Effect of display techniques on simultaneous color contrast

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ABSTRACT

In previous studies, simultaneous color contrast (SCC) was investigated using different display techniques, such as colored papers, electronic displays, and the two-rooms technique. The results suggested that the SCC effects varied depending on the techniques used. The strongest effects were obtained using the two-rooms technique, and the weakest when colored papers were used. However, the results of such studies may be affected by stimulus conditions such as size, chromaticity, and luminance. In the present study, we investigated the effects of three different display techniques on SCC, with the stimuli carefully set up, including with or without objects in the experimental space. Four carefully controlled color stimuli were used. The chromaticity, luminance, chroma, and size of these stimuli remained constant, regardless of the display techniques used. The elementary color-naming method was used to assess the color appearance of the SCC. The results suggested that the SCC effect is device-dependent and that any differences in the effect depend on the underlying mechanisms involved. When paper or LCD techniques are used, the SCC effect is caused by contrast induction from the surrounding colors; when the two-rooms technique is employed, the SCC is caused by chromatic adaptation and contrast induction at the same time.

KEYWORDS Simultaneous color contrast, Display techniques, Contrast induction, Chromatic adaptation, Recognized visual space of illumination, Elementary color naming

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1. Introduction

Simultaneous color contrast (SCC), also known as chromatic induction (Krauskopf *et al*., 1986; Lotto and Purves, 2000; Wu and Wardman, 2007), refers to the effect in which an area of color that is surrounded by another color is perceived differently when the surrounding color changes. A classic example of simultaneous contrast is a gray patch placed at the center of a surrounding color. The gray patch appears as either an opponent color (Jameson and Hurvich, 1959; 1961) or a complementary color (Pridmore, 2007; Phuangsuwan and Ikeda, 2017) relative to the surrounding color.

Researchers have explored this phenomenon using various experimental methods to present color stimuli, including paper (Land, 1959), electronic displays (Arend and Reeves, 1986; Webster and Mollon, 1994; Ekroll *et al.*, 2004; Klauke and Wachtler, 2015), and the two-rooms technique (subject and test rooms) (Ikeda *et al*., 1998; Pungrassamee *et al*., 2005; Ikeda *et al*., 2006; Srirat *et al*., 2014; Phuangsuwan and Ikeda, 2017). Other studies compared the SCC effect between different techniques, such as electronic displays and fabrics (Wu *et al*., 2005), and electronic displays and paper (Jinphol *et al*., 2019). An interesting result was found in a study comparing the SCC effect across techniques, including the two-rooms technique (adaptation to the color of illumination), the paper technique (adaptation to the color of the object's surroundings), and the LCD technique (adaptation to the color of a self-luminous display) (Phuangsuwan and Ikeda, 2018; 2019). The results suggest that the differences in SCC effects were device-dependent, with the strongest effect observed using the two-rooms technique, where the observer directly adapts to the illumination according to the recognized visual space of illumination (RVSI) theory (Ikeda, 2004; Pungrassamee *et al*., 2005; Ikeda *et al*., 2006). In contrast, the weakest effect was observed using the paper technique. Similar results have been found by researchers who compared the effects of chromatic adaptation using colored paper and the two-rooms technique (Ikeda *et al*., 2014; Chitapanya *et al*., 2018).

The RVSI theory explains our color appearance when entering an illuminated room, referred to as the subject room. First, the observer recognizes and understands the illumination and then adapts to its color. Following this, the observer accurately perceives the colors in subject room. To prove this understanding, the two-rooms technique is commonly used. The test room refers to the room where the test patch, which is seen through a window from the subject room, is placed. The advantage of this technique is that it allows for independent control of the lighting between the subject room and the test room. This allows for the clear measurement of the color appearance of the test area of which colorimetric values are constant because it is set in the test room, based on the recognition of illumination in the subject room.

In this work, we aim to study the effects of different display techniques on the SCC effect, using three types of display techniques, as mentioned in Phuangsuwan and Ikeda (2018, 2019). The stimulus conditions and environmental settings in the previous work were not exactly consistent each other. In this study, the stimuli were carefully set to be as similar as possible across the three techniques in terms of chromaticity, luminance, chroma, and size.

Additionally, the information about the display technique was hidden from the observer during the presentation. We also investigated the effect of the environment by adding various colored objects to the scene to simulate daily life (complex scene), comparing this with a scene with no objects to explore the effect of SCC. Many researchers have found that if the colors of objects near the test area harmonize with each other, it is possible to create a consistent set of colors within a subject room, thereby revealing a strong SCC effect (Mizokami *et al*., 2000). In contrast, if the colors of the objects are complex, the effect in the test area seems to decrease (Shevell and Wei, 1998).

2. Methodology

2.1. Stimuli

The classical SCC pattern used in our previous study (Mepean *et al.,* 2023) was also used in this experiment, as shown in Figure 1(a). We simulated the SCC pattern by printing on uncoated paper, through presentation on an LCD screen, and by mixing LED light in two rooms. The five surrounding colors used were red, yellow, green, blue, and gray, with a gray surround as the control condition. The chromaticities of the stimuli are shown in Figure 1(b). For all display techniques, the surrounding colors were the same or closely alike, with constant luminance. The chromaticities and luminance were measured using a Konica Minolta Spectroradiometer CS-2000 with CIE1931 color-matching functions for a 2° observer. A gray patch ($x = 0.332$, $y = 0.351$) with dimensions of 4×4 cm^2 was placed at the center of each surrounding area. The chroma of the colors was quantified using CIE C^*_{ab} 3-43, and the luminance was in the range of 18–37 cd/m^2, depending on the color (see Table 1A, Appendix A). The stimulus size was 21×31 cm^2. The distance between the stimulus and the observer was 0.7 m. The visual angle of the stimulus was $17° \times 25°$ for the surround and $3.3° \times 3.3°$ for the gray patch.

