Observer Metamerism for Assessing Neutrality on Displays

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Abstract. Observer metamerism (OM) is considered the disagreement of color matches due to different color vision between observers. It is a source of uncertainty for color specification and is essential for the design of imaging products. Many experiments have been conducted to quantify the degree of OM. In this paper, two color matching experiments were conducted to study the neutral white on two displays. Based on experiments, 95% ellipses of different SPs and observers were drawn on a*b* plane. Neutrality chromaticity of 2 displays was reported in terms of u'v'. The results of intra-observer and inter-observer variations were reported using mean color difference from a set of mean (MCDM) in terms of CIEDE2000 color differences. Intra-observer variation was calculated using MCDM between 8 repeat matchings. It was found that intra-observer MCDM was 3.9 ranged from 3.1 to 4.4. Inter-observer variation was calculated between observers under each luminance level or SP. It was found that inter-observer MCDM was 5.5 ranged from 4.1 to 7.3. Also, observer variation slightly increased when different SPs were involved.

Keywords: Observer Metamerism · Color Matching · MCDM

1 Introduction

Observer metamerism refers to the phenomenon that under identical viewing conditions, a metameric pair of colors, that match for one observer, can be mismatched for another observer [1]. In other words, normal color vision observers could still have quite different color perceptions. The color received by human eyes is affected by color matching function (CMF). CMF varies from person to person and is affected by many physiological parameters. [2] The difference between CMFs is one of the reasons for observer metamerism. In 2006, CIE proposed CIEPO06 model [3] to generate CMFs of observers with different ages and field size, and it can be used to evaluate observer metamerism. However, observers with the same age and field size still have different color vision. It is necessary to carry out psychophysics experiments to study and measure the color visional differences between observers.

Various studies were carried out [4–6] and their results were reported in terms of MCDM. Each experiment recruited a number of observers to perform color matching

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experiments. The results were reported in terms of inter- and intra-observer variations. In general, they found that the inter- observer variations (MCDM)were around 2.0–4.0 CIEDE2000 units and intra-observer variation is smaller by a factor of about 1.5.

The above experiments performed color matching used a white as the external reference. The present work differs from them and is aimed to study the memory color of white perception. In other words, color matching was performed against an internal reference, i.e. each observer's own white perception.

Many studies have been carried out to investigate the chromaticity of neutral white. Huang et al. [7] studied white appearance of a tablet display under 17 lighting conditions. 63 observers were asked to judge whether the stimulus can be classified as white and estimate the whiteness percentage. It was found that neutrality centers (using u'v') under dark and D65 conditions were (0.2001, 0.446) and (0.1976, 0.4451) respectively. Smet et al. [8, 9] studied chromaticity of unique white viewed in object mode and illumination mode under dark adapted conditions. 13 observers conducted unique white setting and unique white rating experiments. Average of neutrality centers in 3 luminance levels were (0.2086, 0.4655) and (0.2035, 0.4605) for object mode and illumination mode respectively. In this study, the chromaticity of neutral white was further investigated.

Overall, the goals of this study were to find the neutral chromaticity, to investigate the observer metamerism, including intra-observer and inter-observer variations, and to study the impact of different starting points on observer metamerism.

2 Experimental

The experiment for finding neutrality color was divided into two parts using two displays assessed by two independent groups of observers. The aim was to get a general conclusion of the range of observer variations and to compare the similarities and differences between the two experiments.

2.1 Experiment 1

Experiment 1 was carried out at Zhejiang University on a NEC display, using sRGB to display. Color patterns were presented on a 10-bit 'NEC MultiSync PA272W' LCD display. Observers sat 60 cm in front of the display. After chromatic adaptation for 1 min, a color patch with black background appeared on the center of screen, which subtended a 4° field of view (FOV). The experiment was carried out in a complete dark room. 25 observers with normal color vision participated in the experiment. Observers used the keyboard to adjust the test stimulus along CCT and Duv directions. There were 2 luminance levels (18.42 and 40.75 cd/m^2) and 4 starting points. The two parts of Experiment 1 were named Experiment 1L and Experiment 1H for low and high luminance levels, respectively.

2.2 Experiment 2

Experiment 2 was conducted at home of the first author due to the COVID19 outbreak. The experimental conditions were closely followed those of Experiment 1. A laptop computer by assuming an sRGB display was applied. Ten observers with normal color vision participated in the experiment. When matching neutral white, CIELAB a* and b* were adjusted and lightness was fixed at L* of 61. Each match was started at one of the 4 starting points, saturated red, yellow, green and blue. For each starting point, observers repeated 8 times. In total, 320 matches were made, i.e. 10 observers × 4 SPs × 8 repeats.

