Color Appearance of a Patch Explained by RVSI for the Conditions of Various Colors of Room Illumination and of Various Luminance Levels of the Patch

Mitsuo Ikeda, Yoko Mizokami, Sachi Nakane and Hiroyuki Shinoda

Department of Photonics, Faculty of Science and Engineering, Ritsumeikan University, Nojihigashi, Kasatsu, Shiga 525-8577, Japan

(Received September 25, 2001; Accepted February 12, 2002)

Whenever we enter a space illuminated differently from a previous space whether in color or in illuminance, we can quickly adapt to the new atmosphere and can again perceive white for the originally white object; this is known as color constancy. This phenomenon is explained by rotation of the recognition axis of the recognized visual space of illumination (RVSI) toward the illumination color. The explanation then predicts that the color appearance of a test patch changes radically toward the opposite direction from the color of illumination when the physical property of the test patch is kept unchanged at a neutral white. This prediction was confirmed by Experiment 1, where eight different colors of illumination were employed. The test patch appeared very vivid in color and shifted toward the opposite direction from the color of the illumination. In RVSI theory the light source color mode is explained by the release of the test patch from the restriction of RVSI. The release can be achieved by increasing the luminance of the test patch and the color appearance of the patch should then return to its own color as it is no longer controlled by RVSI. In Experiment 2 these predictions were investigated by increasing the luminance of the test patch to a much higher level than that of the objects in the lit room fixed at an illuminance of about 100 lx. The color appearance of the test patch indeed became the light source color and returned to the original neutral white. Emphasis was given in the course of the experiments that the subjects were observing the test patch presented in a real 3D space where the subjects also stayed inside so that they could properly construct RVSI for the space.

Key words: color appearance, color appearance mode, object color, light source color, recognized visual space of illumination, illumination, elementary color naming method

1. Introduction

Color appearance of an object in an environment was successfully explained by the concept of the recognized visual space of illumination (RVSI), the scheme of which is illustrated in Fig. 1. The concept was developed based on the strong notion that the recognition of space comes first and then the perception of color. RVSI is the understanding of a space constructed in one’s brain about its state of illumination when a person looks at or comes into the space. The brightness perception of the space is expressed by the radius of a sphere or circle for simplicity that represents RVSI, R. The color property of RVSI is expressed by the recognition axis, RX, rotated from the fundamental axis, FX toward the illumination axis, IX. The FX is the intrinsic color recognition axis and can be defined as the color recognition axis when a person stays in complete darkness without any illumination. It is assumed to be not too far from the RX for daylight illumination. It is our experience that we quickly adapt to a new illumination and do not feel the space colored so much as the psychophysical property of the illumination. This indicates that the axis RX comes quite close to the axis IX and the angle between these two axes $\theta_1$ is small. An achromatic object in the space reflects the same light as the illumination and is shown by a point on the IX such as $W_1$ in the scheme. Its apparent color is determined by the angle $\theta_1$ and the apparent lightness by the relative distance of the point from the center to the radius of R. We specify red by a clockwise direction from FX and green by a anticlockwise direction. In Fig. 1 the illumination is reddish and the color appearance of the patch $W_1$ should be slightly red as shown by a small angle $\theta_1$. The degree of color constancy can be defined by the angle $\theta_1$ and is 100% if $\theta_1$ is zero. In the study of the color constancy some researchers determined the chromaticity coordinates of a test patch that gave achromatic perception under illumination of various colors. We refer only to these papers among the many reports on color constancy because the authors used a real 3D space to present the test patch and subjects were completely inside the space to simulate an actual living situation. Their results could be directly interpreted by our concept of RVSI. The achromatic perception was apparently obtained when the test patch located on the axis RX.

If we can present a subject in a space with an achromatic...
patch illuminated at a moderate level by daylight only without being affected by the illumination of the space, its position in the scheme should remain on the daylight illumination axis or on the fundamental axis FX as indicated by $W_F$, regardless of the color of the illumination of the space. Its apparent color is determined by the angle $\theta_F$, opposite $\theta_1$ and should be vivid green. If the illumination of the space is changed to another color, the RX rotates toward the new illumination axis and the appearance of the achromatic patch should change accordingly. In Experiment 1 this prediction will be investigated by employing various colors for the space illumination.