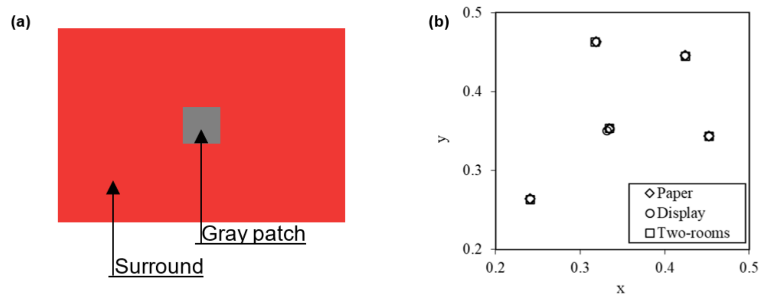

Figure 1. (a) Scheme of SCC stimulus; (b) chromaticities of stimuli among three display techniques plotted in the CIE 1931 chromaticity diagram. (Mepean et al., 2023)

2.2. *Apparatus*

As shown in Figure 2, for all three display techniques, our experiment was conducted in the same room. The room had dimensions of 1.2 m width, 3.0 m length, and 2.0 m height, and included a separating wall so that the single room was divided into a "test room" and a "subject room". The devices were placed in the test room so that the observers were unaware of the apparatus being used, and the stimuli were presented through a window in the wall. This window was designed to slope inward to reduce shadows and make the stimuli appear as if they were part of the wall.

When the paper and LCD techniques were used, the subject room was illuminated by fluorescent lamps in the ceiling; these had an illuminance of approximately 1000 lx measured on the horizontal plane of the observer's eye position, a correlated color temperature (CCT) of 5500K (x = 0.332, y = 0.366), and a color rendering index (CRI) of 80. For the two-rooms technique, a gray uncoated piece of paper, approximately Munsell N6, attached to cardboard was used as the surround stimulation. The center was a 4 × 4 cm^2 window through which the observer viewed the gray patch in the test room. The surrounding color was mixed using LED light in combination with the fluorescent ceiling lamps, which were covered by color filters. This allowed for the simulation of surrounding colors that were the same as the paper stimuli. The two-rooms technique also involved the simulation of the gray patch by placing a whiteboard on the test-room wall opposite the window, with fluorescent lamps mounted parallel to the top and bottom of the window. The luminance on the whiteboard was controlled so that it was equal to that of the gray patch when the paper and LCD techniques were used. In the subject room, black walls were used to reduce the amount of color information resulting from reflected light, and also to define the stimulus presentation area. To this end, the front and side walls were covered with black cardboard (Y = 5.6 cd/m^2, x = 0.322, y = 0.347). When the two-rooms technique was employed, the chromaticities and luminance of the black wall were changed, depending on the subject-room illumination color simulated in the surrounding area, as follows: red (Y = 2.0 cd/m^2, x = 0.494, y = 0.332); yellow (Y = 5.7 cd/m^2, x = 0.429, y = 0.446); green (Y = 4.5 cd/m^2, x = 0.314, y = 0.459); blue (Y = 2.6 cd/m^2, x = 0.225, y = 0.239); and gray (Y = 4.5 cd/m^2, x = 0.327, y = 0.343).

To investigate the effect upon chromatic adaptation of the initial visual information in the space, we asked the observers to judge the color of the stimulus under the conditions of "without objects" and "with objects" such as books, dolls, and artificial flowers; these were placed on a shelf installed on the front wall of the subject room, as shown in Figure 3, and were arranged in such a way as might be witnessed in an everyday indoor setting such as a living room.

2.3. *Observers*

Ten observers participated in the experiment: two males

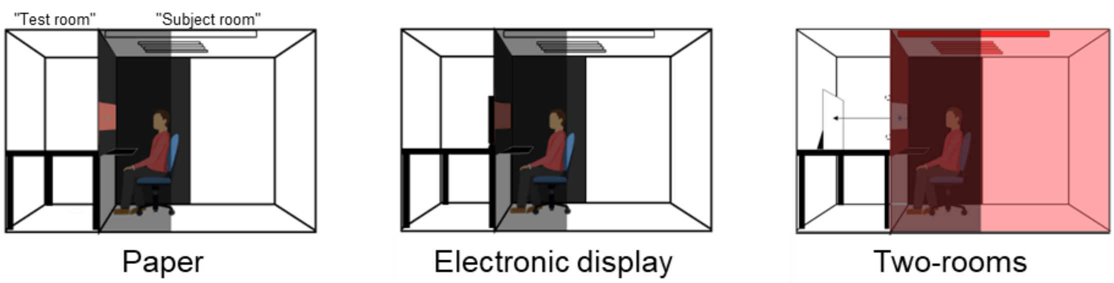

Figure 2. Three display techniques. (Mepean et al., 2023)

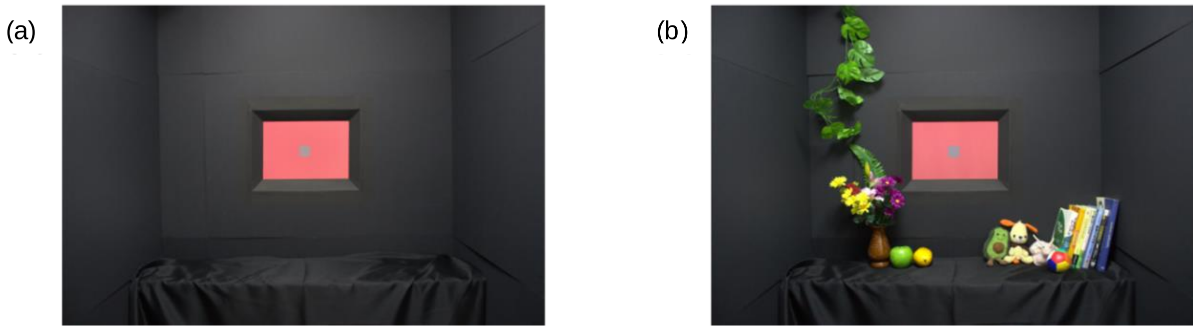

Figure 3. Front view of displayed stimulus in subject room (a) without objects and (b) with objects.

and eight females, ranging in age from 19 to 46 years, with normal color vision as determined by Ishihara testing. Informed consent was given by all participants. Two of the observers were the authors of the present paper, both of whom have many years of experience in psychophysical experiments using the elementary color naming method for assessing color appearance. The eight naive observers were all trained to use this method before commencement of the experiment proper.

