OPTICAL REVIEW Vol. 7, No. 4 (2000) 358–363

Color Property of the Recognized Visual Space of Illumination Controlled by Interior Color as the Initial Visual Information

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(Received February 12, 2000; Accepted May 11, 2000)

It was shown that the color property of the recognized visual space of illumination, RVSI was controlled by changing the initial visual information by arranging objects in the room all shifting toward orange direction. We constructed two miniature rooms, D and I, both illuminated by the same daylight type fluorescent lamps but arranged with furniture of different color, those in room I shifting toward color as if they were illuminated by an incandescent lamp. Subjects felt as if room I were illuminated by an incandescent lamp. A test patch was placed midair in each room and its color was judged. When the test patches were placed in room I their colors were all perceived to be shifted toward greenish blue compared to those of test patches placed in room D, in spite of having the same illumination. The results imply that the apparent color of an object is determined not by its chromaticity, but in relation to the color property of the RVSI of the room where the object is observed.

Key words: color, color appearance, color constancy, interior, illumination, recognized visual space of illumination, simultaneous color contrast

1. Introduction

We perceive the color of an object not only by its luminance and chromaticity but in relation to the environment in which it is placed. Arend and Spehar, for example, demonstrated the lightness change of a test patch for different lightness of the surrounding[1] by displaying the stimuli on a CRT. Gilchrist also demonstrated the lightness change in a test patch depending on the illuminance level at the plane where the patch appeared to belong.[2] Their demonstration and/or interpretation of the results were restricted to a two-dimensional (2-D) plane. We believe, however, that our recognition of the outside world is always for three-dimensional (3-D) space as we live in the space and we perceive the color of objects in relation to the 3-D environment. This makes it important to investigate and interpret color perception by using and in reference to a real 3-D space. The concept of recognized visual space of illumination, RVSI was introduced as a tool and a theory to carry out such a 3-D experiment.[3–5]

The RVSI concept is first explained. When a person enters a room, he/she immediately understands how the space is illuminated, brightly or dimly, or, whitely or a little bit reddishly, for example. This situation is expressed as the RVSI of the room was constructed in his/her brain. For this construction the individual observed objects in the room, luminaires and windows, if any, and utilized their appearance as the first information, which is called the initial visual information. It should be emphasized that the RVSI is not the recognition of just 2-D surfaces but the recognition of an entire space including even midair in the room where no object exists. We cannot see light without reflectance from surfaces but we can recognize light filling in a space using the information presented by the surfaces. Once the RVSI is constructed the person perceives the color of any object in the room in relation to the RVSI. In other words, the appearance of the object and the property of the RVSI should coordinate with each other within the person.

The initial visual information can be controlled, for example, by changing the intensity of a light source, from a dim light to a bright light. All the surfaces in the room now appear brighter and the person in the room perceives the room as brightly illuminated. In terms of the RVSI this is expressed as the brightness size of the RVSI being enlarged. As reflected light from an object is increased and as the lightness of that object is determined in relation to the size, the perceived lightness of the object remains the same. This phenomenon is known as lightness constancy. The initial visual information can also be controlled by changing the lightness of all the objects in the room, say, to higher lightness. The observer perceives the room to become brightly illuminated in spite of the light source being the same intensity. The perceived lightness of a test patch of which nominal lightness was kept constant becomes lower.[6,7].

Another method to control the initial visual information is to change the color temperature of the light source by replacing, for example, a daylight lamp with an incandescent lamp. The chromaticities of all the objects shift toward orange. Consequently, the color property of the RVSI shifts toward orange by almost the same amount as the chromaticities. The perception for the objects should not change, remaining white if the objects were white to begin with. This phenomenon is known as color constancy.

In this paper, yet another way to control the initial visual information to change the color property of RVSI

