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A series of experiments were conducted to find the effects of non-uniform illumination on the surface-color mode perception. Two patterns of the illumination, one-sided illumination and a spotlight, were simulated. Observers adjusted the luminance of the test stimulus so that it just started to appear partially as an aperture-color mode. We found that the upper-limit luminance was significantly lower for all test colors when the directions of the gradient between the test stimulus and the surrounds did not match. On the other hand, in the spotlight conditions the upper-limit luminances changed only when it was contained in the spotlighted area. Our results suggest that the brightest stimulus in the scene does not work as a cue, and that the visual system takes the influence of illumination into account in order to set a criterion for the judgment for the color appearance of the mode.

Key words: Mode of color appearance, surface-color mode, luminance gradient, non-uniform illumination, color vision

1. Introduction

Modes of color appearance can be classified into several groups:[1] surface-color mode and aperture-color mode are the two main groups among them. The mode of color appearance of a test stimulus changes from surface-color to aperture-color not only by increasing its intensity, but also by changing the adjacent condition around the test stimulus.[2–4] When the intensity of an achromatic stimulus increases, the lightness of the stimulus increases, or in other words, its color changes continuously from black to white through several levels of gray, followed by the appearance of luminosity. Thus, the perception of luminosity is closely related to lightness perception.

Several theories such as an anchoring theory[5,6] and highest luminance ratio[7] have been proposed to explain how lightness is evaluated. The anchoring theory explains that the visual system sets an anchor for lightness scaling, and the lightness of the surface is judged based on this anchor. When the stimulus exceeds the scale of the surface, it appears luminous. On the other hand, the highest luminance ratio explains that white works as an anchor for the lightness judgment because it has higher luminance than any object surfaces in the scene.

Moreover, the importance of the organization of the stimulus has been pointed out by several researches.[8–11] For example, Gilchrist showed that perceived lightness changed dramatically depending on the perceived location of the stimulus.[8] Bonato and Cataliotti[9] also pointed out that perceptual organization is an important clue for the judgment of the lightness of a stimulus.

We have measured the upper-limit luminances of the surface-color mode appearance using several colors.[12] We found that brightness, but not luminance, was almost the same for all of the 16 colors we tested. These results indicate that brightness perception plays an important role in determination of the mode of color appearance. We also found that brightness at the upper-limit of the surface-color mode did not exceed that of the brightest stimulus, a white stimulus, presented in the surrounding stimulus. These results suggest that the visual system found the brightest stimulus in the scene and used it as a determining cue for the judgment of the mode. However, our experimental results cannot tell directly which of the two theories described above is correct, as the white stimulus might work as an anchor, which is at the same time the highest luminance stimulus.

Considering that the surface of an object cannot reflect more light than is falling on it, we may take into consideration the lighting of the stimulus, and perceive an object in the aperture-color mode when we estimate that an object has a brightness exceeding that of the maximum intensity allowed in the scene. As a result, the limit for the stimulus to be perceived as a surface might reflect the estimated intensity of the illumination. This notion is explained with the term "recognized visual space of illumination (RVSI)", which has been proposed by Ikeda and his colleagues.[13–15]

Most of the preceding studies using a monitor assumed the stimulus to be uniform. This is simulating an ideal case, which is equivalent to a uniform illumination. Though most of the reported results with a monitor show the same trends as those with a real paper, some studies report that the effects observed with a monitor experiment are smaller than those from experiments with real objects.[16] This discrepancy can be explained if we suppose that the stimuli on a monitor cannot perfectly simulate stimuli made of real papers, *e.g.* some sort of a non-uniform factors such as the luminance distribution within a stimulus are not correctly represented. In most cases, the same color paper is represented in the same way, both in luminance and in chromaticity, regardless of the position in the scene. In natural scenes, we seldom encounter such a perfectly uniformly illuminated scene even if we don't notice the non-uniformity. Even if the paper were flat and matte, it would have some non-uniform luminance distribution. In this sense, the results reported from some preceding experiments[17–19] using actual color papers in an experimental booth may implicitly contain these factors. This may be the reason why the results obtained with real objects are not always the same as those obtained in simulated experiments.

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There can be many non-uniform illuminations. In this study we are going to consider two non-uniform illuminations: illumination lying above one side of the stimulus, and a combination of multiple illuminations. The former illumination results in a luminance gradient in the scene, while the latter produces an incremental luminance change of a certain area within a scene. Most of the illumination can be simulated by combining these two cases.

As for a luminance gradient, several studies have been reported.[20–24] Arend and Goldstein[20] reported that lightness constancy held with a stimulus with a luminance gradient. Agostini and Galmonte[21] showed that the gray region perceived either brighter or darker depending on the gradient direction adjacent to it. Zavagno[22,23] reported that the stimulus appeared luminous in lower luminance when it was displayed with a luminance gradient. These results indicate that the luminance gradient plays an important role and can affect lightness perception.

In this study, we tried to investigate the effects of non-uniform illumination on the upper-limit of the surface-color mode appearance by simulating two illumination conditions. Such display conditions also cause changes in the brightest stimulus in the display. In this study we also examine whether the "apparent" brightest stimulus is working as a determining factor for judgments of the surface-color mode. If so, the upper-limit luminance of the surface-color mode would change when the brightest stimulus in the display changed regardless of its position in the scene.

