Paper

Perception of Colorfulness Influenced by Chromatic Variance in Indoor Environments

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ABSTRACT

We are surrounded by a variety of color distributions, which change greatly according to the surrounding environment. It is not yet well understood how much the appearance of objects is influenced by these color distributions in the surrounding environments. Brown and MacLeod (1997) showed that color appearance depends on the chromatic surround variance; this is known as the "gamut expansion effect." However, Brown and MacLeod used relatively small patterns on a monitor. Whether the same effect would be obtained in an actual room environment has not been investigated. We examined whether the colorfulness perception of an object is influenced by the chromatic variance of its surroundings in a normal environment such as a room with furniture and objects inside. Two miniature rooms, one with gray and one with color-saturated objects inside, were placed side by side and used as a reference and a test room, respectively. Observers compared the colorfulness of a small square patch placed in the reference and the test rooms. The results showed that the apparent colorfulness of a patch was generally lower when it was closely surrounded by color-saturated surfaces, suggesting that the color appearance was changed slightly by the influence of other saturated objects in the room. However, the shift was very small, implying that chromatic surround variance has little influence on color appearance in an actual environment.

KEYWORDS: colorfulness, saturation, color variance, gamut expansion effect, miniature room

1. Introduction

Color distribution varies largely between different environments, both indoor and outdoor. For example, some rooms are decorated with very saturated colors, and others are black and white. It is not well understood how much these color variations influence the appearance of objects within these environments.

Brown and MacLeod showed that color appearance depends on chromatic surround variance; this is known as the "gamut expansion effect"[1)-3)]. Selective adaptation to one axis of chromatic modulation, known as "color contrast adaptation" has also been shown[4)-7)]. However, these studies used relatively small patterns presented on a monitor. Whether the same effect would be observed in an actual room environment is not yet known.

In everyday life, we are able to maintain a perception of the stable color appearance of objects despite large variations of illumination color and brightness; this is known as color constancy. It has been shown that changing the color surrounding an object does not affect the color appearance of the object, but that changing the illumination color (or its recognition) does change the appearance of the object since the observer adapts to the illumination color[8)-10)]. These re-normalizations may occur only for particular changes in color variation, such as illumination, and not for color variation itself. If this were the case, saturation appearance might follow a similar trend. On the other hand, if the gamut expansion effect were caused merely by the color distribution itself, then placing saturated objects in a setting would influence the appearance of other objects in that setting, and awareness of such influence would be critical in situations where precise color evaluation is needed.

In this study, we investigated whether the apparent colorfulness of an object is influenced by the color saturation of its surroundings in a normal environment, such as a room containing furniture and other objects.

We tested the colorfulness appearance of a test patch placed in a miniature room with color-saturated furniture and objects by comparing it with the appearance of a reference patch in another room containing gray furniture and objects.

2. Experiment

As shown in Figure 1, two miniature rooms, one with gray and one with color-saturated furniture, were placed side by side and used as a reference and a test room, respectively. The view from an observer's perspective is shown in Figure 2. The size of each room was the same: 40 cm in width, 55 cm in depth, and 56 cm in height, making

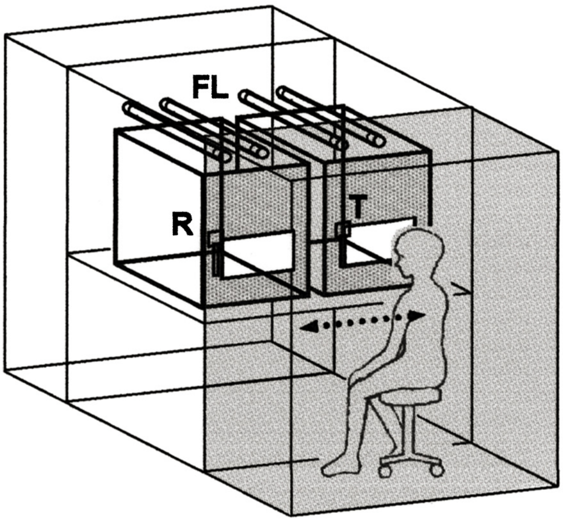

Figure 1 Experimental booth with test and reference miniature rooms. FL, fluorescent lamps; T, test patch; R, reference patch