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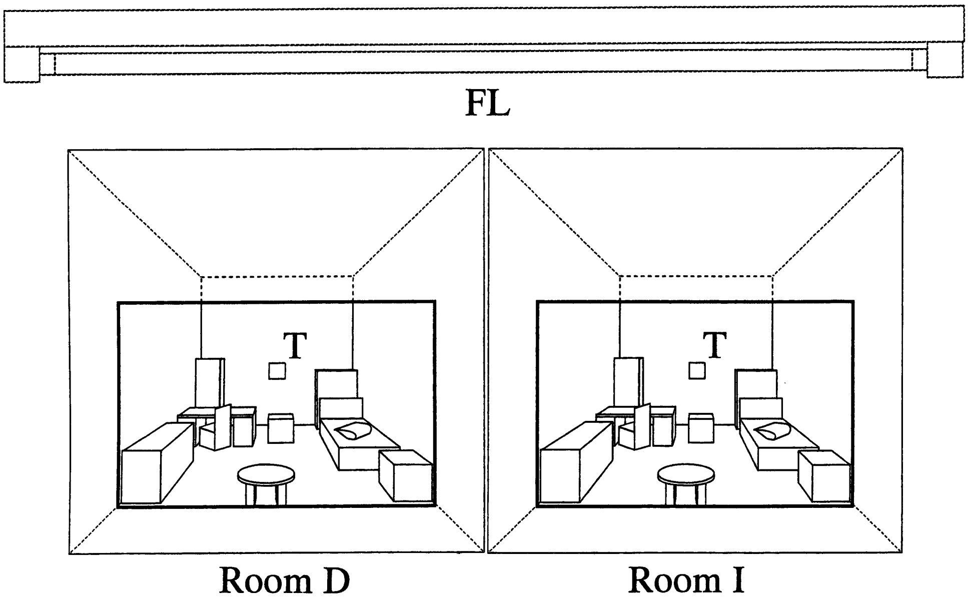

Fig. 1. Front view of the apparatus showing two miniature rooms, D and I. T, test patches; FL, fluorescent lamps of daylight type.

is introduced. The colors of objects in a room were controlled. The same daylight lamps were used for two rooms, but the colors of walls, floors and furniture were different between the rooms. The colors in one room were arbitrarily selected and those in the other room were determined so that they appeared as if the walls, floors and furniture used in the first room were placed under an incandescent lamp, although in fact they were illuminated by the daylight lamp as in the first room. The color property of the observer's RVSI should be changed toward orange similarly as in the room illuminated with the incandescent lamp. If this happens, we can predict that a white test patch placed in the room appears a little greenish blue, as its reflected light does not change because it is still illuminated by the daylight lamp. Another orange test patch should appear white. We will experimentally confirm the prediction in this paper.

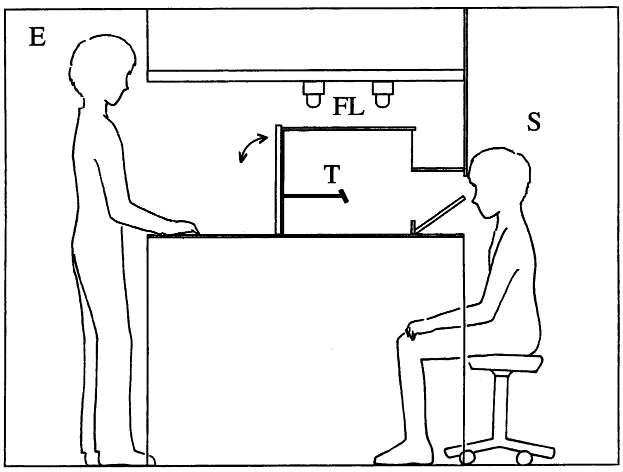

Fig. 2. Side view of the apparatus. T, test patch; FL, fluorescent lamps; S, subject; E, experimenter.

2. Apparatus

Two miniature rooms, D and I, were constructed side by side as shown in Fig. 1. Both rooms had the same dimensions: 38 cm wide, 50 cm deep and 40 cm high and were illuminated by the same fluorescent lamps of daylight type, FL, through opal glass on the ceilings. The illuminance was 230 lx at the floor level of both rooms. Both rooms were arranged with the same furniture but of different colors. The furniture was a desk, a chair, a bed, a blanket on the bed, a bookshelf placed behind the bed, a high chest behind the desk, a low chest placed against the left wall, a table, and two boxes, box 1 at far side and box 2 placed against the right wall. Squares marked by T are test patches for which a subject judged the color. These were pieces of paper 3 × 3 cm in size and attached to the top of 25 cm long poles projecting from the back walls so that the subject could see the patch in midair. Presenting the test patch in this way allowed the subject to judge its color relative to the space of the room and not to the back wall. Large rectangles drawn by thick lines indicate the openings through which the subject observed the inside of the rooms without seeing the ceiling to eliminate it from becoming the initial visual information.