Three experiments were carried out. In Experiment 1 and 2, the effects of a luminance gradient were examined. In Experiment 1, the directions of the gradient both in the surrounding stimuli and in the test stimulus varied in order to clarify the effects of the directions of the gradients on the surface-color mode appearance. In Experiment 2, the stimulus configuration and the position of the test stimulus varied in order to confirm that the effects observed in Experiment 1 are not restricted to the particular stimulus configurations. Moreover, the position of the test stimulus was changed to verify that the judgment for the surface-color mode reflects the change of the local illumination. In Experiment 3, the effects of the local illumination change, which appeared as if the area was illuminated with a spotlight, were tested. If all these experiments reveal the same trends, we can generalize the findings of each experiment.

2. Experiment 1

2.1 Overview

In Experiment 1, the effects of a luminance gradient in the stimulus on the limit of the surface-color mode were examined. Several conditions of the gradients were tested. If the brightest stimulus in the scene were a determinant cue for the surface-color mode perception, then the upper-limit luminance for the surface color would change as the gradient condition changes.

2.2 Method

2.2.1 Apparatus

An experimental booth was used that composed of two small rooms. The subject sat in one room that was illuminated by a D_{65} simulating fluorescent lamp. The stimulus was displayed on a carefully calibrated CRT monitor, which was located in the other room. A viewing window of 14 cm by 8 cm with a shutter was placed in the wall, which separated the two rooms. The subject saw the stimulus binocularly at a distance of 120 cm. The subject could change the luminance of the test stimulus with a trackball.

2.2.2 Stimulus

The stimuli were simulated color chips on a monitor. The stimuli appeared as flat and matte color papers. The surrounding stimuli were composed of several color chips. We selected 16 chromaticities for test colors. The luminances and chromaticities of the test and the surrounding stimuli are shown in Fig. 1. The surrounding stimuli always appeared as a paper surface. When the luminance of the test stimulus was high, the test stimulus appeared luminous. On the other hand, the test stimulus was perceived in the surface-color mode when its luminance was low enough.

A schematic diagram of the array-type stimulus configuration is shown in Fig. 2. In this configuration, a three by three color chip array with a white frame was placed on a gray background. The test color was presented at the center of the array. Each color chip was a 2 deg square and was

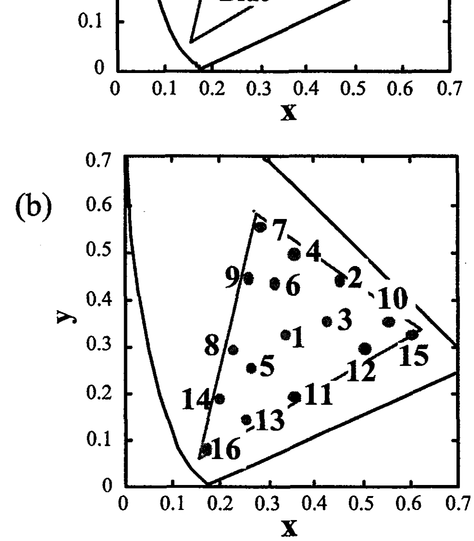

Fig. 1. Chromaticities of (a) the surrounding colors and (b) the test colors. Each test color is referred to by a number in the figures.

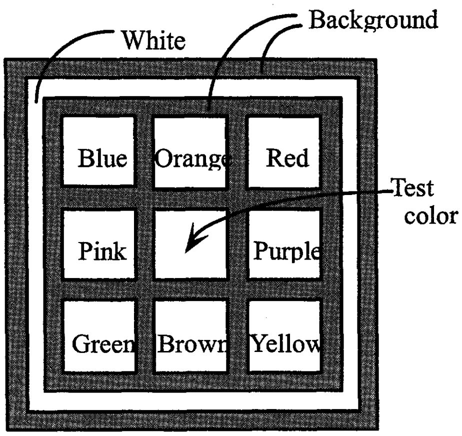

Fig. 2. The schematic representation of the array-type stimulus used in the experiment.

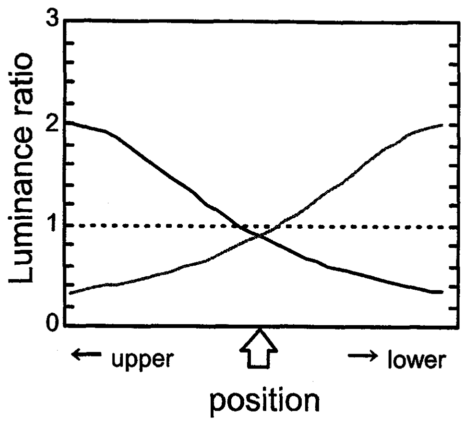

Fig. 3. The luminance gradients used in the experiment 1 and 2. Black and gray lines represents downward and upward conditions, respectively.

separated from adjacent chips by 0.5 deg. A white frame, with a width of 0.5 deg, surrounded the array and was separated from the nearest chip by 0.5 deg.

