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RESEARCH ARTICLE

Strong effect of the simultaneous color contrast in an afterimage

Mitsuo Ikeda | Chanprapha Phuangsuwan

Color Research Center, Rajamangala University of Technology, Thanyaburi, Thailand

Correspondence
Mitsuo Ikeda and Chanprapha Phuangsuwan, Color Research Center, Rajamangala University of Technology, Thanyaburi, Thailand.
Email: mitsuoikeda@rmutt.ac.th and phuangsuwan@rmutt.ac.th

Abstract

The color appearance of the afterimage of the simultaneous color contrast pattern was investigated by the elementary color naming method. The color appearances of the surrounding, an afterimage of the surrounding, and the test patch were measured, and the results were shown on the polar diagram of the opponent colors theory. The colors of both the surrounding and the afterimage of the test patch were the same. The relationship between the afterimage color of the test patch and the afterimage of the surrounding was found to be the same as the relationship between the illumination color and the test patch color in the two-rooms technique, implying that the same visual mechanism works for both situations, that is, eyes chromatically adapt to the afterimage color of the surroundings, and the afterimage color of the test patch is determined with the eyes so adapted.

KEYWORDS

afterimage color, chromatic adaptation, elementary color naming, simultaneous color contrast, two-rooms technique

1 | INTRODUCTION

The well-known simultaneous color contrast phenomenon is explained in text books as follows: if a gray patch is placed at the center of a red piece of paper, it appears as a complementary color, that is, green, and if it is placed on a green paper, the patch appears red.[1] However, in reality, the color of the gray patch does not appear vivid and remains gray,[2] in contrast to the case of the two-rooms technique, despite the fact that the same quantum catch was guaranteed to have occurred over the wide range of the central retina.[3,4] The two-rooms technique involves a subject room and a test room with a separating wall. A subject observes a white board placed in a test room through a window opened on the wall separating the two rooms from the subject room. If the front wall of the subject is white and the subject room is illuminated by a colored light and the test room by a white light, then the retinal image can be made to be the same as a normal pattern of the simultaneous color contrast in color and luminance, yet the color of the window appears to be very vivid.

We experienced to our surprise that the gray patch appeared to be very vivid if we gazed at the pattern for a few seconds and then shifted the eyes to a uniform white field, that is, we observe the afterimage of the simultaneous color contrast pattern. Thus, the simultaneous color contrast becomes very evident in the afterimage, namely, the gray patch now appears to be very vivid. Such a phenomenon was also reported by Shively,[5] who named it a new afterimage. Shively investigated the relationship between the afterimage color of the central gray test patch and the color of the surrounding and found that they were the same. In other words, if the surrounding is red, then the afterimage of the test patch is also red. He explained the phenomenon as being caused by the lateral inhibition. However, his color appearance expression was qualitative, as no quantitative analysis was provided. In the present article, we will measure the color appearance using the elementary color naming method and investigate the visual mechanism of the afterimage.

2 | EXPERIMENT

The pattern for which the color of the afterimage was studied was presented on a Samsung model: UA55H6340TK, LED backlight display 55 in., AC100-240V~50/60 Hz 153 W, Multi System. The central gray test patch was of the size 14×14 cm^2 and luminance of 14.6 cd/m^2, with the chromaticity values of $x = 0.299$ and $y = 0.325$. The display was placed in a test room, and a subject observed it in a subject room through a large window opened at the separating wall between the two rooms; the size of the window was 24 cm high and 38 cm wide, giving an 8° and 13° arc of visual angle, respectively, with a viewing distance of 170 cm. The test size became 4° × 4°. Thirteen colors were employed as the surrounding by adjusting the R, G, and B settings of the monitor; they are shown on the CIE u',v' diagram in Figure 1 by open circles and tentatively numbered 1-13. The color of the white surrounding that surrounds the simultaneous color contrast pattern and that fills the window is the same as that of the test patch, and the luminance was 150 cd/m^2, as shown by the open square in the same figure.

When a subject enters the subject room, which is dimly illuminated, he/she gazed at the center of the test patch with the aid of a fixation point for 15 seconds, and then, the pattern was changed to a uniform white field that is same as the white surrounding of the luminance 150 cd/m^2, on which the subject could see the afterimage of the pattern. He/she judged the color of the afterimage of the test patch by the elementary color naming method, that is, the percentages of the chromaticness, whiteness, and blackness, and similarly, the percentages of the apparent hue(s) of red, yellow, green, and blue were judged. Because the afterimages fade away very quickly, the subject should remember the colors after the afterimage fades away. If necessary, he/she could ask the experimenter to show the original pattern once again to view the afterimage one more time.