2.4. Procedure

Each observer was first asked to look around the room for two minutes, so that they could adapt to the experimental environment. They were then asked to assess the color of gray patches and surrounding areas using the elementary color naming method, giving percentage estimates of chromaticness, whiteness, and blackness, which summed to a total of 100 percent. The apparent hues were then assessed based on the four unique hues of red, yellow, green, and blue, as specified in opponent color theory, again giving a total of 100 percent. The observers were allowed to evaluate apparent hues as one color or as a combination of two colors; however, combinations of opposing colors (red vs. green, yellow vs. blue) were not allowed. We also wanted to check whether the observers would perceive stimuli in different color appearance modes with different display techniques. Thus, we asked the observers to report the mode of appearance of stimuli at the gray patch and the surrounding area using three color appearance modes: “object mode," in which the color appeared as the color object; “self-luminous mode," in which the color appeared as the emitted light from itself or as a light source color; and “unnatural mode," in which the color looked brighter than the object (shiny) but was not the same as the light source color.

After these assessments, the observers were asked to close their eyes for one minute while the experimenter randomly changed the stimulus color within the same technique. Following this, the experimenter changed to another display technique in random order. When all three techniques had been evaluated, this was counted as one round. Each observer performed a total of five rounds.

3. Result and discussion

The results for appearance, such as apparent hue angles and color coordinates, were calculated using equations (see Equations 1–4 in Chitapanya *et al*., 2021) and plotted on polar diagrams that are normally used in studies involving opponent color theory, as shown in Figure 4. The origin of the diagram indicates an absence of chromaticness, and the circumference indicates 100% chromaticness. The R, Y, G, and B axes indicate the unique colors of red, yellow, green, and blue, respectively. The average of the results obtained from the 10 observers was then used to indicate the color appearance of the SCC effect on the gray patch induced by each of the surrounding colors using the three display techniques. The mean values and standard deviations (SDs) for the ten observers are shown in Appendix A (Table 2A). In the absence of objects, for all four colors, the levels of chromaticness perceived in surrounding areas were similar when the paper and LCD techniques were used. However, these values were lower when the two-rooms technique was used. For the four colors, the mean $\pm$ SD values were 59$\pm$3%, 56$\pm$3%, and 26$\pm$2%, for the paper, LCD, and two-rooms techniques, respectively. Moreover, the levels of chromaticness perceived from the gray patches indicated that the SCC effect occurred for all display techniques, with higher levels being obtained when the two-rooms technique was used. In this case, for the four colors, the mean $\pm$ SD values were 19$\pm$5%, 19$\pm$2%, and 50$\pm$4%, using the paper, LCD, and two-rooms techniques, respectively.

It can be seen that, as a result of the SCC effect, the observers’ perception of the color appearance of the gray patch was dependent on the color of the surrounding area. A red surrounding area induced the gray patch to appear green+blue (or cyan); a yellow surrounding area induced the gray patch to appear close to unique blue; a green surrounding area induced the gray patch to appear red+blue (or magenta); and a blue surrounding area induced the gray patch to appear close to unique yellow. Similar results were obtained for all three display techniques when objects were present.

The variation in chromaticness obtained using the different display techniques may now be considered. The RVSI theory suggests that the SCC effect is stronger when an observer is able to adapt to the color of the illumination in the subject room (Ikeda, 2004; Ikeda *et al*., 2006). It may be expected that lower levels of chromaticness will be perceived in surrounding areas when the two-rooms technique is used because the subject room is illuminated by colored light, and chromatic adaptation to illumination occurs by recognition of space and by understanding the illumination based on initial visual information (Mizokami *et al*., 2000). Under such conditions, color constancy is maintained because objects are perceived in their true colors, regardless of any changes in illumination. However, in our experiment, even though chromatic adaptation was not complete (because the color of illumination in the subject room could still be seen, as shown by the chromaticness of the surroundings), a stronger color contrast nevertheless appeared on the aperture at the center; this finding is in line with the results obtained by Phuangsuwan and Ikeda (2018; 2019) in their study of the SCC effect conducted using the two-rooms technique. We anticipated that the effect of chromatic adaptation would be weakest when the paper technique was used. However, we found that the LCD technique produced an SCC effect that was similar to that obtained using paper. Both techniques involved the same stimulus condition and the same viewing condition, and the perception of SCC appeared to have been due to the same mechanism, namely, the chromatic induction of the surrounding areas. These results differ from the findings of Phuangsuwan and Ikeda (2018; 2019), who found that SCC was lower when using the paper technique compared with the LCD technique. However, this difference may be

