM value usually corresponds to a larger size of tolerance ellipse, which reveals a greater variability.

A comparison between our results and those of Liu et al. [8] and Smet et al. [10] were also provided. Both datasets were based on images on display. The MCDMs of Smet et al.'s data were presented in terms of Du′v′ units. Therefore, they were transformed to CIELAB, and MCDMs were recalculated in average about 10 CIELAB units. Liu et al.'s studied sixteen color centers with an averaged MCDM value of 3. This reduction can be a consequence of a limited range of color region

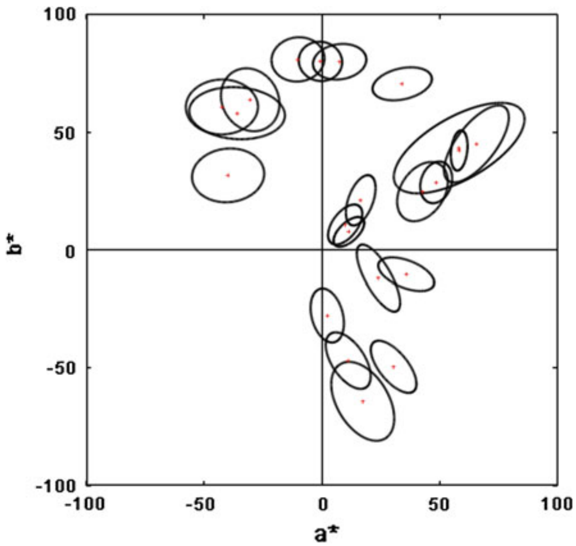

Fig. 14.2 The 22 tolerance *ellipses* in a^*b^* diagram reduced by 2 times of the real size. The *red crosses* represent the color center for each object

used in their experiment. The discrepancy between both datasets was about 15 units.

The overall mean MCDM of 22 memory color studied in this experiment reached 11.25 chromatic ΔE^*_{ab}. According to Bodrogi et al.'s finding, the large variance of long-term memory by observer operation was mainly due to two separable reasons [8]. One was the individual preference, and the other was the individual precision in the memory color matching. These were appropriate reasons that can explain the large variability results in the experiment.

14.4 Conclusions

Memory colors of Chinese people with a set of 22 familiar objects have been studied on a self-luminous display. The typical memory color variation of Chinese observers was about 11.25 chromatic units in terms of MCDM. The results gave larger observer variability compared with the other two datasets. It is because the observers' self-matching method employed in this work was based on descriptive objects' names, while the others were based on images that offered more explicit information. The experimental results can provide effective solutions to Chinese memory colors for further applications of image enhancement.

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