Let us now increase the daylight illumination for the achromatic patch alone without changing the space illumination and see how its appearance changes. Evans noted that when the luminance of a test patch made of monochromatic light was increased without changing the luminance of its surroundings the appearance went through a change from an object color with grey to fluorescent light, and finally to luminous color.\textsuperscript{9} In our concept of RVSI the position of $W_F$ shifts toward the edge of R with increase of the luminance, which results in a higher lightness of the patch.\textsuperscript{9} The patch appearance remains the object color as long as the position stays within RVSI or inside the circle R and its color appearance is determined in relation to RVSI.

If we continue to increase the illumination on the patch its position eventually reaches the border of R, beyond which the patch presents an appearance unnatural as an object in the space any more, being too bright or fluorescent.\textsuperscript{10-13} With a further increase of the illumination of the patch the patch finally appears to radiate light, which is nothing but the light source color. The patch no longer belongs to RVSI and is, so to speak, released from restriction of RVSI. Its color appearance cannot be decided in relation to RVSI any more, nor can the color belong to any object. Without having the recognition axis RX to which the subject can refer, he/she can only refer to the remaining fundamental axis FX. The color appearance should return to its own color determined in relation to the FX, namely the color of the light itself perceived in the dark. The patch should appear achromatic in the present example. In Experiment 2 this prediction of returning to its own color will be investigated by increasing the illumination on the achromatic patch.

2. Experimental Apparatus

It is essential in the present experiment to provide a subject with a situation where he/she can construct RVSI for a space illuminated with a light source of a certain color and can observe a test patch illuminated by itself without being affected by the main illumination. The apparatus was composed of a subject’s room and a test room equipped with ceiling lights $FL_1$, $FL_2$ and $FL_3$ as shown in Fig. 2(a). Each luminair was composed of four fluorescent lamps of 40W producing white, red, green and yellow light, respectively, and an experimenter could manually adjust their intensities independently so that various colors of illumination were obtained. The subject’s room simulated a normal room with a width of 150 cm, depth of 250 cm and height of 210 cm, and with decorations of objects such as books of various colors, a doll, artificial red, yellow, green and blue flowers, a bag, a laptop PC, a printed picture and a Noh mask of more than N9.5 as seen in Fig. 2(b). All inside surfaces were covered with wallpaper of a fairly neutral color of about N9 except for the floor.

A test patch T was presented to the subject by a slide projector P, color compensating filters CF, neutral density filters ND, and a rear screen S placed in the test room and through a circular aperture A of 6 cm diameter on the wall in front of the subject. It became a size with 2° of arc when viewed at a 170 cm distance. The subject perceived the aperture as if a circular patch were pasted on the wall although, in fact, the rear screen was placed 25 cm away from the wall. In a supplementary experiment where the color appearance of the ceiling light was measured the rear screen was replaced by a gray plate but tilted at 45° so that the light from $FL_3$ was reflected toward the subject.

3. Color Appearance Measurement

The elementary color naming method was used to assess the color appearance of the test patch with a slight difference for Experiments 1 and 2, which will be explained in respective procedures.

4. Experiment 1

4.1 Experimental conditions

Illuminations of eight different colors $I_1$ through $I_8$ were
and YM (female, 25), who were all color normal confirmed by Ishihara Test. They used both eyes for observing the test patch.

4.2 Procedure

When an illumination was chosen from among eight different illuminations for the subject's room, the subject adapted to the room for four minutes before judging the color appearance of the test patch. It was confirmed that an adaptation of four minutes was quite long enough to arrive at a stable judgement of this color. During the adaptation period the subject was asked not to fix his/her eyes on the test patch only, but to look around the room so that the adaptation was made for the entire room. The subject's task was to first assess the amount of chromaticness in the test patch by percentage and then the relative amounts of hues by allocating one hundred points to one or two hues out of four unique hues, red, yellow, green and blue. He/she did not have to pay attention to the amounts of whiteness and blackness. During the assessment of the color appearance the subject was also asked not to fix his/her eyes on the test patch but to look around the room from time to time. When the subject reported the color appearance for the test patch, the next illumination was selected and the adaptation began again for the color judgment. The selection of the illumination was in a random order. Within one session all eight illuminations were successively investigated; ten such sessions were carried out for each subject.