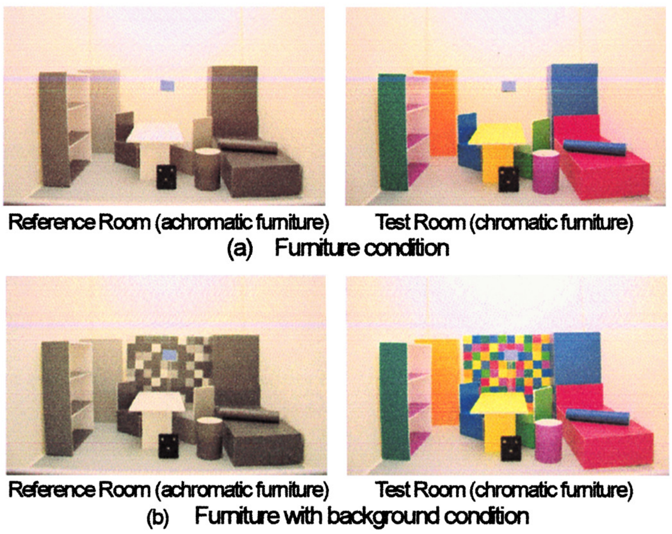

Figure 2 Test room with achromatic furniture and reference room with chromatic furniture. T, test patch; R, reference patch.

Table 1 Color of furniture in the test room as measured by spectrometer

	L*	a*	b*	Munsell
kitchen shelf	72.1	33.8	63.2	4.5YR 7.1/12.2
table	85.9	-2.6	67.8	4.7Y 8.5/9.5
chair 1	60.8	-53.9	42.8	0.4G 5.9/11.1
bookshelf (side)	51.5	-49.2	4.4	0.1BG 4.9/9.1
chair2	47.8	-27.8	-31.9	5.1B 4.6/9.4
closet, blanket	45.6	1.09	-37.6	4.7PB 4.4/9.2
bookshelf (shelf), wastebasket	47.9	38.2	-26.0	7.8P 4.7/10.6
bed	48.2	57.3	10.3	0.3R 4.7/12.8

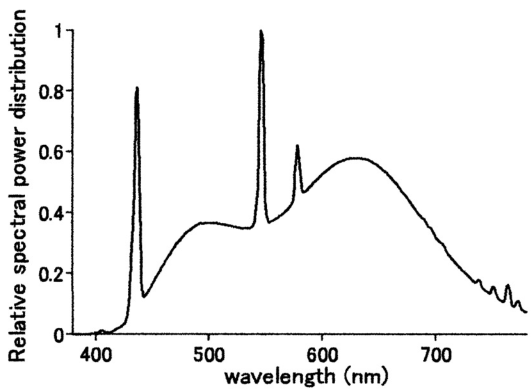

Figure 3 Relative spectral distribution of illuminant

them approximately one-tenth the size of a full-scale room. A reference and test patch for color judgments were placed in the middle of each room. These were elevated on transparent acrylic poles to avoid direct comparison with particular objects in the rooms. They were tilted upward at 45 degrees to reflect the ceiling light directly. The back wall of each room could be opened to enable the experimenter to change the patches.

The ceilings of both rooms were made of opaque glass, and two 20-W white florescent lamps were placed above each room. These were high-color-rendering type florescent lamps (Toshiba FLR20SW-EDL/MA.NU; correlated color temperature, 4200 K; Ra, 97). The relative spectral distribution of the lamps is shown in Figure 3. This distribution was obtained by measuring a white calibration plate placed in the room using a spectroradiometer CS-1000 (Minolta). The correlated color temperature based on this measurement was approximately 3620 K.

The illumination of both rooms was independently controlled by light controllers and set to 500 lx on the floor in front of each patch, as measured by an illuminometer T-10 (Konica Minolta). The walls were covered with white wallpaper and floors were covered with gray paper in both rooms.

The colors in the test room were chosen to provide a variety of hues with high saturation. Their CIELAB and Munsell data, measured by a spectrophotometer CM-3600d (Minolta), are shown in Table 1 and Figure 4. Those in the reference room were all gray and had approximately the same lightness as the corresponding objects in the test room. The average color of both rooms was also similar to avoid color shift to a particular hue.