3 Results and Discussions

The observer metamerism was analysed in 2 parts: intra- and inter- observer variations.

3.1 Intra-observer Variation

Only Experiment 2 results were used to investigate intra-observer variation, because observers in Experiment 1 did not perform the repeated assessments. Table 1 shows the MCDM results for each starting point and its mean together with the overall mean, which was calculated to include all the available 320 data. It can be seen that different SPs could impact on observer variation, i.e. observer performed more consistently for the blue SP (3.1) and least consistent for the Yellow SP (4.4) with a mean of 3.9 MCDM units. Also, when considering the inclusion of all available data, the observer variation became 4.5, increased by a factor about 1.2.

Table 1 Intra-observer variations for experiment 2

Starting point	Experiment 2
SPR	4.3
SPY	4.4
SPG	3.8
SPB	3.1
Mean	3.9
Overall mean	4.5

3.2 Inter-observer Variation

Three sets of experimental results were used to investigate inter-observer variation. Table 2 shows the MCDM results for each starting point and its mean together with the overall mean, which was calculated to include all the matching data. Again, it can be found that different SPs seem to impact on inter-observer variation. For example, in Experiment 2, observers performed more consistently for the green and blue SPs than the yellow and red SPs. The results from Experiment 1L and Experiment 2 performed more consistently

Table 2 Inter-observer variations for each experiment

	Experiment 1L	Experiment 1H	Experiment 2
SP1	5.3	6.0	5.7
SP2	5.2	7.3	5.7
SP3	4.9	4.1	5.3
SP4	4.6	7.0	4.6
Mean	5.0	6.1	5.3
Overall mean	5.5	7.1	5.5

than those in Experiment 1H. Also, when considering the inclusion of all available data (see overall mean), the observer variation increased by a factor about 1.1.

Observer variations can also be expressed by plotting 95% confidence ellipses in a*b* plane. Figures 1a, b show ellipses for Experiments 1L and 1H respectively. It can be seen that the ellipses in Fig. 1b are in general larger and more scatter than those in Fig. 1a. This means less observer consistency in Experiment 1H than Experiment 1L.

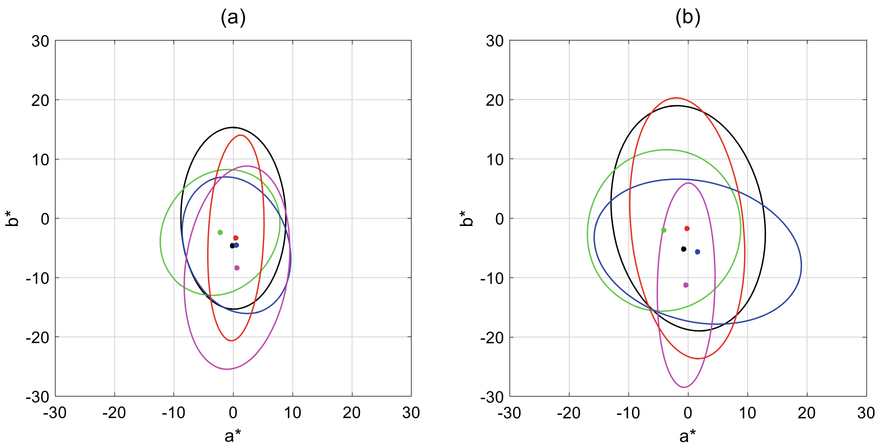

Fig. 1 95% confidence ellipses of the four starting points plotted in a*b* diagram for **a** Experiment 1L and **b** Experiment 1H, respectively. Note that the green, blue, pink, red ellipses represent SP1 ~ SP4, respectively. Black ellipse represents the overall results

Similar to Fig. 1, Fig. 2 plots the 95% ellipses for the 4 SPs for the Experiment 2 results. Figure 3 plots the ellipses for all 10 observers in Experiment 2. Figure 2 showed that all ellipses were very similar in terms of all 3 ellipse parameters, size, shape and orientation, meaning that there was little impact of SPs. It also implies that the results were more consistent in Experiment 2 than those of Experiment 1.