The color appearance of the eight different illuminations used for the subject's room was also measured in a supplementary experiment. The illumination coming from the ceiling light of the test room, namely FL3 in Fig. 2, was colorimetrically equated to one of the illuminations of the subject's room. The rear screen was replaced by a gray plate of about N5 and it was tilted at 45° so that the light coming from FL3 was reflected toward the subject's room through the aperture of the test patch. The luminance viewed by the subject varied depending on the respective illuminations but was about 18 cd/m². The luminance in the subject's room was turned off and the subject judged the color appearance of the light exhibited on the gray plate by the elementary color naming method. Ten determinations were carried out for each illumination.

4.3 Results

When a circular chart of N9.5 of 3 cm diameter was placed in the subject's room at the position of the test patch it appeared to all the subjects almost white for any room illumination with the chromaticness of only a few percent if any, and with a similar hue as the illumination employed. In other words, the white chart remained almost white whatever the color of the illumination was, confirming a high degree of color constancy. This implies that the angle θ1 in Fig. 1 is very small. At the same time the subjects still could recognize the color of the illumination to show that there was a residual of imperfect color constancy.

The results of the color assessment are shown by the NCS polar diagram in Fig. 4 for the subject HY and for two room illuminations, I₁ and I₃ as examples. The hue judgement is prepared for the subject's room with the ceiling light FL₂ distributed evenly in the u'v' diagram as shown by filled circles in Fig. 3. Their chromaticity coordinates are shown in Table 1. The ceiling light FL₁ was not used in the present experiment. The illuminance in the room was set at about 100 lx as seen in the second column of Table 1 when measured on a table 70 cm above the floor. With these illuminations the luminance of the wall near the test patch was around 13 cd/m² as shown in the last column of Table 1, and the luminance of the Noh mask which had the highest lightness in the room was a little higher than 17 cd/m² with some variations depending on the illuminations. The luminance of the test patch was fixed at 10.9 cd/m², slightly lower than the Noh mask and the wall so that it did not appear too grayish to make judgement of the color difficult or too bright to make the appearance luminous. The color was fixed to a neutral color of x = 0.338 and y = 0.344. The chromaticity point of the test patch is shown by the open circle in Fig. 3. The test patch was presented continuously for assessment.

Five subjects participated in the experiment, SN (female, 22 years old), MM (male, 22), HY (male, 22), HH (male, 23) and YM (female, 25), who were all color normal confirmed by Ishihara Test. They used both eyes for observing the test patch.

4.2 Procedure

When an illumination was chosen from among eight different illuminations for the subject's room, the subject adapted to the room for four minutes before judging the color appearance of the test patch. It was confirmed that an adaptation of four minutes was quite long enough to arrive at a stable judgement of this color. During the adaptation period the subject was asked not to fix his/her eyes on the test patch only, but to look around the room so that the adaptation was made for the entire room. The subject's task was to first assess the amount of chromaticness in the test patch by percentage and then the relative amounts of hues by allocating one hundred points to one or two hues out of four unique hues, red, yellow, green and blue. He/she did not have to pay attention to the amounts of whiteness and blackness. During the assessment of the color appearance the subject was also asked not to fix his/her eyes on the test patch but to look around the room from time to time. When the subject reported the color appearance for the test patch, the next illumination was selected and the adaptation began again for the color judgment. The selection of the illumination was in a random order. Within one session all eight illuminations were successively investigated; ten such sessions were carried out for each subject.

The color appearance of the eight different illuminations used for the subject's room was also measured in a supplementary experiment. The illumination coming from the ceiling light of the test room, namely FL₃ in Fig. 2, was colorimetrically equated to one of the illuminations of the subject's room. The rear screen was replaced by a gray plate of about N5 and it was tilted at 45° so that the light coming from FL₃ was reflected toward the subject's room through the aperture of the test patch. The luminance viewed by the subject varied depending on the respective illuminations but was about 18 cd/m². The luminance in the subject's room was turned off and the subject judged the color appearance of the light exhibited on the gray plate by the elementary color naming method. Ten determinations were carried out for each illumination.