In this experiment a luminance gradient was used for both the surrounding stimuli and the test stimulus. We changed the directions of the gradients for the surrounding stimuli and the test stimulus independently in order to find out whether any effect can be observed when the directions of the gradients differed. The luminances of the surrounding stimuli changed vertically. That is, the luminance of the stimulus decreased in a downward direction or in an upward direction. This stimulus configuration simulated a light-source placed above the top or the bottom of the stimulus. When the stimulus had a gradient, these settings gave an impression for all the subjects that the stimulus was illuminated from one side. Three gradient conditions for the test stimulus were set as follows: the same, the opposite direction as the surround stimulus, and no-gradient (uniform) condition. In total, 7 different conditions were tested: three gradient directions (upward, downward and uniform) for the test stimulus under two different directions (upward and downward) for the surrounding stimuli, and a reference condition in which neither the test nor the surrounding stimuli had luminance gradients. The gradient was calculated by assuming the stimulus was a perfect Lambertian surface illuminated with uniform illumination.

The spatial distribution of the luminance gradient used in the experiment is shown in Fig. 3. The ordinates show the ratio of the luminance to that of the reference condition (no gradient nominal condition), where the stimulus did not contain any gradient.

2.2.3 *Procedure*

The subject adapted to the D_{65} simulating fluorescent lamp for 3 minutes before each experimental session started. The subject then opened the shutter to observe the stimulus through the aperture in the wall. In the experimental session, the subject adjusted the luminance of the test stimulus, so that it was perceived to be at the limit of the surface-color mode.

When an adjustment was completed, the subject pressed a button on the trackball. The next trial started after a 2 second blank interval. A session consisted of 16 trials, in which different test colors were presented in a random order. We conducted five sessions for each condition. Also, the upper-limit luminances under uniform illumination were measured to use as a reference. The subject was instructed to pay attention to the whole stimulus while adjusting the luminance of test stimulus.

2.2.4 *Subjects*

3 subjects (2 males and 1 female) with normal color vision participated in the experiments. They were naive as to the design and purpose of the experiments except for YY, who is one of the authors. Color vision was tested with Ishihara plates and the Farnsworth-Munsell 100-hue test.

2.3 *Results and discussion*

Figure 4 shows the results obtained in the experiment. Figure 4(a) and 4(b) indicate the mean luminances across three subjects with the downward and the upward gradient set in the surrounding stimuli, respectively. The abscissa indicates a test color number, as defined in Fig. 1. Solid circles, solid triangles, and open squares denote the same gradient direction as the surrounding stimuli, the opposite gradient direction, and no-gradient condition, respectively. The luminances of the surrounding stimuli are shown in the right panel of each figure. Because of the luminance gradient, the luminance of each color had a certain range, which is shown with the bar. To represent the luminance of the test stimulus, the mean luminance inside the test stimulus was used. The results obtained under the uniform illumination are shown in the same figure with open circle symbols. To show the variation of the setting, the results obtained from one subject (YY) are shown in Fig. 4(c). Error bars indicate standard deviations across 5 settings. Other subjects also had similar values of standard deviations for each color.

As it is shown in Fig. 4, the results of all the gradient conditions showed a similar trend for all test colors. Also, the luminances obtained in the experiment were a little lower than those obtained under the uniform illumination con-

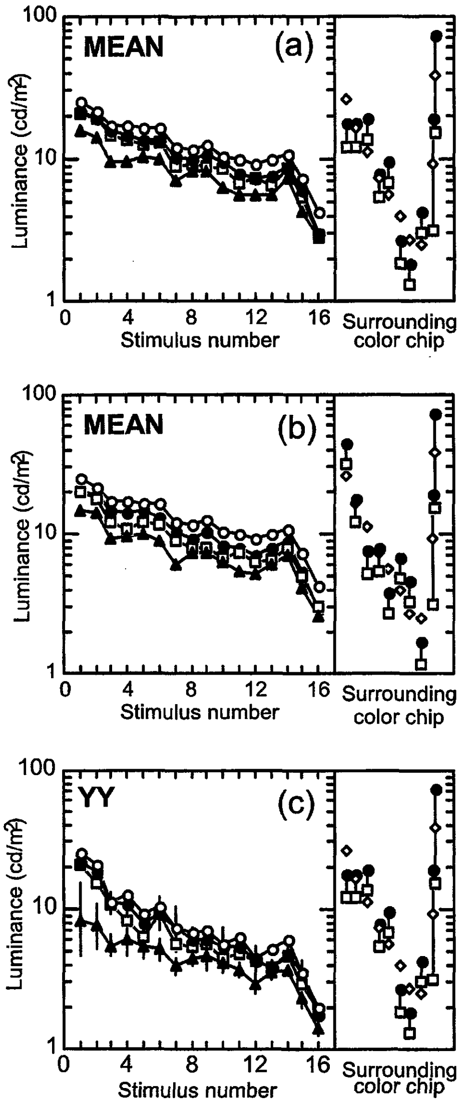

Fig. 4. The upper-limit luminances for the surface-color mode obtained in Experiment 1: Panels (a) and (b) denote the mean luminances across three subjects for downward and upward gradients, respectively. Panel (c) shows the results obtained from subject YY in the downward condition. Error bars indicate plus/minus one standard deviation.