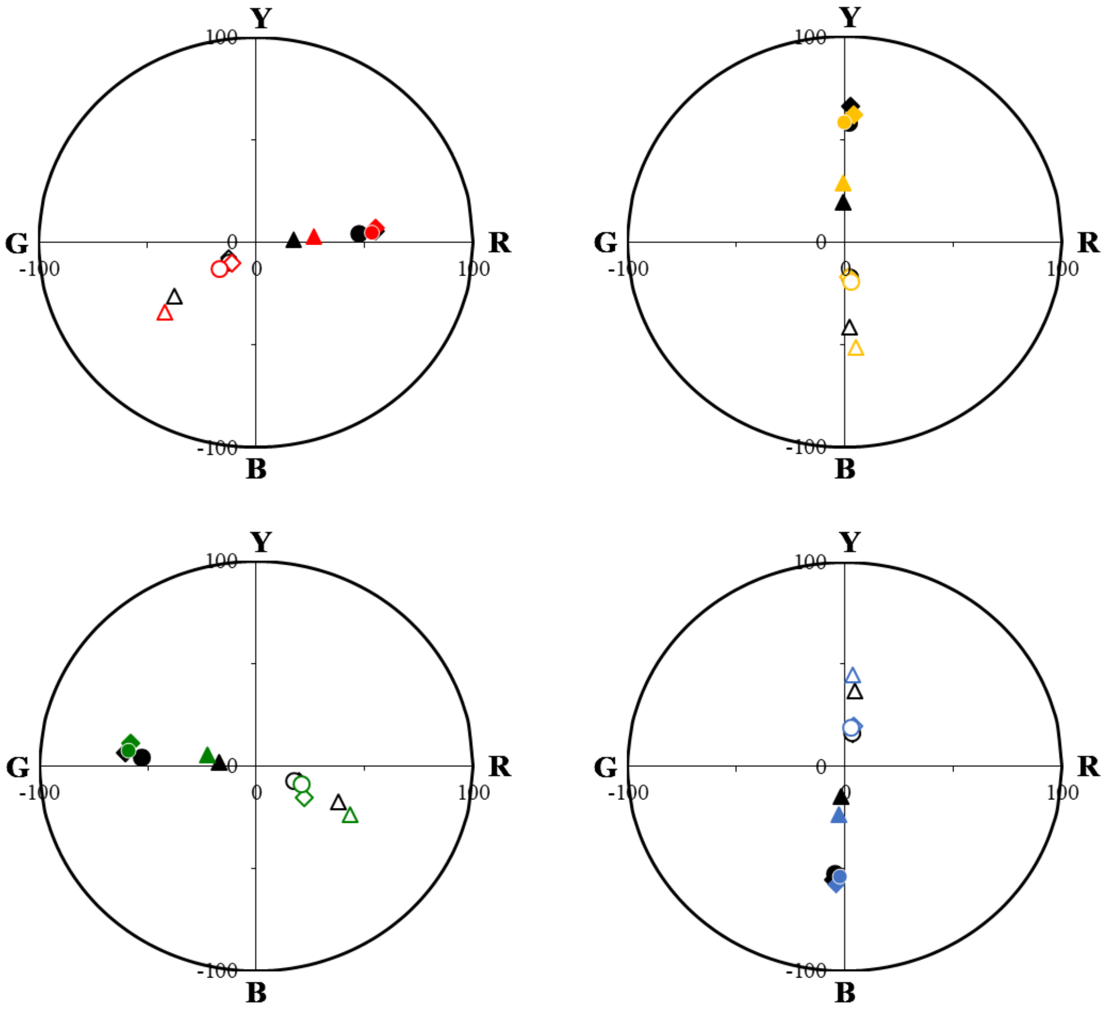

Figure 4. Polar diagram showing an average of 10 observers. The color appearance for the paper (◇), LCD (○), and two-rooms (△) techniques for surrounds (filled symbol) and gray patch (open symbol) in the "without objects" condition indicated by filled color, and in the "with objects" condition by filled black symbols.

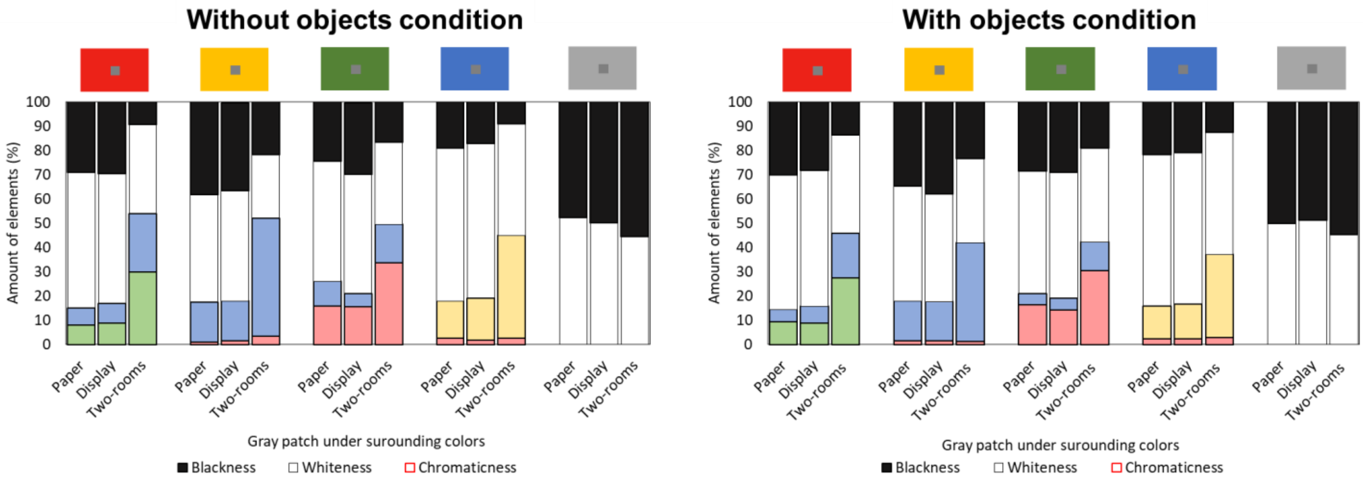

Figure 5. Comparison of mean by elements, chromaticness, whiteness, and blackness of SCC among three display techniques and under "with objects" and "without objects" conditions.

explained by factors such as different experimental conditions and numbers of observers.