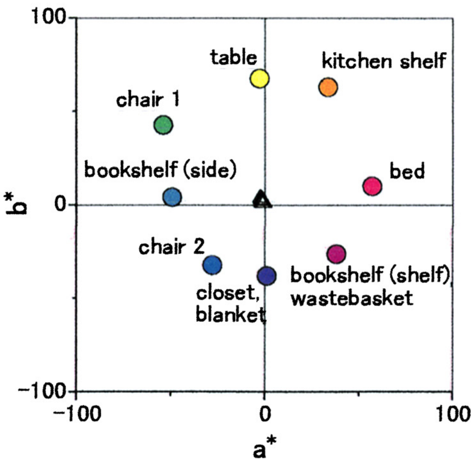

Figure 4 Colors of objects in miniature rooms on the CIE1976a*b* chromaticity diagram. △, reference room; ●, test room

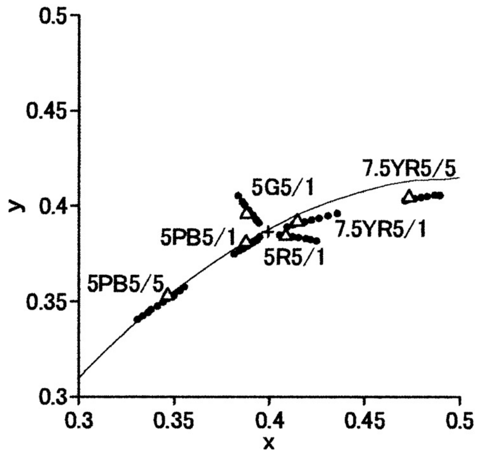

Figure 5 Reference and test patches on the CIE1931 x y chromaticity diagram. △, reference patch; ●, test patch; +, N5. Solid curve indicates the black -body locus.

In addition to furniture, each room was given a checkerboard background to allow examination of the effect of a local, nearby background, as shown in Figure 2 (b). The checkerboards each consisted of four parts so that the arrangement of the squares was changeable. The colors of the squares were identical to those used in the furniture. Each square was 2 × 2 cm, small enough to ensure that the test patch would be surrounded with multiple colors instead of with a single particular color.

The test and reference patches were 2.5 cm square, and their visual angle was 1 degree from the observer's position. Six reference patches of various hues and with low and high chroma were tested; Munsell notations were 5R5/1, 5G5/1, 5YR5/1, 5PB5/1 for low-chroma stimuli and 5YR5/5 and 5PB5/5 for high-chroma stimuli. Hues 5YR and 5PB were chosen because they were along the black-body locus. Test patches distributed along a line from low to high-chroma including each reference patch were prepared. They covered the chroma of /0.5 to /2.0 in steps of /0.25 for low-chroma reference patches, and from /4.5 to /6.75 in steps of /0.25 for high-chroma reference patches. The CIE1931 xy chromaticity coordinates of the reference and the test patches measured by the spectroradiometer CS-1000 are shown in Figure 5.

Three observers with normal color vision participated in the experiment. Each observer compared the appearance of a test patch with a reference patch by viewing the two rooms. The observer was not able to view both rooms at the same time, but could look at each room in turn as many times as required to judge whether the test patch appeared more or less colorful than the reference patch. Given that the observers judged how colorful and vivid the patches were without knowing the actual definitions of chroma, saturation, and colorfulness, we considered that they were making their judgments purely about colorfulness, which is defined as an "attribute of a visual sensation according to which an area appears to exhibit more or less of its hue"[11]. Munsell chroma were used as the parameters for measuring the colorfulness perception of patches. After the observer made each judgment, the test patch was exchanged for one of different chroma; the observer could not look inside the rooms during this process. This process was repeated using test patches with different chroma levels in random order. After all test patches had been compared with a given reference patch, the procedure was repeated for each of the other reference patches. Six reference patches were used, and test patches with about five to seven chroma levels from the prepared set were tested for each reference patch using the method of constant stimuli. One session consisted of judgments for all six colors in random order. Ten sessions were conducted for each observer, so that a total of 10 judgments were obtained for each combination.

