Simultaneous color contrast mechanism explained by the recognized visual space of illumination

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ABSTRACT

Simultaneous color contrast (SCC) is an apparent color deviation of a stimulus when a contiguous surround is introduced; e.g., an achromatic stimulus placed within a green surround appears reddish. In addition, the magnitude of the SCC varies through the incremental luminance of the stimulus. There are a luminance that causes strongest SCC and another luminance that is a threshold of imperceptible SCC. We have studied underneath mechanism of this phenomenon based on a recognition of illumination concept called recognized visual space of illumination (RVSI). In three experiments, first, it was found that the strong SCC could be evoked once the color inherent in the surround is recognized as an attribute of the illumination by means of change the surround from being two-dimensional to three-dimensional. For the second and third, the luminance at strongest SCC and the threshold of imperceptible SCC were found to be determined in relation to the recognized brightness level of the illumination made on the surround. It suggested that the SCC is well explained by the concept of RVSI.

1. INTRODUCTION

Simultaneous color contrast (SCC) is an apparent color deviation of a stimulus caused by its immediate surround; e.g., an achromatic stimulus placed within a green surround appears reddish. We have studied underneath mechanism of this phenomenon based on a recognition of illumination concept called recognized visual space of illumination (RVSI). In the given example, we hypothesized that the visual system recognizes green color inherent in the surround as it belongs to the illumination. Sequentially, apparent color of the achromatic stimulus is perceived based on this recognized greenish illumination (i.e., greenish RVSI), causing reddish appearance. We conducted three experiments to support this basis. For the first experiment[1], we asked and figured out that why typical SCC demonstration made of color paper (e.g., in a text book) is weak. For the second[2] and the third experiments, it was widely known that the magnitude of the SCC varies through the incremental luminance of the stimulus. There is a luminance that causes strongest SCC and another luminance that is a threshold of imperceptible SCC. We found out that what determines these luminance levels.

2. EXPERIMENT I

It has been well known that the SCC is weak when it is demonstrated on a color paper configuration (e.g., in a text book) but the effect is quite strong if the color illumination is used. We thought that the visual system spontaneously and preferably adapts to an illumination color instead of a surface color and the SCC is derived from this adaptation. Thus if somehow the color of a surface is recognized as an attribute of the illumination, the SCC should be stronger. We thought three-dimensionality would probably be in favor of such recognition. Therefore we made a three-dimensional surround (called observer box) made of gray paper that was big enough to cover an observer (Fig. 1). A constant luminance achromatic stimulus was at the center of the front panel; and the box behaved as its achromatic immediate surround. Replaceable colored surrounds, made of color paper which is different in their sizes (Fig. 1), were successively put in one at a time and treated as experimental conditions; e.g., beginning from the edge of the stimulus (Fig. 1a), crossing the corner (Fig. 1b), and finally covering the whole inner surface of the box (Fig. 1c). If the three-dimensionality

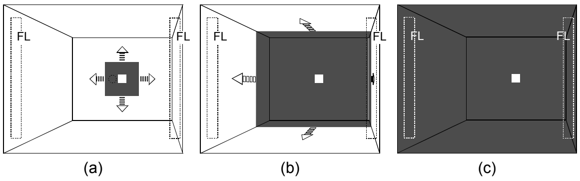

FIG. 1. The observer's view. Stimulus, white squares; Gray areas, the replaceable colored surround; Arrows, enlarge direction of the colored surround; (a), 1st condition; (b), 6th condition; (c), 7th condition; FL, the fluorescent lamps.