In terms of chromaticness, as shown in Figure 4, we found that the results obtained using the paper and LCD techniques differed from those obtained using the two-rooms technique. However, any increase in chroma-ticness must also correspond to a decrease in either whiteness or blackness.

Figure 5 shows the chromaticness (colored bar), whiteness (white bar), and blackness (black bar) elements of the SCC effect. The mean and SD values for the ten observers are provided in Appendix A (see Table 3A). No SCC effect was observed under gray surrounding conditions. A three-way ANOVA with 95% confidence was applied to check the SCC effect on the chromaticness in the four colors' surrounding conditions in the display techniques. The three factors are display techniques, objects (with and without), and colors. The results indicated a significant difference between techniques (F(2, 216) = 116.11, p < .001). Tukey's HSD post hoc analysis revealed that the two-rooms technique was significantly different from both the paper (M = -28.13, SE = 2.12, p < .001) and LCD (M = -27.87, SE = 2.12, p < .001) techniques. However, there was no significant difference in chromaticness between the paper and LCD techniques (p = .99) (see Appendix A, Table 5A, post hoc Comparisons—Technique). There were also no significant differences in chromaticness among the color surround conditions within techniques (F(3, 216) = 1.29, p = .27). The average results of the SCC for the four color surrounds are shown in Figure 6, which were compared between the conditions of with and without objects; the mean and SD values are shown in Appendix A (see Table 4A). It was found that the chromaticness between the conditions of with and without objects showed a slight difference (F(1, 216) = 4.70, p = .03); however, this is due to the differences between the paper and two-rooms techniques, as well as between the LCD and two-rooms techniques.

We assumed that the addition of objects to the subject room would help observers to better perceive the illumination in the space, and then adapt to it. More simply, we hypothesized that the observers would perceive an increase in SCC in the gray patch with objects condition. However, we found that there were no significant differences between the conditions of with and without objects for the paper, LCD, and two-rooms techniques, at p > .05 (see Appendix A, Tables 5A-6A: post hoc Comparisons—Techniques ✻ Objects). Although the two-rooms technique showed a p-value of 0.06, meaning no significant difference between the "with objects" and "without objects" conditions, if we look at Figure 6, the chromaticness appears to be slightly different. In the "with objects" condition, the chromaticness is smaller than the "without objects" condition; this may be due to the surrounding object colors in the complex scene. With many highly saturated objects, the test stimulus was likely judged to have lower chromaticness. This result is consistent with the findings of previous studies, which indicated that chromatic induction from a surrounding area into a central patch decreases when there is an inhomogeneous region outside the surrounding area (Jenness and Shevell, 1995; Shevell and Wei, 1998; Barnes *et al*., 1999). Although the previous results were obtained using an electronic display, our findings showed similar results upon adding colorful objects to the scene illuminated by a single color

Initially, we suspected that the color appearance mode might have been one of the factors affecting the SCC. However, the results indicated that the observers' color

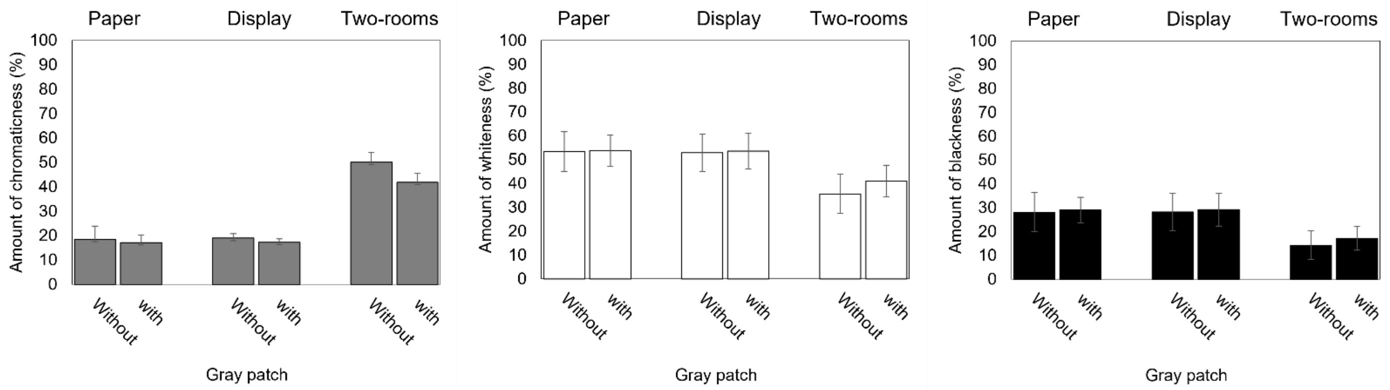

Figure 6. Comparison of elements, chromaticness, whiteness, and blackness of the SCC with and without objects for three display techniques. Error bars denote SD values for ten observers.

appearance mode was the object mode for those techniques. This suggests that the highest chromaticness in the two-rooms technique is not influenced by the color appearance mode.

The results for the SCC hues obtained using the three display techniques were plotted, as shown in Figure 7. The ordinate represents the hue angle of the SCC and the abscissa represents the hue angle of the surrounding area. We also compared the relationship between the SCC hue, which was induced by the surrounding hue in the present study, to the arrangements expected using opponent color theory and complementary color theory (see Figure 10 in Phuangsuwan and Ikeda, 2017). The display techniques chosen to present the stimuli appear to have little influence on the perception of SCC hue, either with or without objects. We compared the SCC hues for each of the four surrounding colors across different display techniques, considering three factors: display technique, objects (with or without), and color. The results showed no significant difference in SCC hues ($F(6, 204) = 0.155$, $p = .988$) (see Table 7A in Appendix A). This finding is similar to the findings of other studies of color appearance conducted using different devices, which found that the hue does not change (Wu, 2005; Billger, 2000; Kutas *et al.*, 2005; Phuangsuwan and Ikeda, 2018; 2019).