We also measured the color of the surroundings and their afterimage color. For the former, the judgment was made for a surrounding area of the test patch but near it when the entire pattern was presented. Another measurement was for the afterimage color of the surroundings. A stimulus of the same size as the test patch was made to be of the same color as the surroundings, and the subject judged its afterimage color after gazing at it for 15 seconds.

Three subjects, CP, MI, and YM, who all had normal color vision and were experienced in psychophysical experimentation, participated in the experiment.

3 | RESULTS

The results are plotted on polar diagrams used in the opponent colors theory, as shown in Figure 2, for a set of raw data. The apparent hue is determined as $R = 50$ and $Y = 50$, and it lies along a line of $\theta = 45°$. The amount of chromaticness is 80 from the origin on the 45° line, zero being at the origin and 100% at the circumference. The amount of red hue is shown on the red axis at 56.6, and that of yellow along the yellow axis at 56.6. θ is called the hue angle. The mean data of the three subjects are shown in Figure 3. Open circles in (A) denote the color appearance of the surrounding itself, and filled circles denote the appearance of the test patch in the afterimage. According to these data, the chromaticness of the afterimage is not small, and the color is quite vivid, in contrast to the case of normal simultaneous color contrast. The apparent hues of the surrounding field and of the afterimage of the test patch are similar as noted by Shively.[5] It is more clearly shown by plotting the hue angle of the afterimage of the test patch against the hue angle of the surrounding $\theta_{(surround)}$, as shown by open circles in Figure 4. The solid line is the 45° line, and the dotted line is the regression line. These two lines almost overlap, implying $\theta_{(testafter)} = \theta_{(surround)}$, that is, both apparent hues are the same.

The solid squares in Figure 3B show the color appearance of the afterimage of the surrounding, and the open squares show the color of the surrounding. The relationship between $\theta_{(surround)}$ and $\theta_{(surroundafterimage)}$ is in good agreement with the previous results.[6] The open triangles in Figure 3C show the color appearance of the afterimage of the surrounding, which were given in Figure 3B by solid