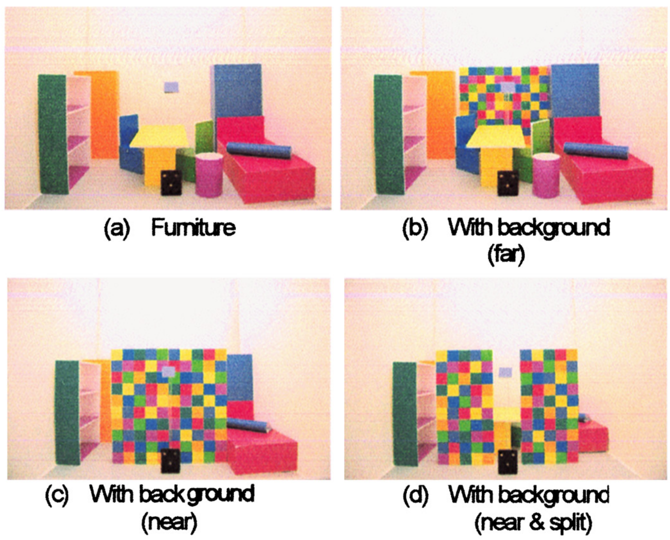

Figure 6 Room conditions with (a) furniture only, (b) background checkerboard just in front of the back wall, (c) background directly behind the test/reference patch, (d) near and split background

Four test-room conditions were used, as shown in Figure 6. For the "furniture" condition (a), only furniture was placed in each room. For the condition with a distant background (b), the color and gray checkerboard backgrounds were placed near the back walls of the rooms to allow examination of the effect of an adjacent background. For the condition with a near background (c), the checkerboards were moved to a position immediately behind the patches to examine the effect of a background closer in depth. A final condition, with a near and split background (d), was also tested to examine the effect of a local boundary; this was accomplished by dividing the color checkerboard background into two parts with 2 degrees of separation. For the conditions using the checkerboard, the arrangement of the squares was changed between sessions so that the immediate surround of a given patch was different in each session. In addition to the four room conditions, a control condition with no furniture in either room was conducted.

3. Results

Figure 7 shows the results for observer MS for reference patch 5R5/1. The abscissa shows the chroma of the test patches, and the ordinate shows the percentage of test patches that MS thought more colorful based on 10 judgments. Each series corresponded to a different room condition with a curve fitted using the Weibull distribution function. If the colorfulness of the test and reference patches appeared to be the same, the result would be 50%. Therefore, the Munsell chroma of the test patch at 50% was considered as a "colorfulness match." In the case of the control condition, the chroma of the test patch at 50% was close to /1, meaning that the test and reference patches appeared almost the same. On the other hand, the chroma shifted to around /1.4 under the condition with the near and split background (d). This shows that the test patch with the same chroma as the reference (/1) appeared less colorful, and higher chroma was needed for the test patch to match the colorfulness of the reference patch.

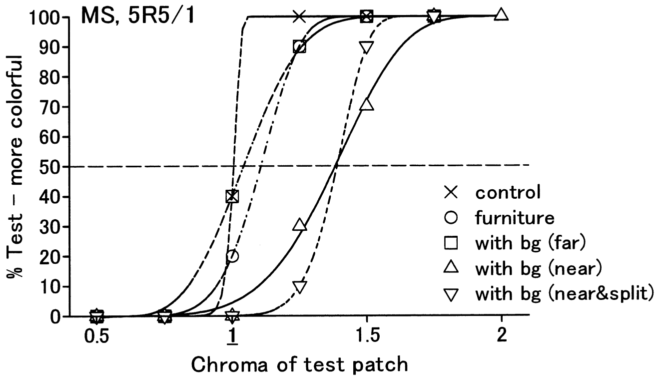

Figure 7 Results for observer MS for reference patch 5R5/1. The percentage of test patches judged as more colorful. Each series corresponds to a different room condition with a curve fitted using the Weibull distribution function. The Munsell chroma of the test patch at 50% was considered as a "colorfulness match".