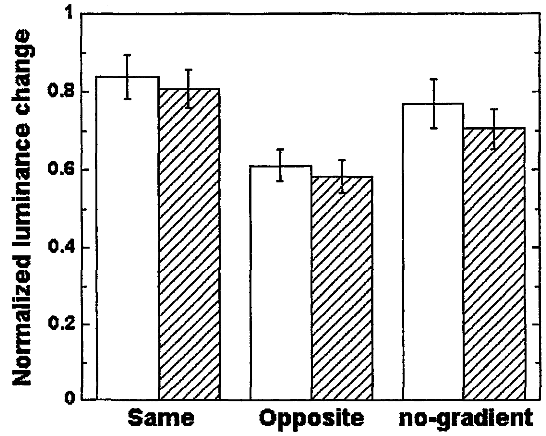

Fig. 5. Normalized luminance changes relative to the reference condition. Each bar shows the mean values across 16 test colors. Error bars indicate the standard deviations of the normalized luminance change of all the test colors. Solid and hatched bars indicate the values obtained in the downward and upward directions, respectively.

dition. Similar results were obtained in the no-gradient condition and in the same direction condition. However, it is obvious that the luminances obtained in the opposite direction condition were lower than those of the other condition.

To show the effects of the direction of the gradient, we normalized the results of each condition to that of the nominal condition. The mean values across 16 test colors are plotted in Fig. 5. Each block indicates a different gradient direction. Solid and hatched bars indicate the mean values obtained from the downward and upward direction, respectively. Error bars show the standard deviations of the 16 test colors. It is clearly shown that the results obtained in the opposite direction are lower than other conditions.

These luminance values were similar to our previous results.[12)] As we previously reported, the upper-limit luminances were different among test colors. When these luminances of each test color are multiplied by B/L values for that color in order to convert the luminance to brightness, those differences in brightness among test colors were much smaller.

Although the highest luminance contained in the surrounding stimulus, a white frame in this experimental setup, approximately doubled compared with that under the uniform illumination condition, the results did not show a corresponding change. This result suggests that the brightest stimulus was not necessarily a determining factor for the surface-color mode appearance. When a subject encounters a non-uniform illumination, the subject apparently discounts the effects caused by that illumination by excluding stimuli that are too bright to estimate how bright the surface in the scene can be. This means that the judgment for the mode of color appearance was conducted after the judgment of the illumination has been completed.

When the test color had an opposite gradient direction with the surrounding stimulus, all the subjects reported as if they were observing a different plane under another illumination through an aperture. At least the test stimulus looked quite unnatural even when it was dark. This discrepancy of the direction of the gradient would have prevented the stimuli from perceptually grouping to form the same group. In order to perceive a stimulus in the surface-color mode, the estimation of the illumination for the stimulus should not show any discrepancy within the scene. Thus, the perception of the illumination for the entire scene and the clues to infer the illumination such as luminance gradient are important in the judgment of the mode of appearance.

3. Experiment 2

3.1 *Overview*

In Experiment 1, we showed that the condition of the illumination is important for the judgment of the surface-color mode. Then how did the subjects obtain information about its non-uniform illumination? In Experiment 1, the stimuli contained a large continuous luminance change over a wide area of the display such as a gray background and a white frame. In Retinex theory,[25] the local continuous luminance gradient was not taken into account to judge the lightness of the stimulus. If the luminance gradient over a wide area were not explicitly displayed in the scene, the information of the discrete change in luminance would also probably work as a cue for the judgment of the overall illumination. Here we adopted mosaic-type surrounding stimuli in order to exclude the continuous change in luminance over a wide area of the stimulus. In this experiment, the position of the test stimulus was also changed to check whether the upper-limit luminances of the surface-color mode would reflect the local intensity of the surrounding stimuli.

3.2 *Method*

Most of the methods in Experiment 2 are identical with Experiment 1. The same apparatus was used, and so were the same subjects. As explained in Overview, a different configuration of the stimulus was used in order to remove the continuous changes in luminance. Moreover, the test stimulus was presented in different positions along the luminance gradient of the surrounding stimuli in order to find whether subjects can properly estimate the intensity of the illumination in a certain position.

3.2.1 *Stimuli*

In Experiment 2, in addition to the array-type stimulus, a mosaic-type stimulus configuration was used. Two gradient directions, upward and downward, were tested as in Experiment 1. In the mosaic configuration, the stimulus was filled with many small color chip elements. A schematic diagram of the configuration for the mosaic-type stimulus is shown in Fig. 6. In this configuration, each color chip had no luminance gradient in it. The luminance of the color chips changed discretely. The luminance of each color was determined in order to show the same luminance change as Experiment 1. The color elements of the mosaic were 0.75 deg square, and the test stimulus was 1.5 deg square. Consequently, the test stimulus was surrounded by 12 small color chips. The chromaticities of the color elements and the total amount of color information given to the observer were the same in both stimulus configurations.

The test stimulus was presented in three different positions. In the array condition, the test stimulus was displayed at one of the three chips in the center column. When an upper or a lower position was used to present the test stimulus, the color originally displayed in that position was presented at the center of the array. In the mosaic configuration, the test stimulus was positioned in one of three locations shown with a bold square in Fig. 6.

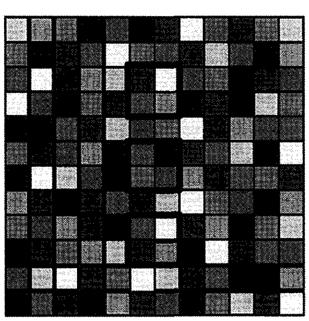

Fig. 6. Schematic diagram of the mosaic-type stimulus used in the experiment 2. The test stimulus was presented in one of the three positions indicated with bold squares.