4.3 Results

When a circular chart of N9.5 of 3 cm diameter was placed in the subject's room at the position of the test patch it appeared to all the subjects almost white for any room illumination with the chromaticness of only a few percent if any, and with a similar hue as the illumination employed. In other words, the white chart remained almost white whatever the color of the illumination was, confirming a high degree of color constancy. This implies that the angle θ₁ in Fig. 1 is very small. At the same time the subjects still could recognize the color of the illumination to show that there was a residual of imperfect color constancy.

The results of the color assessment are shown by the NCS polar diagram in Fig. 4 for the subject HY and for two room illuminations, I₁ and I₃ as examples. The hue judgement is prepared for the subject's room with the ceiling light FL₂ distributed evenly in the u'v' diagram as shown by filled circles in Fig. 3. Their chromaticity coordinates are shown in Table 1. The ceiling light FL₁ was not used in the present experiment. The illuminance in the room was set at about 100 lx as seen in the second column of Table 1 when measured on a table 70 cm above the floor. With these illuminations the luminance of the wall near the test patch was around 13 cd/m² as shown in the last column of Table 1, and the luminance of the Noh mask which had the highest lightness in the room was a little higher than 17 cd/m² with some variations depending on the illuminations. The luminance of the test patch was fixed at 10.9 cd/m², slightly lower than the Noh mask and the wall so that it did not appear too grayish to make judgement of the color difficult or too bright to make the appearance luminous. The color was fixed to a neutral color of x = 0.338 and y = 0.344. The chromaticity point of the test patch is shown by the open circle in Fig. 3. The test patch was presented continuously for assessment.

Five subjects participated in the experiment, SN (female, 22 years old), MM (male, 22), HY (male, 22), HH (male, 23) and YM (female, 25), who were all color normal confirmed by Ishihara Test. They used both eyes for observing the test patch.

4.2 Procedure

When an illumination was chosen from among eight different illuminations for the subject's room, the subject adapted to the room for four minutes before judging the color appearance of the test patch. It was confirmed that an adaptation of four minutes was quite long enough to arrive at a stable judgement of this color. During the adaptation period the subject was asked not to fix his/her eyes on the test patch only, but to look around the room so that the adaptation was made for the entire room. The subject's task was to first assess the amount of chromaticness in the test patch by percentage and then the relative amounts of hues by allocating one hundred points to one or two hues out of four unique hues, red, yellow, green and blue. He/she did not have to pay attention to the amounts of whiteness and blackness. During the assessment of the color appearance the subject was also asked not to fix his/her eyes on the test patch but to look around the room from time to time. When the subject reported the color appearance for the test patch, the next illumination was selected and the adaptation began again for the color judgment. The selection of the illumination was in a random order. Within one session all eight illuminations were successively investigated; ten such sessions were carried out for each subject.

The color appearance of the eight different illuminations used for the subject's room was also measured in a supplementary experiment. The illumination coming from the ceiling light of the test room, namely FL₃ in Fig. 2, was colorimetrically equated to one of the illuminations of the subject's room. The rear screen was replaced by a gray plate of about N5 and it was tilted at 45° so that the light coming from FL₃ was reflected toward the subject's room through the aperture of the test patch. The luminance viewed by the subject varied depending on the respective illuminations but was about 18 cd/m². The luminance in the subject's room was turned off and the subject judged the color appearance of the light exhibited on the gray plate by the elementary color naming method. Ten determinations were carried out for each illumination.
plotted along the arc of the polar diagram and the chromaticness along the radius. The outermost circle corresponds to 100% of chromaticness and the center 0%. Filled circles show the color appearance of the illuminations themselves. There are ten data points after ten experimental sessions but some of them overlapped one another, which should indicate a good accuracy of the elementary color naming method. The illumination $I_1$ appeared almost pure red and $I_3$ almost pure green to this subject. The chromaticness was very large for both illuminations indicating a very saturated color. The open square at the center shows the color appearance of the test patch itself as judged without the room illumination. The open circles show the color appearance of the test patch seen in the lit subject’s room. The color appearance changed greatly to become a very saturated color as seen by the position along the radius which shifted considerably from the center. The direction of the change was roughly opposite from the original color of the room illumination. It should be noted that the original color of the illumination corresponds to the illumination axis IX in Fig. 1, and then the color appearance of the test patch corresponds to the fundamental recognition axis FX perceived based on the recognition axis RX having the angle $\theta_F$.