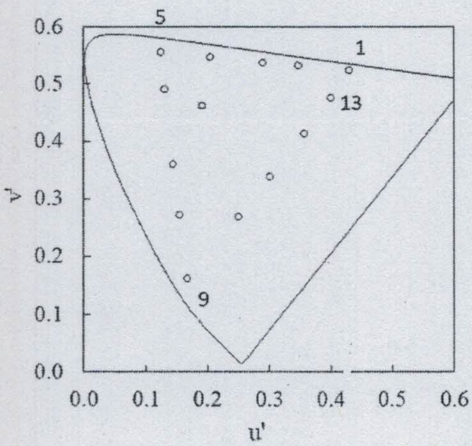

FIGURE 1 Chromaticity values of the stimuli used for the surroundings

Chr	White	Black	R	Y	G	B	θ	R	Y
80	20		50	50			45	56.6	56.6

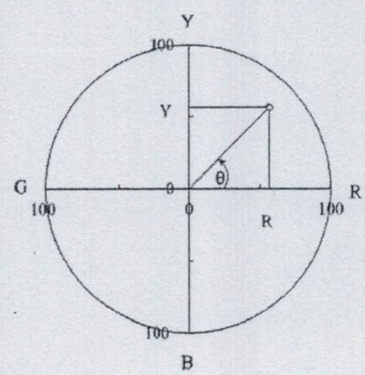

FIGURE 2 Plot of the data points on a polar diagram

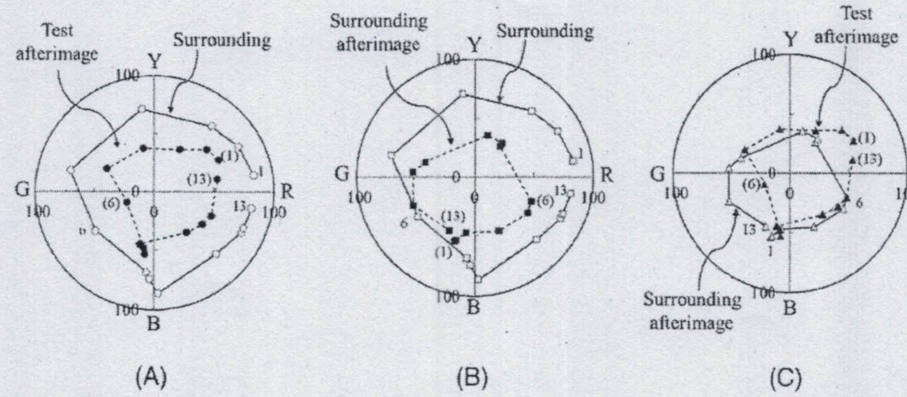

FIGURE 3 Color appearance exhibited on polar diagrams: A, color of the surrounding and the test patch afterimage, B, color of the surrounding and the surrounding afterimage, and C, color of surrounding afterimage and the test patch afterimage. Numbers attached to color patches are shown in brackets for afterimages

squares, and the solid triangles show the afterimage color of the test patch.

4 | DISCUSSION

We confirmed Shively's finding that the simultaneous color contrast is very clearly observed in the afterimage and that the color appearance of the afterimage of the test patch is the same as the color appearance of the surrounding. By measuring the color appearance using the elementary color naming method, quantitative analysis was able to elucidate the relationship between the color appearances of the surrounding and that of the test patch afterimage.

By using the results shown in Figure 3B, we analyzed the relationship between $\theta_{(surround)}$ and $\theta_{(surroundafter)}$. We plotted the data of $\Delta\theta = \theta_{(surroundafter)} - \theta_{(surround)}$ against $\theta_{(surround)}$ using crosses in Figure 5. If $\Delta\theta = 180°$, as shown by the dotted horizontal line, then the two colors are conjugate to opponent with each other in color. The crosses approach the data expressed by the open symbols, which were obtained using the two-rooms technique.[3] The data expressed by open circles and open squares were obtained using LED illumination and fluorescent illumination, respectively. The property shows the state of the visual system that was adapted to the colored illumination of a space. The fact that the crosses came close to the open symbols implies that the color of the afterimage is the result of the chromatic adaptation to illumination, as concluded in the previous article.[3] A similar analysis applies to the results shown in Figure 3C. It is interesting to see the relationship between $\theta_{(testafter)}$ and $\theta_{(surroundafter)}$, where $\theta_{(testafter)}$ is the hue angle of the afterimage of the test patch and $\theta_{(surroundafter)}$ is the hue angle of the afterimage of the surrounding, both being read out from Figure 3C. The difference between the hue angle of the test patch afterimage and the hue angle of the surrounding afterimage, $\Delta\theta$, is plotted against $\theta_{(surroundafter)}$ by filled circles in Figure 5; the filled circles are also close

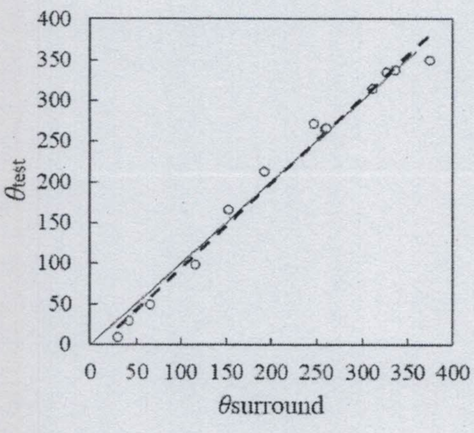

FIGURE 4 Relationship between the hue angle of the afterimage of the test stimulus and that of the surrounding in the simultaneous color contrast pattern. The thin solid line is a 45° line, and the dashed line is the regression line for the data points

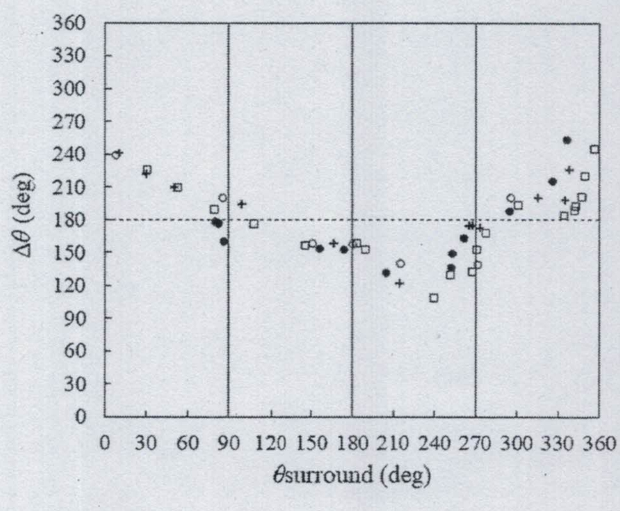

FIGURE 5 Hue difference $\Delta\theta$ plotted for the hue angle of the surrounding. Vertical thin solid lines indicate hue angle at unique hues, and a dotted line is drawn at 180°