3.3 *Results and discussion*

The results of Experiment 2 are shown in Fig. 7. Panels (a) and (b) denote the results obtained in the array-type stimulus and in the mosaic-type stimulus, respectively. As the direction of the gradient did not affect the results, the results obtained in the downward condition are shown here. In each panel, the solid circle, the open square and the solid triangle symbols denote the results obtained when the test stimulus was presented at the top, middle, and bottom position, respectively. The luminances of the surrounding color chips are shown in the right side of each panel. The luminances of the surrounding stimuli are shown with a bar because of the luminance gradient. Maximum and minimum values of each color are shown with solid circle and solid

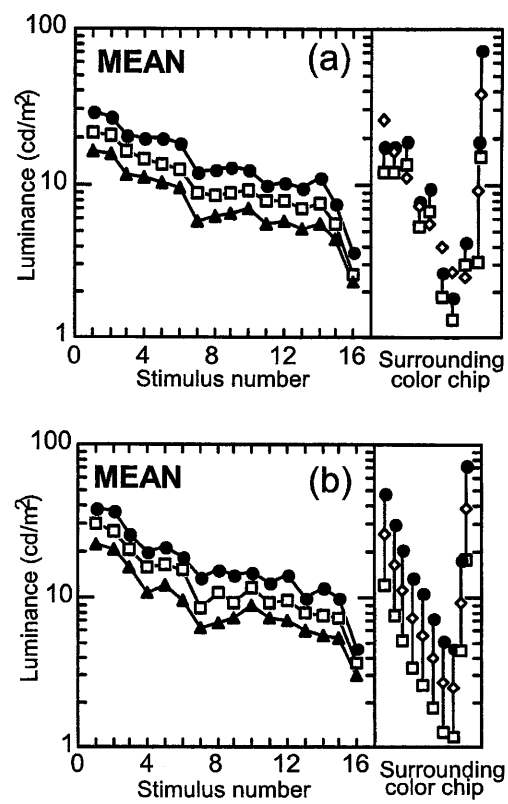

Fig. 7. The upper-limit luminances of the surface-color mode appearance obtained in Experiment 2. Panels (a) and (b) denote results obtained in the downward gradient condition with the array-type and mosaic-type stimulus, respectively. Solid circles, open squares and solid triangle symbols indicate the results obtained in the top, middle, and bottom position, respectively.

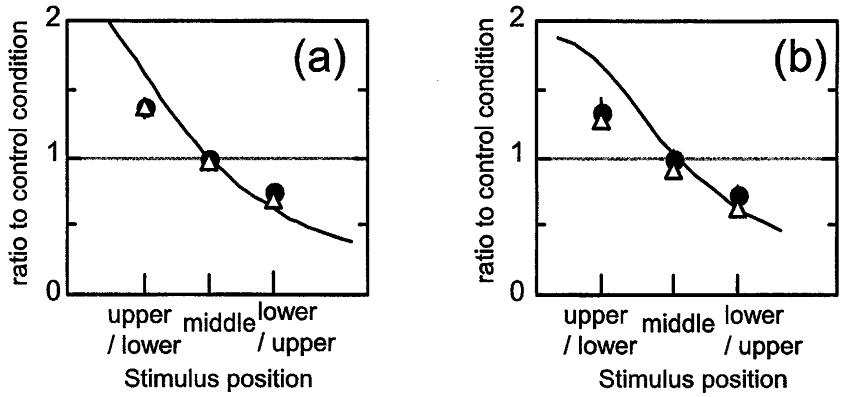

Fig. 8. The changes of the upper-limit luminance relative to the nominal luminance condition (no gradient) for each test color position obtained from Experiment 2 (Panels (a): array-type, and (b): mosaic-type stimulus.) Solid circles and open triangles indicate the different gradient directions: downward and upward, respectively.

square symbols.

The results showed the same trends in both stimulus configurations. When the adjacent luminance level was higher, the upper-limit luminances of the surface-color mode were also higher, and vice versa. To show that the position of the test stimulus did not simply account for those differences, we measured the upper-limit luminance with these two stimulus configurations with no gradient as well. The upper-limit luminances for the surface-color mode obtained in this experiments were the same for all the positions. These results clearly show that the results obtained in this experiment were not due to the position of the test color, but were due to the luminance gradient.

To analyze how much change of the upper-limit luminances was associated with changes in the surround luminance level, we calculated a ratio of luminance change under the gradient condition. The luminances obtained with the gradient are divided by those under the uniform illumination condition. Figure 8(a) and (b) show the mean ratio across all test colors for the array-type and the mosaic-type stimulus, respectively. Standard deviations of each condition are indicated with bars. The solid circle symbols denote the downward gradient condition, and the open triangle symbols denote the upward gradient condition. The solid lines indicate the change in luminance of the surrounding stimuli. The abscissa indicates the position of the test stimulus and the ordinate indicates the ratio to the uniform illumination condition. The abscissa indicates two different conditions at the same position. As the luminance change was vertically symmetric in the gradient directions, the two positions (top/bottom) are surrounded by the same luminance pattern. Thus, "upper/lower" ("lower/upper") in the abscissa indicates the result of the upper (lower) position for the downward gradient, and that of the lower (upper) position for the upward gradient. The figure clearly shows that the directions of the gradient did not affect the results, especially for the array-type stimulus. The ratios of the change are almost the same for both stimulus types, which means that continuous luminance change is not an essential cue: discrete luminance steps can produce a similar effect.