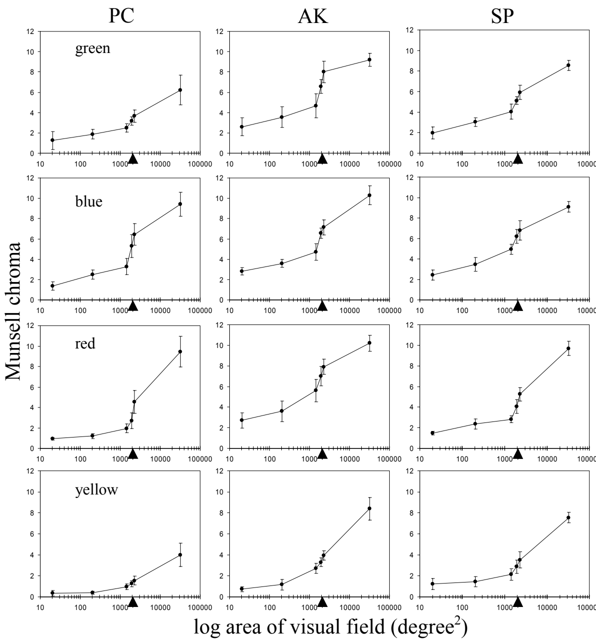

FIG. 2. The results of three observers for four color replaceable surrounds. *(Data from Cunthasaksiri et al.[1])*

significantly evokes the recognition of color illumination, the SCC should be stronger at the corner where the colored surround is changed to be three-dimensional.

The front panel of the observer box was 48°x41° for an observational distance at 80 cm having the stimulus (1°x1°) at the center. Two 4500K fluorescent lamps (FL) were used. The experiment was conducted for seven colored surround sizes. The first condition was no colored surround, as a reference condition. Then the colored surround was introduced, with 4.5°x4.5° in the second, 14°x14° in the third, 42° x 34° in the fourth, 48° x 41° in the fifth, 52° x 44° in the sixth, and the whole inner observer box in the seventh condition. The colors of the colored surround were green, red, blue, and yellow. The stimulus and its immediate area were kept theirs luminance constant at 22 and 27.5 cd/m^2 respectively. Subjects were asked to do color matching between the chromatic appearance of the stimulus and the Munsell chart. Each match was repeated ten times

The results for the reference condition for each observer using the Munsell chroma scale were as followings: 2.1 for PC, 1.3 for AK, and 1.5 for SP. Other results are plotted in Fig. 2 showing the relationship between the area of visual field (abscissa) and the Munsell chroma of the match (ordinate) obtained from three observers. The results of each colored surround are plotted separately; each row shows the results of each color and each column shows the results of each observer. The results of each condition are averaged across 10 repeats. Each average (with its standard deviation) is presented as a filled circle. All filled circles are connected with a line whose slope indicates a degree of change in Munsell chroma due to the change of colored surround size. The first filled circle on the left indicates the result of the second condition and the remaining filled circles indicate the results of the remaining conditions respectively. The arrows pointing at the abscissa divide the results into two groups; the left side shows the results where the surrounds are in a two-dimensional plane, whereas the right side shows the results where the surrounds are three-dimensional.

The results show that from the fourth to the sixth conditions, where the surround was enlarged to cover the front panel of the box at the fifth condition (48°x41°) and then turned to be three-dimensional at the sixth condition (52°x44°), the slopes here change abruptly for all observers and all colored surround. The major question of this experiment was whether the recognition of three-dimensionality could evoke the strong SCC. Because the physical properties of the immediate surround were kept constant along the second through the sixth conditions, the abrupt change in slopes between the fourth and sixth conditions indicates a large change in perceived chromaticness caused by the three-dimensional surround. This implies that when the surround was altered to be three-dimensional (i.e., beginning to enclose the space), the recognition of the illumination became more chromatic, resulting in the stronger SCC.

3. EXPERIMENT II

Another widely known characteristic of the SCC is that its the magnitude varies in relation to the change of the stimulus luminance in a given immediate surround. Generally, in a given chromatic