A side view of the apparatus is shown in Fig. 2. The booth of the subject S was kept dark and a hood was attached for each room in front of the subject so that he/she could see only one room at a time thus eliminating any other information than that of room being observed. Only the RVSI for the room can be constructed in this way. The test patch T was tilted upward so that it was directly illuminated by the ceiling light. An experimenter E changed the test patch by opening the back walls as

Table 1. Color specifications of objects in the Munsell Notation.

Room D		Room I	
Items	Munsell Notation	Items	Munsell Notation
Walls	N5	walls	7.5YR5/6
Floor	N5	Floor	7.5YR5/6
Desk (upper)	3.2B7/6	Desk (upper)	9.2Y7/3
Desk (side)	5.3PB3/7	Desk (side)	3.5YR4/2
Chair (side)	9.9P4/10	Chair (side)	5.1R5/9
Chair (upper)	2.6RP5/14	Chair (upper)	3.1R5/14
Bed (upper)	7.6RP7/7	Bed (upper)	5.5R7/10
Bed (back)	8.8RP6/13	Bed (back)	6.0R6/14
Bed (side)	3.9R6/9	Bed (side)	7.8R6/14
Bookshelf (upper)	1.0PB6/8	Bookshelf (upper)	3.6Y6/1
Bookshelf (side)	5.4B5/10	Bookshelf (side)	4.4B5/5
High Chest (side)	5.2Y4/0.2	High Chest (side)	3.9YR5/4
High Chest (side)	2.7P4/3	High Chest (side)	3.9YR5/4
Low Chest (upper)	0.7G6/11	Low Chest (upper)	5.9GY6/6
Low Chest (side)	6.2B4/7	Low Chest (side)	5.2Y4/0.2
Table	2.4Y7/9	Table	4.0YR7/13
Box 1 (side)	8.9Y9/8	Box 1 (side)	8.0YR8/12
Box 1 (upper)	4.9Y9/8	Box 1 (upper)	8.0YR8/12
Box 2	5.6G4/4	Box 2	5.0Y5/3
Blanket	1.0BG5/9	Blanket	5.6G4/4

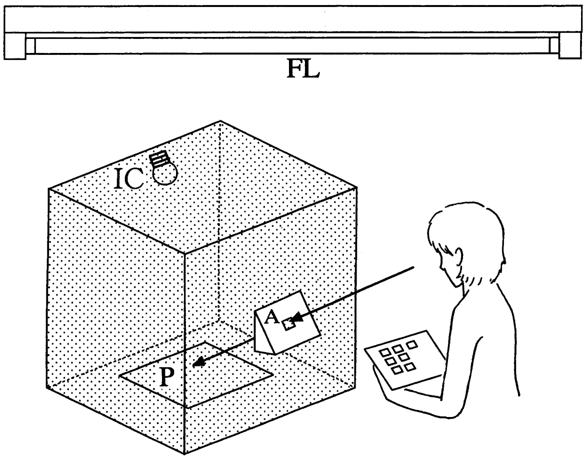

Fig. 3. Scheme of the color matching to obtain the color of objects in room I. FL, fluorescent lamps of daylight type; IC, incandescent lamp; P, colored paper; A, square aperture.

shown by an arrow.

The colors of furniture in room D were of various colors and are shown in Table 1. The neutral color of N5 was used for walls and floors.

Now the objects in room I should have the chromatic specifications produced when illuminated by an incandescent lamp although, in fact, they are illuminated by the daylight-type lamp. To obtain the colors to satisfy this condition we used a subjective method instead of a physical method. It is possible to use a physical method to obtain the colors, but we preferred a subjective method because it was more direct and simple. The color could be subjectively obtained for the upper surface of the low chest, for example, by observing that part in room D in which only the surface is illuminated by the incandescent lamp, all other objects being illuminated by the daylight type lamp. This cannot be easily achieved experimentally, however, so we employed another equivalent method. As shown in Fig. 3, a color paper P of a certain surface of an object in room D was placed in a closed box illuminated inside by an incandescent lamp IC. An observer sees the paper through a small square 1×1 cm aperture A made on the tilted surface of a hood projecting from the box. The observer's room is illuminated by a daylight type lamp FL. When she looked at the paper in this way it appeared to her as if it were attached to the aperture and she perceived the paper as one object in the room where she was and not in the room inside the box. The condition mentioned above was satisfied. The observer then matched the observed color with a reference color chart placed in her hands. This color matching was repeated for all other surfaces of objects in room D. These charts were used for the surfaces of objects in room I, and are shown in Table 1. They are all oriented toward orange compared to the objects in room D. The color shifts of corresponding furniture from room D to I are shown by solid arrows in Fig. 4, tails showing the colors in room D and heads those in room I. All the arrows tend toward orange.