The results of Experiments 1 and 2 indicate that the total impression of the illumination, or global information, is important for the judgment of the surface-color perception. Some local cues, such as local contrast, are not negligible. Ullman pointed out that several factors are simultaneously correlated in detecting a light source in the scene.[26] Our experimental results support this notion, but what is important is that all of the information provided by those factors should be coincident.

4. Experiment 3

4.1 *Overview*

Experiment 1 and 2 dealt with the luminance gradient contained in the stimulus. In Experiment 3, we simulated a different non-uniform illumination, a spotlight/cast shadow, trying to find effects of such illumination conditions on the surface-color mode perception.

4.2 *Method*

Most of the experimental methods, including the procedures, were identical with Experiment 1 except the stimulus as described below.

4.2.1 *Stimulus*

The luminance inside a defined area was presented as an increment (brighter) or as a decrement (dimmer). In the increment, the area was perceived as if it were illuminated with a spotlight. In the decrement, it was perceived as if a shadow had been cast on it. A steep luminance gradient was set at the edge of the spotlight area.

The spotlight/shadow area was a 4.5 deg diameter circle whose position varied. In the inside condition, the center of the spotlight coincided with the area of the test stimulus. In the outside condition, the test stimulus was not included in the spotlight/shadow area. The schematic configurations of the stimulus used in the experiment are shown in Fig. 9. Figure 9(a) denotes the inside condition, while (b) denotes the outside condition. Relative luminance changes for the local illumination area in relation to the nominal stimulus luminance level were: 40%, 75%, 125% and 150% in the inside-condition, and 40% and 150% in the outside-condition. At 100% luminance level, the whole stimulus

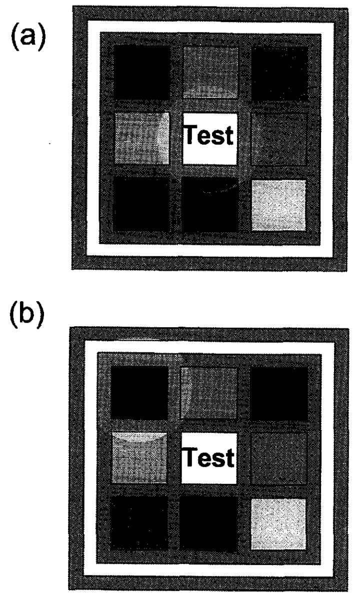

Fig. 9. The schematic representation of the stimulus used in Experiment 3. Panels (a) and (b) denote inside condition and outside condition, respectively.

appeared to be under a uniform illumination. Both the array- and the mosaic-type stimulus were used in this experiment.

4.3 *Results and discussion*

Figure 10 shows mean luminances across subjects in the array-type stimulus obtained in Experiment 3. Panels (a) and (b) indicate the results of the inside condition, and the outside condition, respectively. In Fig. 10(a), different symbols denote the different percentages of local illumination. The results under uniform illumination (100%) are shown together with open square symbols. Figure 11 shows mean luminances across subjects in the mosaic-type stimulus. The panels and symbols are the same as those in Fig. 10.

It is obvious that the upper-limit luminances for the surface-color mode changed only in the inside condition for both stimulus configurations. If the brightest area in the display simply determined the upper-limit for the surface-color mode, then the results would have to change according to changes in the brightest stimulus. In the outside condition, the highest luminance in the surrounding stimuli changed in the increment condition (150%). Our results, however, didn't show a corresponding change. This means that the subject didn't set the criterion for the upper-limit of the surface-color mode to the absolute highest luminance point in the display. Instead, the subject estimated that the brightest luminance in the display was located under a different illumination, and the subject ignored the brighter area of the white frame when judging the mode of the appearance.

Figures 10 and 11 showed almost the same change. In the mosaic condition, white was included in the inside condition while in the array-type it was not. Thus, it is more plausible that the observer can set the criterion without any help of an explicitly displayed stimulus.

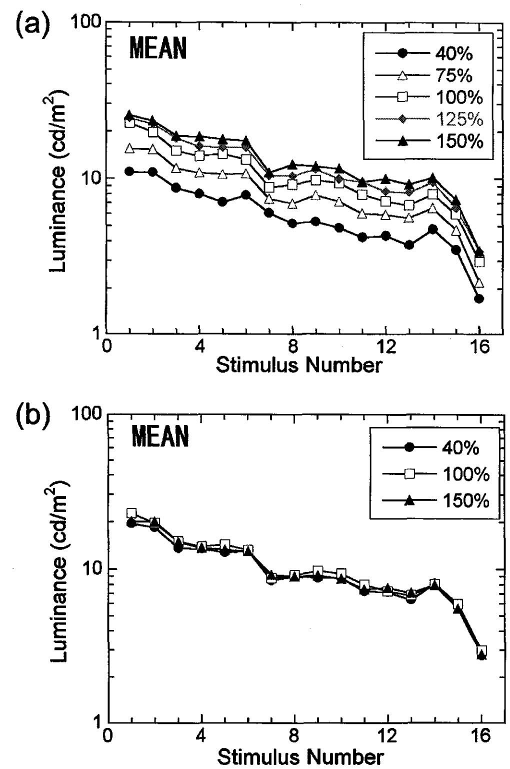

Fig. 10. The upper-limit luminances obtained with an array-type stimulus in Experiment 3. Mean luminances across three subjects are shown. Panels (a) and (b) denote inside condition and outside condition, respectively.