Figure 8 shows the "colorfulness match" for the three observers, MS, AT, and EM. Colorfulness matches under the control condition (indicated by cross symbols) are shown on the dashed lines corresponding to the chroma of

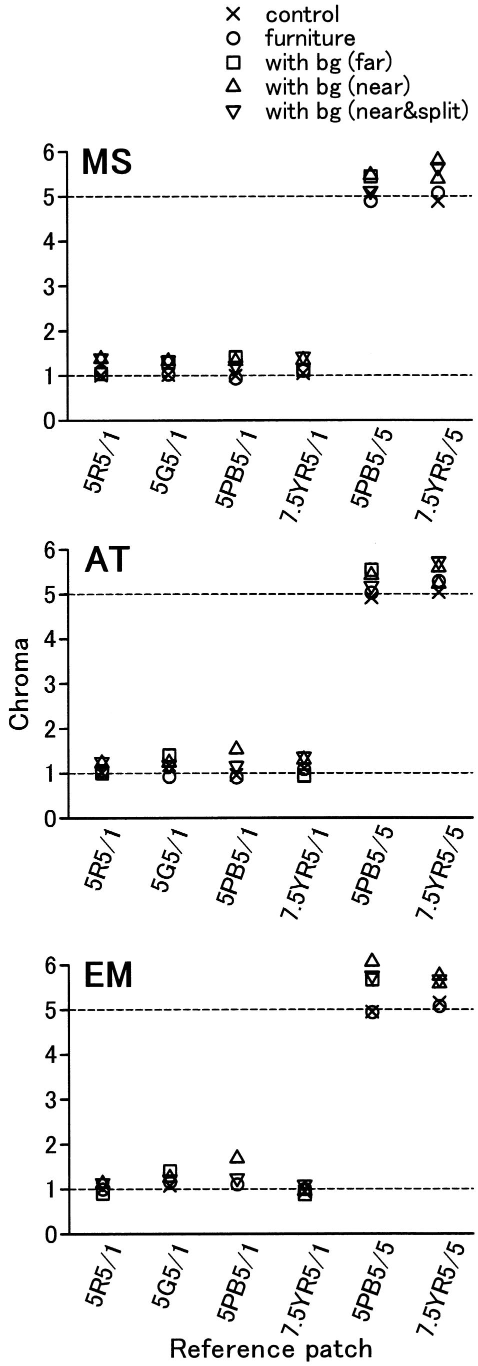

Figure 8 Results for Munsell chroma for colorfulness match by the three observers, MS, AT, and EM. Each symbol indicates the result for each room condition. Dashed lines correspond to the chroma of the reference patches (/1 or /5).

the reference patches (/1 or /5), showing the reliability of judgments. In the case of the furniture condition (circle), most of the matches are still on the dashed line, meaning that furniture color had little effect. Those with a colored checkerboard background show higher colorfulness matches, indicating that the apparent colorfulness of the test patches was generally lower. However, the shift in color appearance was very small. This suggests that the

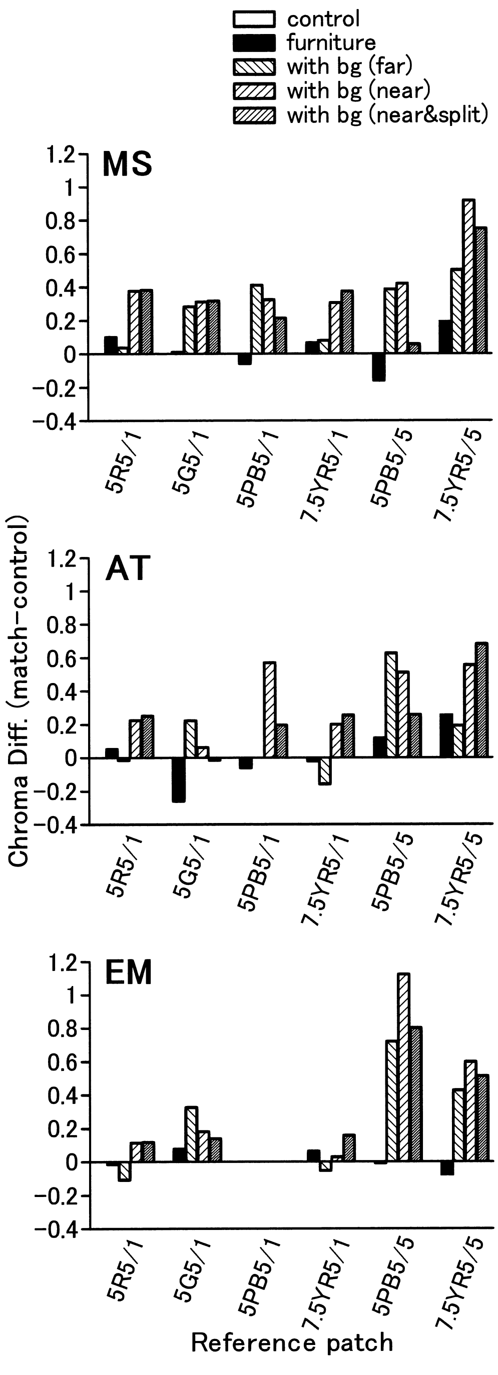

Figure 9 Differences in chroma at colorfulness match under each condition compared with that under the control condition for the three observers, MS, AT, and EM. Each bar indicates the result for one room condition.

colorfulness appearance of a patch was changed only slightly by the influence of saturated objects in the room.