Nineteen colors were employed for the test patches varying from 7.5YR8/3.5 to 10BG8/1.0 via N8 with 0.25 Munsell Chroma steps as shown by open squares of which chromaticities measured by a colorimeter for D65 in the *xy* diagram of Fig. 5. The Munsell Value N8 was chosen because it is bright and was easier for subjects to judge the color. The Munsell Hue 7.5YR was chosen because it was the hue that matched an achromatic N5 paper in the experiment done with the apparatus shown

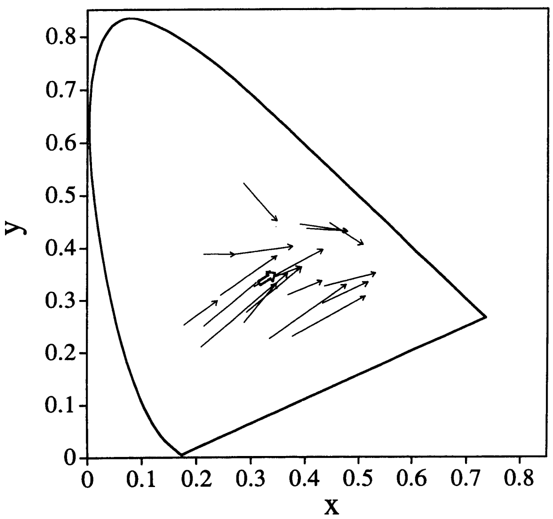

Fig. 4. The color shifts of furniture from room D to I shown by solid arrows. An open arrow indicates the shift of neutral white perception in the experimental results.

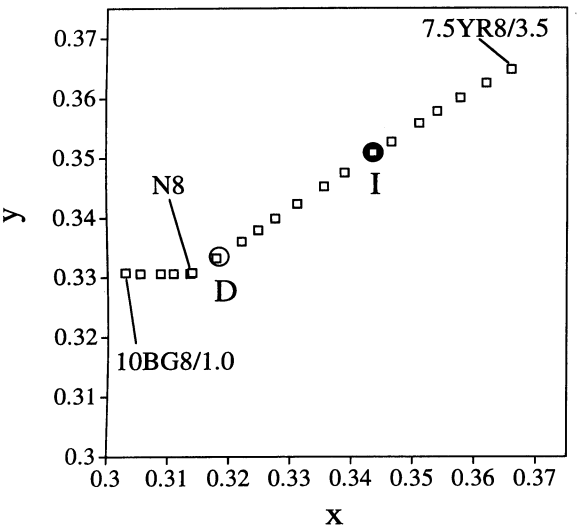

Fig. 5. Chromaticity coordinates of test patches shown by small open squares. Large circles indicate neutral white perceptions. Open circle, room D; A filled circle, room I.