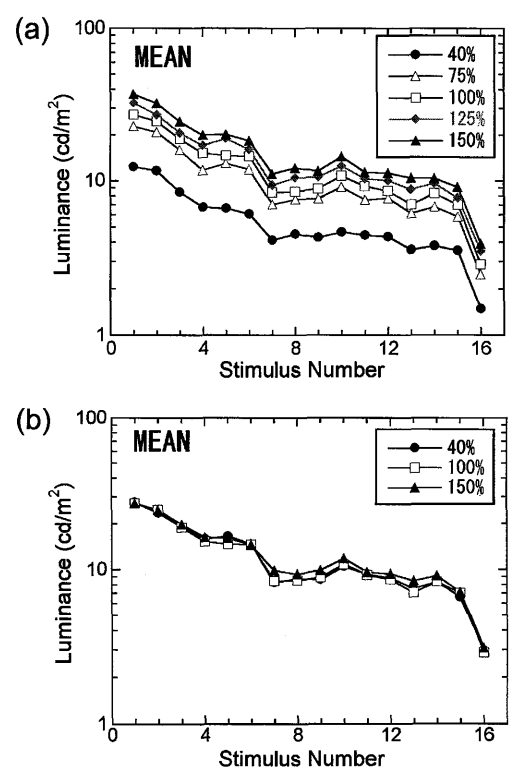

Fig. 11. The upper-limit luminances obtained with a mosaic-type stimulus in Experiment 3. Panels (a) and (b) denote inside condition and outside condition, respectively.

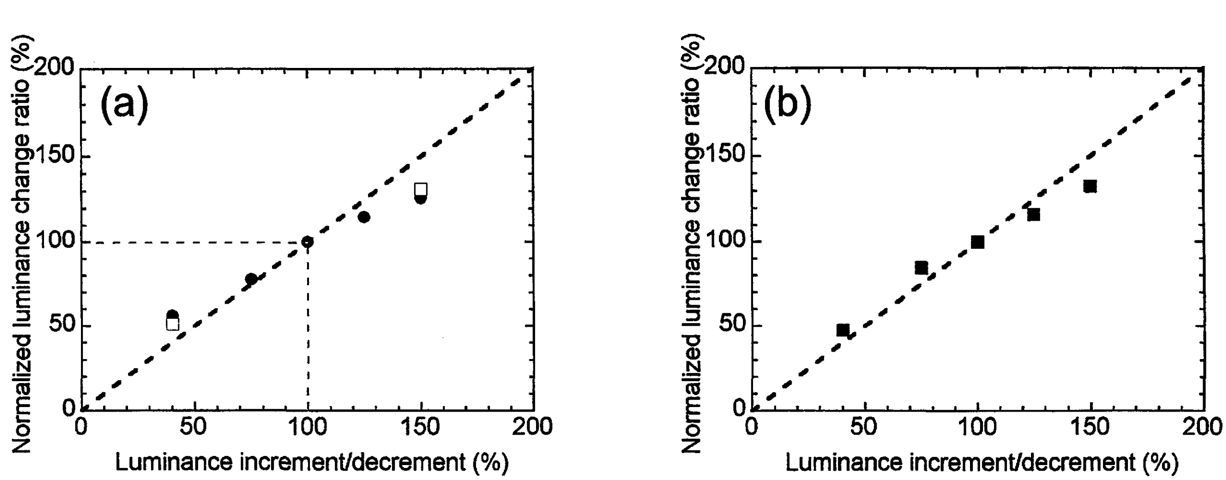

Fig. 12. Normalized luminance change ratios obtained in Experiment 3. For each color, the luminances obtained in the nominal condition (no increment/decrement) served as a standard. Panels (a) and (b) denote the normalized changes in the array-type and mosaic-type stimulus, respectively. Open squares show the normalized luminance change ratio when the entire luminance of the stimulus changed to 40% and 150%, which were reported elsewhere.[12)]

The results of Experiment 3 can be analyzed in the same way as was done for Experiment 2. In the inside condition, the upper-limit luminances for the surface-color mode changed according to the increment/decrement. Here we normalize the experimental results using those luminances of the nominal (100%) condition. By dividing the upper-limit luminance of each test stimulus by that obtained in the nominal condition, we obtained a normalized luminance change ratio as a function of intensity change. If the changes were a result of local luminance contrast, those values would be identical with the experimental change in intensity for a spotlighted or a shadowed area, providing a slope of 1.0.

The normalized values are shown in Fig. 12. Panels (a) and (b) indicate results for the array-type and the mosaic-type configurations, respectively. The abscissa indicates how much the luminance of the central area changed. A dashed line indicates the theoretical change, assuming that only the local luminance ratio causes the change in the upper-limit luminances. As shown in Fig. 12, the changes were not identical with the theoretical line in either stimulus configuration. The more the intensity changed, either by increment or decrement, the more the results departed from the theoretical line. These results show that almost the same effects were evoked regardless of the stimulus configuration. In Fig. 12(a), we plotted the normalized luminance change ratio when the luminance of the entire stimulus changed to 40% and 150%, which are shown with open squares.[12)] The luminance change ratios are close to each other, which mean that the upper-limit for the surface-color mode can be properly inferred in both cases.