Pridmore (2007) suggested that SCC hues on gray patches induced by surrounding colors are understood in terms of complementary color theory. Pridmore also analyzed the SCC data obtained by Luo *et al*. (1995) and Wu and Wardman (2007), and asserted that the SCC can be better interpreted in terms of complementary colors theory. Therefore, in Figure 7, we compare the relationship between the surrounding hue and SCC hue as estimated by both opponent color theory and complementary color theory, based on information from Phuangsuwan and Ikeda (see Figure 10 in Phuangsuwan and Ikeda, 2017). The sum of squared differences (SSD) indicates that the

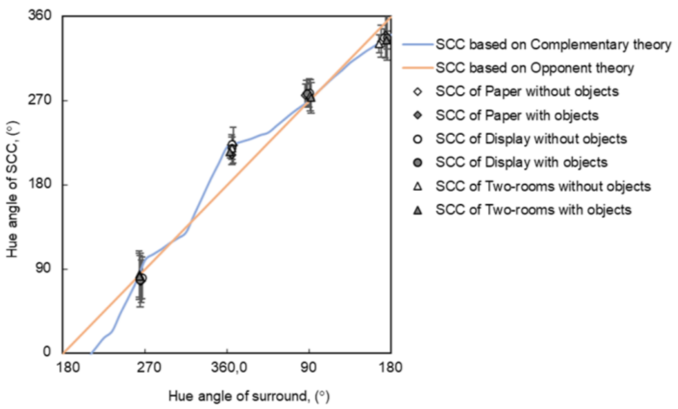

Figure 7. Relationship between surrounding hue and SCC hue (gray patch), compared to opponent color theory and complementary color theory. Error bars denote SD values for ten observers.

SCC hue corresponded more closely with complementary color theory (blue line), which consistently outperformed opponent color theory (orange line) for red (SSD = 206 vs. 7046), green (SSD = 125 vs. 162) and blue surrounds (SSD = 70 vs. 142). In the yellow surround, both models performed almost equally (SSD = 353 vs. 354), supporting supports Pridmore's assertion (Pridmore, 2007). Our results strongly suggest that complementary color theory provides a more accurate prediction of SCC hue shifts compared to opponent color theory.

Furthermore, we found that, with yellow surrounds, observers who perceived the surrounding area as yellow + red perceived the SCC color as blue + red. Similar results have been reported in previous research, including studies on afterimage color (Wilson and Brocklebank, 1995) and chromatic adaptation using the two-rooms technique (Phuangsuwan and Ikeda, 2017). This finding is surprising because, according to both opponent color theory and complementary color theory, yellow + red induction would be expected to cause a blue + green perception.

4. Conclusion

The results of the present study suggest that the SCC effect is device dependent, and that variations in the SCC effect obtained using different display techniques may be caused by two mechanisms:

1. When either the paper or LCD technique is used, the SCC effect seems to be caused by the color of the surrounding area. This may be understood as chromatic induction from the color of the surrounding area, leading to the appearance of contrast color at the center.

2. When the two-rooms technique is used, the SCC effect seems to be caused by chromatic adaptation and contrast induction at the same time.

3. It is suggested that SCC relies on the complexity of the scene in the two-rooms technique, as the various color attributes of objects in the subject room provide visual information to the observer.

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6. Conflict of interest declaration

The authors declare no conflict of interest.

7. Funding source declaration

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Licensing terms

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Appendix A

Color	Device	Y (cd/m^2)	*x*	*y*	C^*_{ab}
Red surround	Paper	23	0.453	0.342	42
	Display	23	0.453	0.343	41
	Two-rooms	22	0.452	0.344	42
Yellow surround	Paper	37	0.424	0.442	42
	Display	37	0.424	0.449	43
	Two-rooms	36	0.424	0.446	43
Green surround	Paper	28	0.315	0.465	38
	Display	26	0.321	0.464	36
	Two-rooms	26	0.318	0.464	35
Blue surround	Paper	18	0.239	0.262	32
	Display	18	0.242	0.263	32
	Two-rooms	18	0.241	0.264	31
Gray surround	Paper	27	0.335	0.353	3
	Display	27	0.335	0.35	5
	Two-rooms	27	0.335	0.354	3
Gray patch	Paper	24	0.332	0.351	5
	Display	24	0.335	0.351	5
	Two-rooms	24	0.333	0.352	5

Table 1A. Luminance values, chromaticities, and chroma CIE C^*_{ab} of colors in the paper and display stimuli.

Mean value of color appearance with SD in polar diagram (without objects condition)					
Technique	**Color**	**Surround**		**Gray patch**	
		x	***y***	***x***	***y***
Paper	Red	55±11	7±15	-11±15	-10±15
	Yellow	4±5	62±9	2±9	-17±9
	Green	-57±8	11±11	21±11	-15±11
	Blue	-4±9	-58±9	4±9	18±9
Display	Red	53±12	5±12	-13±12	-11±12
	Yellow	0±3	59±10	3±10	-18±10
	Green	-59±8	8±12	19±12	-8±12
	Blue	-3±2	-54±14	3±14	19±14
Two-rooms	Red	27±15	3±2	-42±2	-34±2
	Yellow	-1±14	28±19	5±19	-52±19
	Green	-23±1	5±18	43±18	-24±18
	Blue	-3±1	-24±1	4±1	45±1