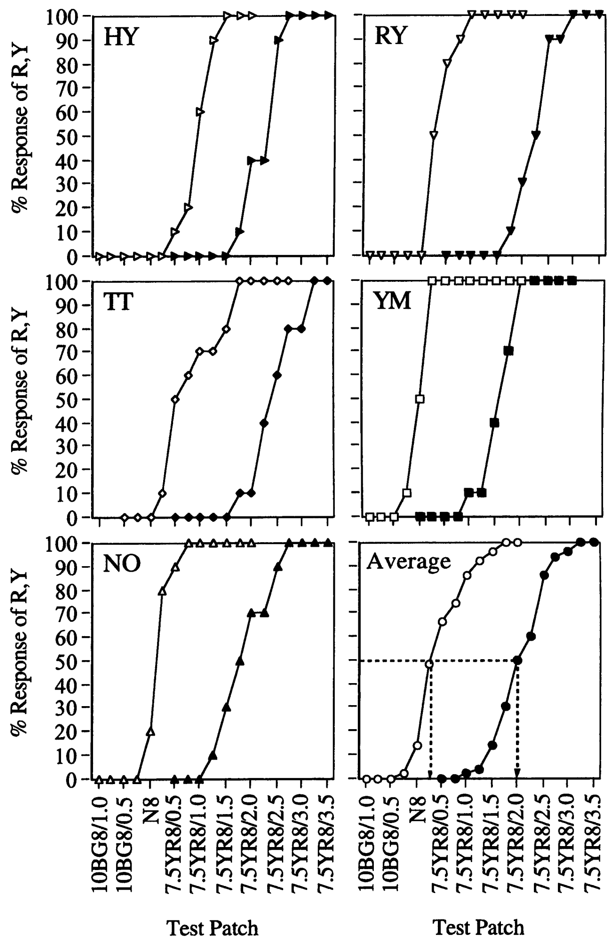

Fig. 6. The result from five subjects, HY, TT, NO, RY, YM and their average. The percentage of response of R, or Y, or R and Y. Open symbols, room D; filled symbols, room I.

in Fig. 3, and it was anticipated that a white perception in room I would be obtained for a test patch of this hue. The Munsell Hue 10BG was chosen because it is opposite Munsell Hue 7.5YR on the NCS hue ring, and the former is the opponent color to the latter. Large circles labeled D and I will be explained later.

3. Procedure

A subject was asked to view one of the two rooms by approaching the observing hood and to look around inside the room during his/her task. The subject's task was to judge the color of test patches presented one after another and to report the color(s) perceived by one or two hues from four unique hues, Red, Yellow, Green and Blue. No other response such as white was allowed. An experimenter changed the test patches in a random order. When about 15 test patches in order to cover the white perception had been presented, the subject switched to another room and the judgment was repeated. Two repetitions of this experiment completed one session and five sessions were conducted for each subject.

Five subjects, HY (21 years old, male), TT (21, male), NO (22, male), RY (23, female) and YM (24, female) participated in the experiment. All had normal color vision. Subjects HY and TT had not experienced this kind of experiment before and did not know its purpose. The other experienced subjects knew the purpose.

4. Results and Discussion

The subjects could see the difference in colors of objects between the two rooms, D and I, but at the same time they felt the rooms were differently illuminated, one by a white light and the other by an orange light, in spite of the fact that both rooms were illuminated by the same white light. In other words, the color property of the recognized visual space of illumination in the subject's

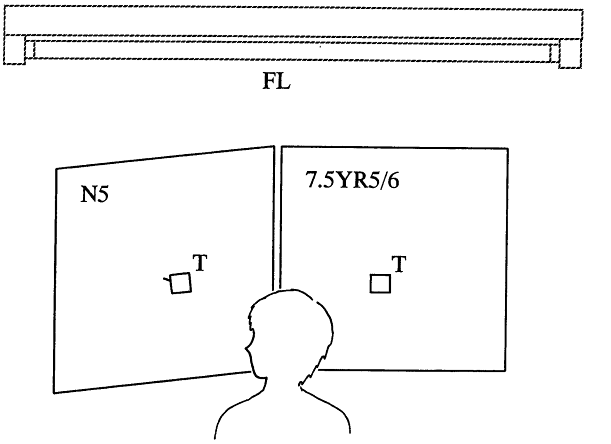

Fig. 7. Scheme of the supplemental experiment. T, test patches; FL, fluorescent lamps of daylight type.

brain for room I shifted toward orange.

The results are shown in Fig. 6 for the two rooms and for all the subjects. The mean among the subjects is also shown. The abscissa indicates the Munsell Hue of the test patch starting from 10BG to 7.5YR and the ordinate the percentage of responding R, or Y, or R and Y calculated from ten responses at each test patch. The rest indicates the percentage of responding G, or B, or G and B. The zero percentage of the ordinate indicates that a subject always responded by G and/or B, and the one hundred percentage by R and/or Y. The fifty percentage then indicates that the responses scattered among yellowish red and greenish blue with equal weight and implies the subject perceived the test patch to be neutral white.

The open symbols indicate the responses for room D. The color perception for the test patch gradually changed from greenish blue to yellowish red in accordance with its nominal color. By reading out the nominal color of the test patch corresponding to the 50% response, we can see that all the subjects perceived neutral white for N8 or near that color. The filled symbols indicate responses for room I. All the curves shifted toward an orange direction. The subjects now perceive greenish blue for the N8 patch and neutral white for a patch shifted toward orange, namely, the patch with Munsell Chroma of about 2.0. The right lower section shows the average of the five subjects. The shift of the test patch for neutral white is about 1.72 in Chroma, from 0.28 in room D to 2.0 in room I. The chromaticities corresponding to these two patches are shown by large circles, D and I in Fig. 5. The subjects perceived the orange patch I as neutral white in room I arranged with furniture all shifted toward the orange direction, though the ceiling light was unchanged from room D.