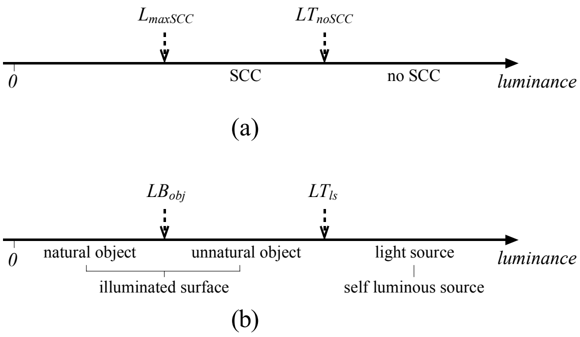

FIG. 3. The existence of the SCC (a) and various modes of appearance (b) in relation to the incremental luminance level of an achromatic stimulus within a chromatic surrounding; Horizontal axes, luminance of the stimulus; SCC, simultaneous color contrast; L_{maxSCC}, luminance at maximum magnitude of the SCC; LT_{noSCC}, imperceptible SCC threshold luminance; LT_{ls}, light source mode threshold luminance; LB_{obj}, object mode border luminance; Other terms, please see in context.

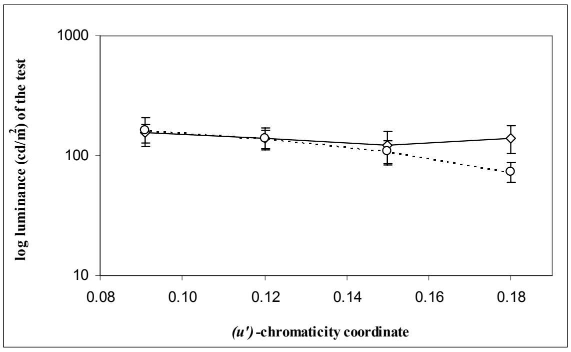

FIG. 4. The results of the observer PC; Open circles connected with dashed line, the results of the imperceptible SCC *(L_{maxSCC})*; Open diamonds connected with solid line, the results light source mode threshold luminance *(L_{ls})*; The conditions order from left to right for the 4th to the 1st condition respectively. *(Data from Cunthasaksiri et al.[2])*

surrounding, there is a luminance level of an achromatic stimulus that causes highest strength of the SCC; defined as L_{maxSCC}. Increasing the luminance from the L_{maxSCC} reduces the magnitude of the SCC and, simultaneously, increases perceived whiteness of the stimulus. When the luminance is adequately increased, the magnitude of the SCC becomes negligible (i.e., the stimulus turns to appear achromatic). We define this imperceptible SCC threshold luminance as the LT_{noSCC}; there is no SCC exhibits hereafter if the luminance is larger than. Fig. 3a shows the existence of the SCC relating to the incremental luminance level of the stimulus, including aforementioned definitions.

It was asked that what determines previous described characteristic. Based on the RVSI, if the SCC is derived from the recognition of illumination, it would be imperceptible when the stimulus appears as self luminous source. This is because the fact that light from an illuminated surface includes attributes of both ambient illumination and surface reflectance; meanwhile, light from a self luminous source is self emitting and not affected by the ambient illumination. And, this fact is possibly adopted into the behavior of the visual system on perceiving outside world.

Previous study[3] showed that not only the magnitude of the SCC but also the mode of appearance changes with the incremental luminance level. There are three modes pf appearance; natural object, light source and unnatural object. The natural and unnatural object mode are the illuminated surface appearance; meanwhile, the light source mode is the self luminous source. We define the light source mode threshold luminance as LT_{ls}. Fig. 3b expresses various phases of the mode of appearance relevant to the incremental luminance level of a stimulus, including aforementioned definitions. Based on the RVSI concept, it could be expected that the LT_{noSCC} would never exceed the LT_{ls}. Using a variable luminance achromatic stimulus within a chromatic surround, various modes of appearance (e.g., illuminated surface and self luminous source) and various magnitude of the SCC were achievable. We used the same gray observer box of the first experiment illuminated by adjustable purity green illumination together with a variable luminance achromatic stimulus in this experiment. Four kind of illumination were used; from green to white. Many object were put in to have the visual system well recognized the color of the illumination. The *(u', v')*-chromaticity coordinates measured at the immediate area of the stimulus for each of four kinds of chromatic illuminations were as the followings; (0.18, 0.50), (0.15, 0.52), (0.12, 0.54) and (0.09, 0.55) for the 1st to the 4th condition respectively. The luminance at this area was kept constant at 20 cd/m^2. The *(u', v')*-chromaticity coordinates of the stimulus were kept constant at (0.38, 0.39) for all conditions. Observer was asked to make two luminance setting tasks; for LT_{noSCC} and $LT_{ls.}$