From other illuminations and other subjects similar data were found about the variation among sessions and the average was calculated. The results are shown in Fig. 5 with different symbols for subjects and with filled symbols for the illumination and open symbols for the test patch seen in the lit subject’s room. The large filled circle and the large open circle in each figure show the averages of five subjects for the room illumination and for the test patch, respectively. Thick lines connecting the large filled circle, the open square at the center and the large open circle are drawn to indicate the amounts of chromaticness of the illumination and the test patch, and the shift direction of the test patch appearance relative to the illumination appearance.

### 4.4 Discussion

It was shown that the color appearance of a test patch changed radically when the color of the illumination of the subject’s room was changed, in spite of the fact that the physical property of the test patch was kept unchanged at a neutral color. When the color of the room illumination was changed from one to another the subjects noticed the change and felt the new color of the illumination at that moment, but they very quickly felt that the room was illuminated by a relatively neutral light. In parallel they perceived the change of the color of the test patch. These phenomena took place almost instantaneously and no practical time was needed for the subjects to adapt to new room illumination.

The direction of the change of the color appearance of the test patch is roughly opposite from the color appearance of the room illumination itself when the two color appearances are plotted in the polar diagram of the opponent colors theory or of the NCS system shown in Fig. 5. For examples, the red room illumination $I_1$ changed the test stimulus to a
greenish color and the green room illumination I3 changed it to a reddish color. But the opponency is not exact in the diagram, as seen by the angle between the two lines connecting the room illumination color to the original test patch color and to the test patch color under the room illumination deviating from 180°. Under the red illumination I1 the test patch did not appear its opposite color, green, but rather blue with a little bit of green. Under the almost unique blue illumination I5 and I6, the test patch did not appear unique yellow but yellow-red. The angle of almost 180° was only found for green I3 and bluish green I4, and possibly for reddish blue which is between I6 and I1. The opposite colors in RVSI seems different from the Hering’s opponent colors.

The amounts of chromaticness of the room illumination itself were relatively similar, around 70 or 80%, but the amount of chromaticness of the test patch varied greatly depending on the illumination. It was large under the red illumination I1 and I5, but small under the reddish yellow illumination I2 and the green illumination I3, for instance. The ratio of the chromaticness of the test stimulus to that of the illumination was calculated. It took large values of nearly 1.0 for the illuminations that had red and/or blue color, namely I1, I5, I6, I7 and I8, but small values for the illumination that had yellow and/or green color, namely I2, I3 and I4. Here again, there seems to exist a different function of the room illumination to the test patch from what might be expected from the opponent colors theory. No good correlation was found between the angle defined above and the ratio.

5. Experiment 2

5.1 Experimental conditions

In Experiment 2 the luminance of the test patch had to be changed from a low level to a high level so that the appearance of the test patch changed from the object color to the light source color. Neutral density filters ND and color compensation filters CF placed in front of the projector P in Fig. 2 were properly selected to obtain eleven levels of luminance for the test patch, 3, 6, 10, 14, 25, 36, 55, 100, 139, 273 and 538 cd/m². The chromaticity coordinates were x = 0.342 and y = 0.362, which were slightly different from Experiment 1. Three illuminations of the subject’s room I1, I3 and I4 were employed with the illuminance kept at about 100lx as before.

Three subjects participated in the experiment, TM (male, 22 years old), YT (Thai female, 23) and YM (female, 25). The last subject participated in Experiment 1 also. They were all color normals and used both eyes.

5.2 Procedure

The subjects were first asked to estimate the amount of chromaticness, blackness and whiteness in the test patch by allocating one hundred points to them and then the amounts of hues by allocating another one hundred points to one or two hues from among four unique hues, red, yellow, green and blue. At the same time they were asked to judge whether the test patch appeared natural as an object placed in the subject’s room or unnatural because for example, it appeared too bright as an object in the room or appeared dazzling or luminous. The subjects were asked not to fix their eyes on the test patch but to look around the room at the assessment as practiced in Experiment 1.

The room illumination and the test patch luminance were randomly chosen for the assessment and all three illuminations and the eleven luminance levels were investigated in one session. Ten such sessions were conducted.