Note that the data of reference 5PB5/1 for observer EM and AT are missing for some conditions, as they found it too difficult to judge the colorfulness of the test stimulus and reference 5PB5/1 due to the slight redness of the illumination (3620 K), which also affected the appearance of hue.

Figure 9 shows the chroma shift calculated by subtracting the chroma for the colorfulness match for each room condition from that for the control condition to compare the differences between conditions more easily. The conditions with a color checkerboard background showed larger decreases in colorfulness perception, implying that nearer saturated surfaces had a stronger influence. A similar effect was observed in most cases when the test patch was not immediately surrounded by a colored background, which is consistent with previous research showing that the gamut expansion effect is not entirely a local effect [1].

Figure 10(a) shows the averaged responses of the three observers according to room condition. The figure shows little effect for any of the colors under the furniture condition, and a generally small shift under the other room conditions. The amount of shift seems larger with high-chroma references, i.e., 5PB5/5 and 5YR5/5. However, as shown in Figure 10(b), if we compare relative chroma, which is the ratio of a matched chroma to the control condition, there was no systematic difference in the strength of the effect depending on the original chroma of the reference patch.

4. Discussion

Our results show that the apparent colorfulness of test patches barely changed under the furniture-only condition, but decreased slightly under conditions with a high-saturation color checkerboard background. This suggests that colorfulness perception was influenced by surroundings in a real three-dimensional miniature room. However, these were relatively small shifts, implying that the color variance of an object's surroundings has little effect on colorfulness appearance in an actual scene.

Although we cannot compare the effect directly to previous studies because of differences in evaluation methods, the effect is much smaller than that found in previous studies. For example, the highest value of the relative chroma in Figure 8 was less than 1.5-times that found under the control condition, in contrast to the findings of Brown and Macleod, where the "relative richness of matches" in colored surrounds were two or more times greater than those found with a gray surround. Faul et al.[3] suggested that stimulus conditions were critical for the occurrence of this "gamut expansion effect", such as color contrast between the target and the

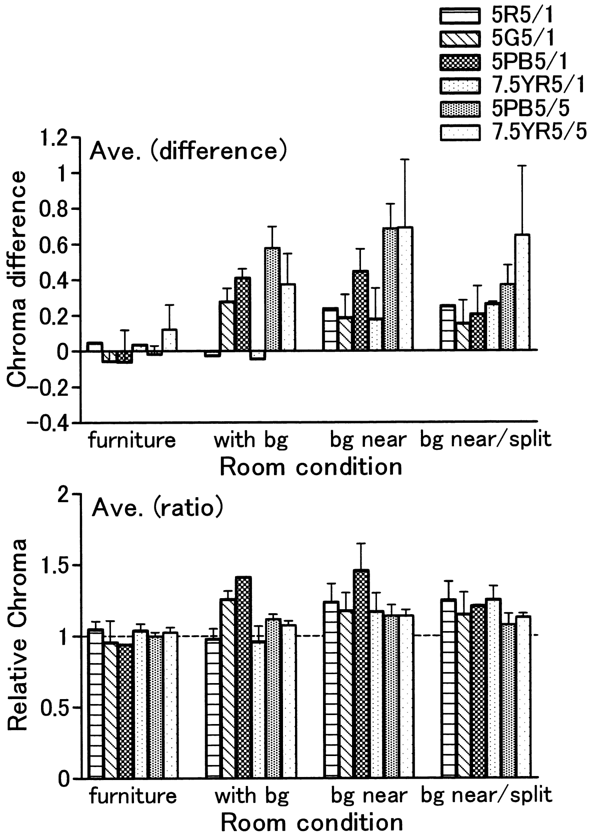

Figure 10 Average scores of the three observers. (a) Difference of chroma at colorfulness match from that under the control condition. (b) Relative chroma (the ratio of a matched chroma to the control condition). Each bar indicates the result for one reference patch.

surround, a limited role of the amount and the spatial distribution of color variance, and that the effect was mainly local. It appears that the effect of chromatic surround variance on colorfulness appearance occurs under limited conditions, may be masked by other visual factors, and may be smaller in an actual environment than in research settings.