The shift in the perception of neutral white is shown by an open arrow in Fig. 4, superposed on the arrows indicating the color shifts of furniture. The shift of the neutral white is along the same direction as the furniture change and we can conclude that the subjects' RVSIs were changed toward orange direction simply by changing the color of furniture. It is noted here that the amount of the shift is less than the color shift of the furniture. This would imply that the change in the color property of the RVSI is less than the shift of the color of the initial visual information. This may agree with our experience of incomplete color constancy. We can still feel a bit reddish in a room illuminated by an incandescent lamp. But the difference of length between the open arrow and solid arrows is too large to be explained by the incompleteness obtained for different illuminating lights.[8,9] We must conclude then that the color shift of the RVSI induced by changing the color of the interior is less than that induced by changing the color of illumination. The reason for the difference may be that the subjects could recognize the color of furniture itself and only a small part of the color change was attributed to the illumination color in contrast to the lightness case where a large amount of the change in furniture was attributed to the illumination.[7]

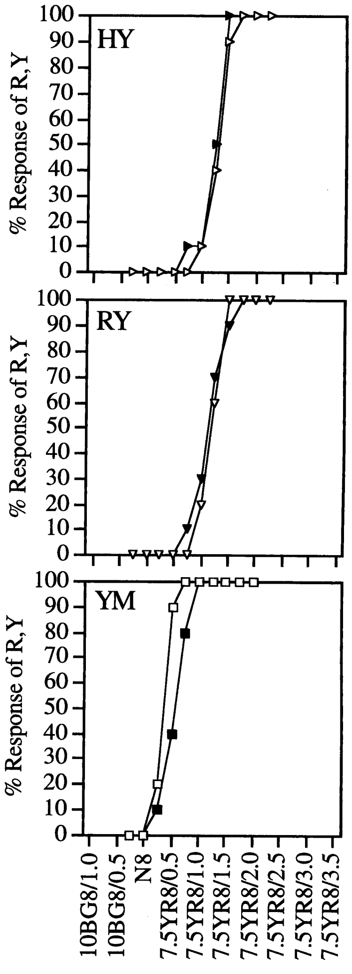

Fig. 8. The results of supplemental experiment from three subjects, HY, RY and YM. The percentage of response of R, or Y, or R and Y. Open symbols, background N5; filled symbols, background 7.5YR5/6.

We emphasized that the test patch was located midair in the room so that the subject could judge its appearance in relation to the color of the 3-dimensional space. It might be pointed out, however, that the test patches were nevertheless surrounded by different colors of back walls in the retinal image and the colors of the patches were differently perceived by the effect of simultaneous color contrast. To see whether the explanation was valid we conducted a supplemental experiment.

Figure 7 is the arrangement for the experiment. Two color boards were vertically placed side by side in a room illuminated by fluorescent lamps of daylight type. The boards were respectively made the same as room D and I both in color and size of the back walls, namely N5 and 7.5YR5/6, and 38 cm wide × 40 cm high. Test patches were attached to the top of poles projecting 10 cm from the boards toward the subject so that he/she could see the patch in midair. The experimental procedure was the same as the main experiment but only three subjects; HY, RY and YM participated in this experiment. The results are shown in Fig. 8. The open symbols indicate the responses for the background of N5 and the filled for the background of 7.5YR5/6. It is quite clear that the curves almost coincide with each other in all subjects. The mere effect of simultaneous color contrast on the retina is thus eliminated in interpreting the main experimental results.

The difference in the experimental setup between the present main experiment and the supplemental experiment can be considered in relation to the recognized visual space of illumination. In the main experiment the subject saw a test patch located in 3-D space, D and I. In other words, the subject judged its color appearance in relation to the RVSI of D and I, respectively. In the supplemental experiment the subject's RVSI was for the room where he/she stayed and for daylight type lamps. The two color boards were then mere plane objects as elements of the room and he/she judged the color of the test patch in relation to the RVSI and not in relation to the boards. It is no wonder that there was no difference in the judgment between the two boards.

Most investigators use plane stimuli in investigating color appearance. It is our opinion that 3-D space must be used instead because that is the dimension in which we live. It must be quickly pointed out here, however, that plane stimuli can induce a 3-D space and a subject can perceive color as such.[10]

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