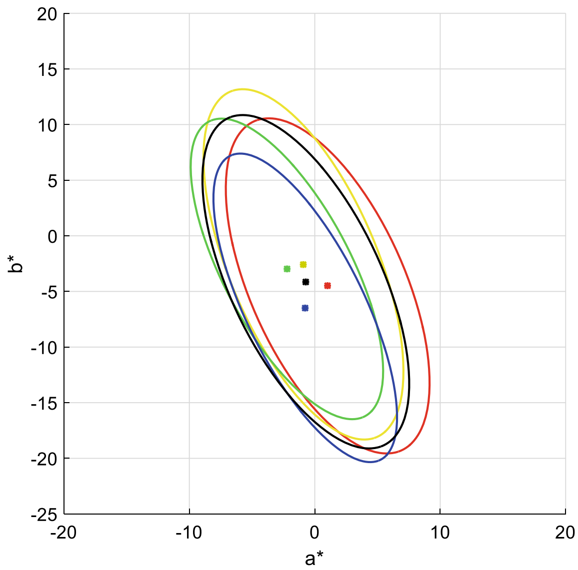

Fig. 2 Experiment 2 ellipses and centers for the 4 starting points plotted in a*b* plane. The red, yellow, green, blue ellipses represent the 4 starting points. Black ellipse represents the overall result

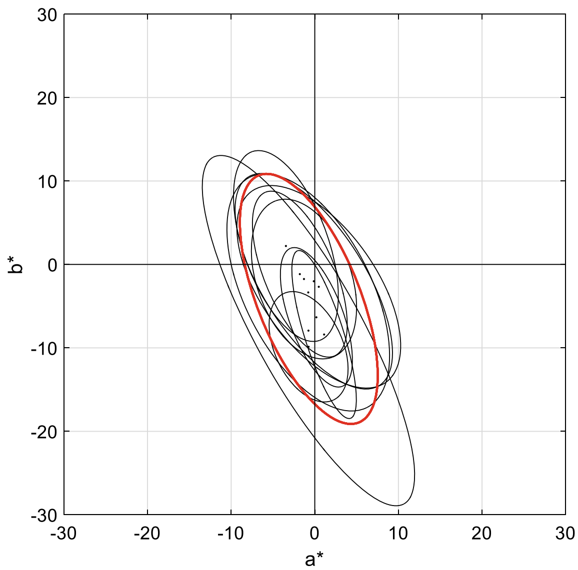

Fig. 3 Experiment 2 ellipses of 10 observers. The red ellipse represents the overall results from all observers

3.3 Neutrality Chromaticity

The goal of the two experiments was to find the neutral chromaticity. For each experiment, all observers' neutrality results were averaged. Figure 4 shows the ellipse and neutral center for 2 displays in u'v' chromaticity diagram, and their neutrality chromaticity are listed in Table 3. It can be seen in Fig. 4 that the color centers are reasonably close and the ellipses from the two experiments are different but they all located along the blackbody locus. This implies that observers are more tolerable in yellow & blue direction. The difference between the two centers was about 0.019 in CIE 1976 u'v' units. This discrepancy is due to the observer metamerism together with different display primary sets as reported by Hu et al. [10].

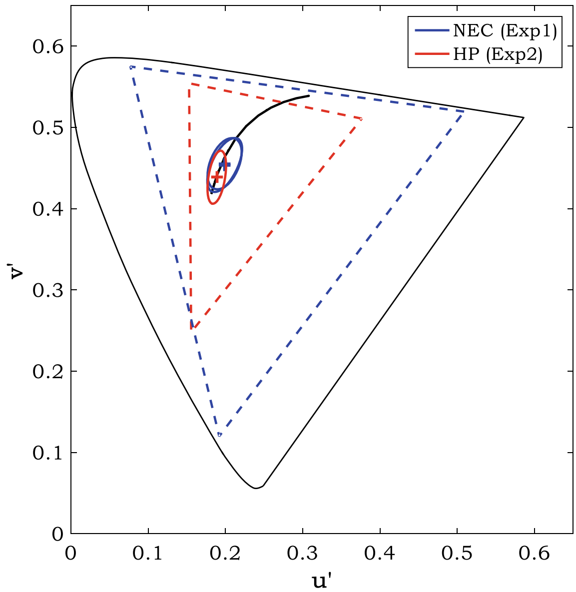

Fig. 4 Ellipses and neutral centers of 2 displays in u'v' plane. Neutral centers were marked as '+'.The areas plotted using dash lines represent the color gamut of 2 displays

Table 3 Neutrality chromaticity in u'v' diagram for Exp 1 and Exp 2, respectively

	u'	v'
Experiment 1L	0.1990	0.4536
Experiment 1H	0.1989	0.4553
Experiment 2	0.1887	0.4386

4 Conclusions

In this paper, experiments were conducted to find neutrality chromaticity from 2 displays. The chromatic difference between the two neutrality points are about 0.019 u'v' units but the ellipses were orientated along the blackbody locus.

It was found that there were differences in observer metamerism between the 2 experiments studied, which were measured to quantify the degree of observer metamerism. The results in terms of intra- and inter-observer variations in terms of MCDM CIEDE2000 units were 3.9 and 5.5 CIEDE2000 units, respectively. It could provide reference for the design of displays.The display with less observer metamerism will make observers' color perception more consistent.

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