Mean value of color appearance with SD in polar diagram (with objects condition)					
Technique	**Color**	**Surround**		**Gray patch**	
		x	***y***	***x***	***y***
Paper	Red	55±16	5±13	-12±12	-8±8
	Yellow	3±5	66±16	3±4	-18±9
	Green	-60±13	6±7	20±13	-7±7
	Blue	-5±6	-56±18	4±5	16±10
Display	Red	47±13	5±11	-12±7	-10±11
	Yellow	2±3	58±17	2±4	-18±10
	Green	-53±12	4±8	18±10	-7±6
	Blue	-5±5	-53±20	3±5	16±10
Two-rooms	Red	18±8	1±3	-37±19	-27±23
	Yellow	-1±2	19±8	2±7	-42±13
	Green	-17±6	1±7	38±16	-18±16
	Blue	-2±0	-15±1	5±8	37±16

Table 2A. Mean values of color appearance in polar diagram with SD in Figure 4.

Mean values of amount of elements with SD (without objects condition)								
Technique	**Color**	**Chromatic ness**	**Whiteness**	**Blackness**	**Red**	**Yellow**	**Green**	**Blue**
Paper	Red	15±12	56±16	31±14	0	0	52±25	48±30
	Yellow	18±14	44±19	38±19	6±13	0	0	94±38
	Green	26±14	50±18	25±17	61±26	0	0	39±19
	Blue	18±11	63±18	19±17	14±18	86±17	0	0
	Gray	0	52±15	48±15	0	0	0	0
Display	Red	17±14	53±18	30±16	0	0	52±29	48±26
	Yellow	18±15	45±19	36±20	9±11	0	0	91±29
	Green	21±17	49±16	29±17	74±28	0	0	26±18
	Blue	19±13	64±15	17±14	10±8	90±30	0	0
	Gray	0	50±17	50±17	0	0	0	0
Two-rooms	Red	54±12	37±9	91±1	0	0	56±20	44±20
	Yellow	50±7	26±11	22±15	7±9	0	0	93±8
	Green	52±6	34±7	17±9	68±9	0	0	32±9
	Blue	45±18	46±11	9±7	6±9	94±7	0	0
	Gray	0	45±12	56±12	0	0	0	0

Mean values of amount of elements with SD (with objects condition)								
Technique	**Color**	**Chromatic ness**	**Whiteness**	**Blackness**	**Red**	**Yellow**	**Green**	**Blue**
Paper	Red	14±13	56±22	30±24	0	0	64±38	36±31
	Yellow	18±10	47±19	35±18	9±12	0	0	91±12
	Green	21±14	50±22	29±18	78±15	0	0	22±15
	Blue	16±10	62±16	55±17	14±27	86±26	0	0
	Gray	0	50±20	50±19	0	0	0	0
Display	Red	16±14	56±21	28±21	0	0	57±39	43±33
	Yellow	18±10	44±19	38±16	9±10	0	0	91±10
	Green	19±11	52±22	29±18	74±28	0	0	26±20
	Blue	17±9	62±18	21±17	13±24	87±23	0	0
	Gray	0	51±20	49±18	0	0	0	0
Two-rooms	Red	46±17	40±18	14±9	0	0	60±27	402±7
	Yellow	42±13	35±14	23±13	3±8	0	0	97±8
	Green	42±20	39±24	19±12	72±18	0	0	28±18
	Blue	37±17	50±6	13±13	8±11	92±11	0	0
	Gray	0	46±15	54±16	0	0	0	0

Table 3A. Mean values of amount of elements with SD in Figure 5.

Technique	**Condition**	**Mean values of amount of elements with SD**		
		Chromaticness	**Whiteness**	**Blackness**
Paper	Without objects	19±10	53±11	28±3
	With objects	17±11	54±20	29±19
Display	Without objects	19±12	53±10	28±5
	With objects	17±11	54±20	29±18
Two-rooms	Without objects	50±16	36±17	14±9
	With objects	42±17	41±15	17±13

Table 4A. Mean values of amount of elements with SD in Figure 6.

ANOVA - Chromaticness

	Sum of Squares	df	Mean Square	F	p
Techniques	41834.8	2	20917.4	116.1136	< .001
Objects	847.5	1	847.5	4.7045	0.031
Color	699.7	3	233.2	1.2947	0.277
Techniques ✻ Objects	619.9	2	309.9	1.7204	0.181
Techniques ✻ Color	1361.6	6	226.9	1.2597	0.277
Objects ✻ Color	38.6	3	12.9	0.0714	0.975
Techniques ✻ Objects ✻ Color	99.3	6	16.5	0.0918	0.997
Residuals	38911.5	216	180.1		

Post Hoc Comparisons - Techniques

Comparison							
Techniques		Techniques	Mean Difference	SE	df	t	p_{tukey}
Paper	-	Display	-0.262	2.12	216	-0.124	0.992
	-	Two-rooms	-28.137	2.12	216	-13.259	< .001
Display	-	Two-rooms	-27.875	2.12	216	-13.135	< .001

Note. Comparisons are based on estimated marginal means

Post Hoc Comparisons - Objects

Comparison							
Objects		Objects	Mean Difference	SE	df	t	p_{tukey}
With	-	Without	-3.76	1.73	216	-2.17	0.031

Note. Comparisons are based on estimated marginal means

Post Hoc Comparisons - Color

Comparison							
Color		Color	Mean Difference	SE	df	t	p_{tukey}
R	-	Y	-1.00	2.45	216	-0.408	0.977
	-	G	-3.28	2.45	216	-1.340	0.539
	-	B	1.40	2.45	216	0.571	0.941
Y	-	G	-2.28	2.45	216	-0.932	0.788
	-	B	2.40	2.45	216	0.979	0.761
G	-	B	4.68	2.45	216	1.911	0.226