Some hypotheses or interpretations explaining the gamut expansion effect have been proposed; for example, it might be due to a sensitivity change of cone-opponent neurons and the contribution of a contrast-adaptation mechanism. The contributing mechanism is still not clear, as Faul et al. supported an alternative explanation relating to color scission. Our results do not enable examination of the mechanism because the effects were very small. However, our findings suggest the following conclusions. The effect cannot be determined by the color gamut distribution of the visual field, as the furniture condition showed no effect, even though the colors used were the same as for the other conditions. The conditions with a color checkerboard background showed a small effect, but no clear difference was found between these conditions, suggesting that it was not a local lateral-inhibition-type effect in the early visual system.

The behavioral purpose of preserving colorfulness has been mentioned in previous papers[1, 12)]. Such preservation might help to cope with illumination changes caused by fog, mist, or smoke. Under such conditions, the visual system would do well to expand the gamut to maintain colorfulness. However, the conditions in this paper involved simply placing colorful objects in a room. The gamut expansion effect may be relevant only in conditions under which our visual system needs to maintain the appearance of the scene (or objects), not for simply adjusting to the color gamut of any given environment. Further investigation is needed to determine which factors or conditions contribute to the gamut expansion effect in real environments.

5. Conclusions

It was shown that the apparent colorfulness of test patches was influenced by surrounding high-saturation colors. Although little effect was observed under a condition with only furniture in the room, the perceived colorfulness of the reference patch decreased slightly with a color checkerboard background.

Colorfulness perception does seem to be influenced by the variance of surrounding color in a real environment. However, the color variance of surrounding objects may have little effect on the color appearance of an object in everyday life.

Acknowledgment

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References

(1) Brown, R. O. and MacLeod, D. I.: Color appearance depends on the variance of surround colors, Curr Biol, 7-11, pp.844-849 (1997).

(2) Brenner, E., Ruiz, J. S., Herraiz, E. M., Cornelissen, F. W. and Smeets, J. B.: Chromatic induction and the layout of colours within a complex scene, Vision Res, 43-13 pp.1413-1421 (2003).

(3) Faul, F., Ekroll, V. and Wendt, G.: Color appearance: The limited role of chromatic surround variance in the "gamut expansion effect", J Vis 8-3 pp.30 31-20 (2008).

(4) Krauskopf, J., Williams, D. R., and Heeley, D. W.: Cardinal directions of color space, Vision Res, 22-9, pp.1123-1131 (1982).

(5) Krauskopf, J., Williams, D. R., Mandler, M. B. and Brown, A. M.: Higher order color mechanisms, Vision Res, 26-1, pp.23-32 (1986).

(6) Webster, M. A. and Mollon, J. D.: Colour constancy

influenced by contrast adaptation, Nature 373-6516, pp.694-698 (1995).

(7) Webster, M. A., Malkoc, G., Bilson, A. C. and Webster, S. M.: Color contrast and contextual influences on color appearance, J. Vis 2-6, pp.505-519 (2002).

(8) Mizokami, Y., Ikeda, M., and Shinoda, H.: Color Property of the Recognized Visual Space of Illumination Controlled by Interior Color as the Initial Visual Information, Optical Review, 7-4, pp.358-363 (2000).

(9) Brainard, D. H.: Color constancy in the nearly natural image. 2. Achromatic loci, J. Opt. Soc. Am. A Opt Image Sci, Vis. 15-2, pp.307-325 (1998).

(10) Mizokami, Y., Ikeda, M. and Shinoda, H.: Color Constancy in a Photograph Perceived as a Three-Dimensional Space, Optical Review, 11-4, pp.288-296 (2004).

(11) Hunt, R. W. G., *Measuring Colour,* 3rd ed. (Fountain Press, Kingston-upon-Thames, England 1998).

(12) Hurlbert, A.: Colour vision: putting it in context, Curr Biol 6-11, pp.1381-1384 (1996).