The luminance setting results of the observers PC is shown in Fig. 4. The abscissa and the ordinate represent the color measured at the immediate area of the stimulus taken in *(u')*-chromaticity coordinate and the luminance of the stimulus taken in log scale respectively. The settings for each condition are averaged across 12 settings. Each average (with its standard deviation) is presented as an open circle connected with the dashed lines for the LT_{noSCC} task. For the LT_{ls} task each average is presented as an open diamond connected with the solid lines. The most left results are derived from the 4th condition and the most right ones are obtained from the 1st condition. The results show that the graph of the LT_{noSCC} remains under the graph of the LT_{ls} for all conditions. This implies that the SCC do not occur in self luminous source even though the purity of the immediate surround was varied about 0.1 unit in the *(u', v')*-chromaticity coordinates. Thus the hypothesis of the study was confirmed that the LT_{noSCC} is determined in relation to the RVSI.

4. EXPERIMENT III

Further effort has been made to explain the L_{maxSCC} based on the recognition of illumination concept. It has been known that typically the SCC is strongest where the simultaneous brightness contrast (SBC) is weakest[4]. For a variable luminance achromatic stimulus within a given chromatic surrounding, the weakest SBC would occur where the brightness of the stimulus and the brightness of its surrounding are equal. Previous study[3] showed that the object luminance border defined as LB_{obj} (Fig. 3b) reflects the recognized brightness level of illumination for a space because a stimulus could no longer be perceived as an reflectance object anymore if its brightness is higher than the brightness of its environment. In other words, it is analogous to the fact that the intensity of any reflection light is never more intense than the incident light receiving from its ambient illumination. Therefore it is natural to expect that the L_{maxSCC} and the LB_{obj} should be coincident. The analogous methodology to the second experiment was employed. The experimental apparatuses and conditions were very same. The tasks in this experiment are to adjust the stimulus luminance for the L_{maxSCC} (i.e., the most chromatic appearance of the stimulus) and for the object luminance border LB_{obj} (i.e., the possible highest luminance for the object mode appearance). Fig. 5 shows the settings result for both tasks of the observer KR. All legends are the same as used in the previous section. It obviously shows that the luminance settings of the both tasks are coincident for all illumination conditions supporting that the L_{maxSCC} is determined in relation to the RVSI.

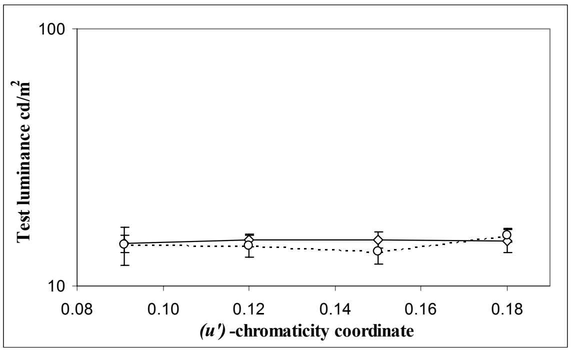

FIG. 5. The results of the observer KR; Open circles connected with dashed line, luminance at maximum magnitude of the SCC settings *(L_{maxSCC})*; Open diamonds connected with solid line, object mode border luminance settings *(LB_{obj})*; The conditions order from left to right for the 4th to the 1st condition respectively.

5. CONCLUSIONS

We proposed and demonstrated that the SCC is derived from an attempt of the visual system to recognize the state of illumination over a space. It was found that the strong SCC could be evoked by three dimensional surround. In addition, the luminance at strongest SCC and the threshold of imperceptible SCC were found to be determined in relation to the brightness level of the RVSI. As several characteristics of the SCC were well explained by the RVSI, it suggested that the RVSI is an underneath mechanism of the SCC.

References

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