Note. Comparisons are based on estimated marginal means

Post Hoc Comparisons - Techniques ✻ Objects

Comparison									
Techniques	Objects		Techniques	Objects	Mean Difference	SE	df	t	p_{tukey}
Paper	With	-	Paper	Without	-1.3250	3.00	216	-0.4415	0.998
		-	Display	With	-0.1000	3.00	216	-0.0333	1.000
		-	Display	Without	-1.7500	3.00	216	-0.5831	0.992
		-	Two-rooms	With	-24.6500	3.00	216	-8.2133	< .001
		-	Two-rooms	Without	-32.9500	3.00	216	-10.9789	< .001
	Without	-	Display	With	1.2250	3.00	216	0.4082	0.999
		-	Display	Without	-0.4250	3.00	216	-0.1416	1.000
		-	Two-rooms	With	-23.3250	3.00	216	-7.7719	< .001
		-	Two-rooms	Without	-31.6250	3.00	216	-10.5374	< .001
Display	With	-	Display	Without	-1.6500	3.00	216	-0.5498	0.994
		-	Two-rooms	With	-24.5500	3.00	216	-8.1800	< .001
		-	Two-rooms	Without	-32.8500	3.00	216	-10.9456	< .001
	Without	-	Two-rooms	With	-22.9000	3.00	216	-7.6302	< .001
		-	Two-rooms	Without	-31.2000	3.00	216	-10.3958	< .001
Two-rooms	With	-	Two-rooms	Without	-8.3000	3.00	216	-2.7655	0.067

Note. Comparisons are based on estimated marginal means

Table 5A. Results of the SCC effect in terms of chromaticness using a three-way ANOVA and post hoc test with display techniques, objects (with and without), and colors.

ANOVA - Whiteness

	Sum of Squares	df	Mean Square	F	p
Techniques	12175.9	2	6087.9	20.5056	< .001
Objects	281.7	1	281.7	0.9487	0.331
Color	9920.7	3	3306.9	11.1384	< .001
Techniques ✻ Objects	309.3	2	154.7	0.5209	0.595
Techniques ✻ Color	93.9	6	15.7	0.0527	0.999
Objects ✻ Color	67.4	3	22.5	0.0756	0.973
Techniques ✻ Objects ✻ Color	140.6	6	23.4	0.0789	0.998
Residuals	64128.6	216	296.9		

Post Hoc Comparisons - Technique

Comparison							
Techniques		Techniques	Mean Difference	SE	df	t	p_{tukey}
Paper	-	Display	0.362	2.72	216	0.133	0.990
	-	Two-rooms	15.287	2.72	216	5.611	< .001
Display	-	Two-rooms	14.925	2.72	216	5.478	< .001

Note. Comparisons are based on estimated marginal means

Post Hoc Comparisons - Objects

Comparison							
Objects		Objects	Mean Difference	SE	df	t	p_{tukey}
With	-	Without	2.17	2.22	216	0.974	0.331

Note. Comparisons are based on estimated marginal means

Post Hoc Comparisons - Color

Comparison							
Color		Color	Mean Difference	SE	df	t	p_{tukey}
R	-	Y	9.53	3.15	216	3.03	0.014
	-	G	4.22	3.15	216	1.34	0.538
	-	B	-8.05	3.15	216	-2.56	0.054
Y	-	G	-5.32	3.15	216	-1.69	0.331
	-	B	-17.58	3.15	216	-5.59	< .001
G	-	B	-12.27	3.15	216	-3.90	< .001

Note. Comparisons are based on estimated marginal means

Post Hoc Comparisons - Techniques ✻ Objects

Comparison									
Techniques	Objects		Techniques	Objects	Mean Difference	SE	df	t	p_{tukey}
Paper	With	-	Paper	Without	0.450	3.85	216	0.1168	1.000
		-	Display	With	0.250	3.85	216	0.0649	1.000
		-	Display	Without	0.925	3.85	216	0.2401	1.000
		-	Two-rooms	With	12.825	3.85	216	3.3287	0.013
		-	Two-rooms	Without	18.200	3.85	216	4.7238	< .001
	Without	-	Display	With	-0.200	3.85	216	-0.0519	1.000
		-	Display	Without	0.475	3.85	216	0.1233	1.000
		-	Two-rooms	With	12.375	3.85	216	3.2119	0.019
		-	Two-rooms	Without	17.750	3.85	216	4.6070	< .001
Display	With	-	Display	Without	0.675	3.85	216	0.1752	1.000
		-	Two-rooms	With	12.575	3.85	216	3.2638	0.016
		-	Two-rooms	Without	17.950	3.85	216	4.6589	< .001
	Without	-	Two-rooms	With	11.900	3.85	216	3.0886	0.027
		-	Two-rooms	Without	17.275	3.85	216	4.4837	< .001
Two-rooms	With	-	Two-rooms	Without	5.375	3.85	216	1.3951	0.730

Note. Comparisons are based on estimated marginal means

Table 6A. Results of the SCC effect in terms of whiteness using a three-way ANOVA and post hoc test with display techniques, objects (with and without), and colors.

ANOVA - SCC hue

	Sum of Squares	df	Mean Square	F	p
Techniques	52.9	2	26.4	0.0941	0.910
Objects	172.7	1	172.7	0.6152	0.434
Color	2.10e+6	3	698343.5	2487.4964	< .001
Techniques ✻ Objects	37.4	2	18.7	0.0667	0.936
Techniques ✻ Color	546.0	6	91.0	0.3241	0.924
Objects ✻ Color	1011.3	3	337.1	1.2007	0.311
Techniques✻ Objects ✻ Color	261.0	6	43.5	0.1550	0.988
Residuals	57271.3	204	280.7		

Table 7A. Results of three-way ANOVA for SCC hue with display techniques, objects condition (with and without), and colors.