to the open symbols. In the two-rooms technique, the subject's eyes adapted to the illumination of the subject room, and the results were interpreted to show the chromatic adaptation to illumination, not to a colored object that the subjects saw. The fact that the afterimage for a simultaneous color contrast pattern showed the same property as the results of the two-rooms technique implies that the same mechanism of color vision is responsible for both experiments, that is, the subject's eyes adapted to the surrounding color in the afterimage regarding the illumination,[7] and the test patch color was determined by the adapted color. This interpretation is different from that of Shively, who explained the phenomenon as being caused by lateral inhibition. In fact, even if a subject looked at a normal simultaneous color contrast pattern that gave the exact same visual stimulation as that of the two-rooms technique, the color of the test patch never appears as vivid as it is in the two-rooms technique; thus, as in the afterimage technique.[4,7] The lateral inhibition cannot explain the difference. We conclude that the afterimage color of the test patch is produced as a result of the chromatic adaptation caused by the afterimage color of the surrounding that functions as the adapting illumination.

ORCID

Mitsuo Ikeda http://orcid.org/0000-0002-2809-9925

Chanprapha Phuangsuwan http://orcid.org/0000-0002-7173-9879

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AUTHORS' BIOGRAPHIES

Mitsuo Ikeda graduated from Osaka University, Japan in applied physics and holds a Ph.D. degree from University of Rochester, USA in physiological optics. He was a professor at Tokyo Institute of Technology, Kyoto University, and Ritsumeikan Univerisity in Japan. He was a visiting professor at Chulalongkorn Univeristy, Thailand, and presently a professor at Color Research Center, Rajamangala University of Technology Thanyaburi, Thailand. He served as President of AIC, Division 1 Director of CIE, and President of Color Science Association of Japan, Japan CIE, receiving the Judd Award from AIC. He works to encourage scientist in ASEAN countries for the color science by helping a tutorial tour of CRC every year, and by serving a coordinator for Asia Color Association which holds a conference every year in a country or district in South Asia. His research interest is the color vision mechanism.

Chanprapha Phuangsuwan received a Ph.D. degree in imaging from Chulalongkorn University in 2012. Her PhD thesis was on the color constancy in photographic picture demonstrated by D-up viewer. After graduating she resumed her work at Rajamangala University of Technology, Thanyaburi. Since 2013 she has served as the Director of Color Research Center CRC. CRC did activities to distribute the color science and human vision knowledge to ASEAN countries by visiting lecture to Vietnam (2015), Myanmar (2016), Indonesia (2017), and Laos (2018) as well as to some domestic universities. She served an organizing committee member of Asia Color Association ACA to organize the international conference in 2013 in Thailand. This year 2018 we invited again to hold ACA conference in Thailand on 5-8 December at Chiangmai.

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29	2017 IEEE World Haptics Conference, WHC 2017	conference and proceedings	0.285	10	0	115	0	163	112	0.00	0.00
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32	International Journal of Automotive Engineering	journal	0.250 Q4	7	26	71	499	51	68	0.69	19.19

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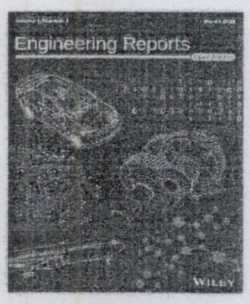

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Quartiles

chart data table

The set of journals have been ranked according to their SJR and divided into four equal groups, four quartiles. Q1 (green) comprises the quarter of the journals with the highest values, Q2 (yellow) the second highest values, Q3 (orange) the third highest values and Q4 (red) the lowest values.

Category	Year	Quartile
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Human Factors and Ergonomics	2009	Q3
Human Factors and Ergonomics	2010	Q2
Human Factors and Ergonomics	2011	Q2
Human Factors and Ergonomics	2012	Q2
Human Factors and Ergonomics	2013	Q2
Human Factors and Ergonomics	2014	Q2
Human Factors and Ergonomics	2015	Q2
Human Factors and Ergonomics	2016	Q3
Human Factors and Ergonomics	2017	Q3
Human Factors and Ergonomics	2018	**Q**3
Human Factors and Ergonomics	2019	Q3
Human Factors and Ergonomics	2020	Q3

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