5.3 Results

When the luminance of the test patch was set at the lowest level of 3 cd/m² the test patch appeared just as a colored object placed on the wall of the subject’s room. With increase in the luminance the test patch still remained as an object but its lightness increased. With further increase the test patch began to appear unnatural as an object placed in the room, which implies that the position of the patch moved out beyond the border of RVSI. Figure 6 shows the percentage of the unnatural appearance at ten observations at each test patch luminance. Results from the three subjects are plotted separately. Different symbols represent the results from different subjects.

![Figure 6: Percentage of unnatural appearance of the test patch plotted for the luminance of the patch judged under three different illuminations.](image)

Fig. 6. Percentage of unnatural appearance of the test patch plotted for the luminance of the patch judged under three different illuminations. O, I1; △, I3; □, I6. The vertical lines give the border luminance, solid line for I1, dashed for I3 and dotted for I6. Each figure corresponds to a subject.
room illuminations, circles for $I_1$, triangles for $I_3$ and squares for $I_6$. The percent curves of subjects YM and YT showed rapid increase at low luminance while subject TM showed a gradual and uneven increase at high luminance.

The border luminance between the natural and unnatural appearance can be obtained by the luminances at 50% of the unnatural appearance and they are shown by vertical lines, a solid line for $I_1$, a dashed line for $I_3$ and a dotted line for $I_6$. For subject TM, smooth curves were drawn for the data points by visual inspection to obtain the border luminance. The border luminance was very low in subjects YM and YT. The test stimulus sometimes appeared unnatural to them even at the low luminance of 6 cd/m² because the patch appeared too vivid in color to be an object. A similar result was found by Thangthangtum et al. in a different experiment in which the border luminance was obtained for 39 colored patches, where the border luminance was very low for patches of vivid color, particularly red. It must be pointed out that there were objects in the room of which luminance was much higher than 6 cd/m² such as the Noh mask of about 17 cd/m² and walls of 13 cd/m² and yet the test stimulus of 6 cd/m² appeared unnatural sometimes. The border luminance of subject TM was very high compared to the previous subjects. It was possible that the test patch did not work as a mere test probe but as one of the objects already existing in the room, or that he had a different perception for the test patch which caused the border to be at a high luminance as will be pointed out later.

The results of the color appearance are shown for respective subjects by the polar diagrams in Fig. 7. A filled circle in each figure shows the color appearance of the room illumination of $I_1$, a filled triangle, $I_3$, and a filled square, $I_6$. Open circles show the color appearance of the test patch of difference luminance seen in the subject’s room illuminated by $I_1$, open triangles, $I_3$ and open squares, $I_6$. Each point is the average of ten determinations. The end point most remote from the center was from the lowest luminance 3 cd/m² of the test patch. As the luminance was increased the point gradually shifted toward the center of the diagram, excepting subject TM, to indicate the decrease in chromaticness of the test patch. The appearance of the test patch became a neutral white at the highest luminance 538 cd/m².

A short line segment drawn intersecting each color appearance curve indicates the border between natural and unnatural appearance of the test patch as obtained from Fig. 6. The hue appearance of the test patch took a rather complex and curved course of change, particularly when the test patch was at low luminance. In the case of green room illumination $I_3$ the test patch appeared more bluish at very low luminance than at high luminance, particularly to subject TM.

To see the change in amounts of chromaticness, blackness and whiteness for the luminance increase of the test patch Fig. 8 was prepared, where the amounts are taken along the ordinate and the luminance along the abscissa. The shaded area represents the chromaticness, the black area the blackness and the clear area the whiteness. The vertical dotted line in each figure indicates the border luminance between the natural and unnatural appearance. The left figures are for the subject YM, the middle for YT and the right for TM. The top figures are for the illumination $I_1$, the middle for $I_3$, and the bottom for $I_6$. It is clearly shown that for each subject the chromaticness started to decrease at around the border luminance and continued to decrease gradually until it dropped to almost zero at the highest luminance employed, 538 cd/m². The chromaticness was substituted mostly by the whiteness for higher luminance. The test patch became a bright and luminous white aperture to indicate that the appearance returned to its own neutral color as predicted by RVST theory. In subject TM the borders were at high luminance and the chromaticness indeed started to decrease at these high luminance levels. The amount of chromaticness given by him was small at low luminance and a peak appeared in each chromaticness curve. From the figures we see that the chromaticness was substituted by the blackness at the low luminance in this subject. It seems that with the large amount of blackness the
test patch continued to appear natural as an object to him toward higher luminance levels compared to the other two subjects. This might be the reason for the high border luminance of this subject.

5.4 Discussion

The predictions based on the theory of RVSI were confirmed in Experiment 2. When the test patch had a relatively low luminance compared to other objects in the subject's room and it was recognized as another object in the room, its color appearance was determined in relation to RVSI. When the test patch had a high luminance and it was not recognized as an object in the space but merely as a light source, its color appearance was no longer evaluated in relation to RVSI and returned to its own color, a neutral white in the present case.

The test patch went through various phases of color appearance when its luminance was increased. It appeared a normal object having a gray component at very low luminance. Its lightness increased with a further increase in luminance but the appearance of an object was preserved. Then it reached a transition border from natural appearance to unnatural appearance as an object. With further increase in the luminance it began to appear fluorescent and finally luminous, which is called the light source color mode. These phases were also noticed by Evans and earlier by us.

Similar to the results of Experiment 1 the color appearance of the test patch was always the opposite of the color of the room illumination. For example, when the illumination was red as shown by filled circles in Fig. 7 the color appearance of the test patch was green or bluish green as shown by open circles. When the former was blue as shown by filled squares the latter was yellow or yellowish red. Details of the oppositeness, however, differed from those found in Experiment 1. In Experiment 1 subject YM assessed the test patch as showing almost 90% of blue and only 10% of green for the illumination I1 as shown by an open circle in Fig. 5, but in Experiment 2 she assessed it as having only 50% of blue as shown by open circles in Fig. 7. This lower estimation of blue elementary color was also found by subjects YT and TM although their results can only be compared with those obtained by other subjects in Experiment 1. A possible reason for the discrepancy may be found in the slightly different method of color naming. In Experiment 1 subjects were asked to estimate the amount for chromaticness only and not for blackness or whiteness at the first step, while in Experiment 2 they were asked to estimate the amounts for all three elements. There is a possibility that the blackness was counted as blueness in Experiment 1 thus making it larger.

Fig. 8. Percentage of chromaticness (shadowed), blackness (black) and whiteness (clear) of the test patch assessed at different luminance of the test patch. A vertical dotted line in each figure represents the border luminance between natural and unnatural appearance of the test patch. Results from the three subjects, YM, YT and TM are shown for illumination I1, I3 and I6.
6. General Discussion

The theory of RVSI predicted in the present experiment two specific phenomena. One was that the color appearance of a test patch was determined in relation to RVSI and consequently should change toward the opposite direction from the color of a room illumination if the psychophysical property of the patch was kept unchanged and its luminance was kept low enough to appear an object color. The other was that the color appearance of the test patch should return to its own color, a neutral white in the present experiment, when the luminance was increased so that the test patch moved out beyond the border of RVSI and was released from its restriction. Both predictions were confirmed by Experiments 1 and 2.

The present paper offers an explanation for the color appearance mode. The light source color is the result of the release from RVSI. The appearance of the light source color is the color of the light as it is observed alone. In the present case it was a neutral white. In Evans’ case it was monochromatic light and he noticed that the color appearance became desaturated at the light source mode. It remains for future research to investigate the color appearance of any color patch when it turns to the light source color, or the color appearance of the patch when freed from RVSI.

The present experiments aimed to show the validity of the concept of RVSI by predicting and confirming the color appearance of a test patch of which the physical property was kept unchanged under different room illumination. By presenting the test patch in this unusual way it may sound as though the results have no implication in our daily life. But the truth is that in recent years we frequently have such a situation. The test patch can represent cases of self luminous displays such as a mobile LCD display of a transparent type. The luminance of the display is not generally high enough to appear as the light source color and the color of images displayed on it can suffer a change in appearance depending on the environment where it is used. The present experiments suggest that one way to avoid this change is to make the luminance of the display high enough to bring about the light source color or to control the colorimetric property of the display by the room illumination such as is practiced in a display of a reflective type.

Acknowledgment

This research was partially supported by a Grant-in-Aid for Scientific Research No. 10650047 from Japan’s Ministry of Education, Science, Sports, Culture and Technology.

References