5. General Discussion

It is generally supposed that judgment of the mode of color appearance is based on stimuli that are perceived as sharing the same illumination as the test stimulus. Here we discuss whether this judgment can be adopted for the estimation of the illumination in the scene. We then attempt to interpret our results with the anchoring theory.

5.1 *Is the mode of color appearance applicable for the estimation of the illumination?*

Some studies have proposed using the luminosity threshold as a probe for the judgment of the illumination.[13–15,27)] Our empirical results obtained in Experiment 2 and 3 indicate that the upper-limit luminances for the surface-color mode correctly reflects the difference between the intensity of the spotlighted area and the rest of the stimulus to some extent. These results suggest that judgment of the surface-color mode perception would be useful for the evaluation of a change in illumination intensity. However, for large changes of the intensity of illumination, the relationship is not longer linear, so the applicable range of this criterion is restricted to small luminance changes. Once the standard has been set, a certain range of the change in the intensity can be correctly estimated. We cannot conclude how the absolute criterion for the judgment was established from the information contained in the scene. We will discuss later the possibility of an anchor. Individual differences are also observed, but if the measurement for the surface-color mode was achieved in several luminance conditions, it may be possible to establish some scale for the judgment.

5.2 *CRT vs. real paper*

Next, we refer to the discrepancies of the empirical results between the experiments with a CRT and those with papers. As we described earlier, most of the studies have reported the same or the similar results, but some results show smaller effects from experiments with a monitor.[16)] Real scenes have many implicit clues for the judgment of the scene. Our previous experiments[12)] and the experiments reported by Speigle and Brainard[19)] are similar in the criterion. They measured luminosity threshold, while we measured the upper-limit luminance for the complete surface-color mode appearance. Considering the perception of the luminosity comes after the break of the surface-color mode appearance, the luminances obtained from our experiments should be lower than those by Speigle and Brainard. However, the results reported by them are much lower than our results. As we showed previously that the upper-limit luminances for the surface-color mode decreased when the surrounding stimuli were darker,[12] the luminances of the background might have affected the results. However, the luminances of the background were similar in both experiments. One big difference is that they conducted the experiment with a real paper in a room, while we conducted the experiment with a monitor. Even though the illumination was carefully set, there might have remained some non-uniformity. As we showed in Experiment 1, the direction of the luminance gradient is an important factor. They illuminated the test stimulus with a different illumination from that used to illuminate the experimental room. If the test stimulus appeared differently from the surrounds because of some factors such as a luminance gradient, the luminosity threshold could be lower, as we showed in Experiment 1 with the case of the opposite gradient condition. Our results showed that the luminances decreased to about 75% when the surrounding stimuli had a luminance gradient and the test stimulus was uniform. The differences between the results of our study and those of Speigle and Brainard are much larger, about 2 to 3 times. So merely the luminance gradient cannot explain all the differences between two researches. Schirillo *et al.* replicated the experiment reported by Gilchrist[8] that demonstrated an effect of depth perception on lightness on a CRT monitor, in which they obtained smaller effects.[28] Gilchrist suggests that the articulation of the stimulus affects the lightness perception.[29] The articulation can also explain the differences between our results and those by Speigle and Brainard.

5.3 *Anchoring theory and perceptual organization*

Finally, we attempt to explain our experimental results with an anchoring theory and perceptual organization.

In anchoring theory, the anchor that serves as a criterion for lightness scaling is set for a scene. There may exist several clues to find an anchor. Moreover, the number of anchors is not necessarily limited to one in a natural scene. Under multiple illuminations, the scene can have as many anchors, of course. Gilchrist referred to the range that a single anchor can hold as sub-frame. In this sense, the anchor can be set for each sub-frame. Our results clearly show that different anchors were set in all experiments. The spotlighted area had a different anchor than the surrounds, which nearly correctly reflects the relative intensity difference. Luminance gradients served quite effectively to isolate each area as a sub-frame. We repeated the same experiments with a sharp edge condition and obtained the same results. This means it is important to provide some information to construct the impression of a sub-frame. The results of Experiment 1 and 2 can also be explained this way. The luminance gradients helped to restrict the area where the same anchor is applicable. In this sense, it is critical to understand the way in which the scene is interpreted, or its organization. It has been reported that stimuli with the same luminance can be perceived as having different lightness depending on the configuration of the scene.[10] This is another example of the importance of scene organization. Our results indicate that observers try to interpret the scene in the most plausible way, or divide the scene into many sub-frames that share the same anchors, followed by setting anchors for each. Based on this information, detection for the light-source might be carried out.

Our results still cannot clarify how the visual system finds the anchor for the surface-color in the scene. As Ullman pointed out, many factors might be combined, and they might correlate with each other. For example, if the luminance of a stimulus is high enough we may perceive it in the surface-color mode when the mean luminance of the surrounds are also high enough, as it would be natural to think that the scene is brightly illuminated so that the stimuli look bright. The luminance of a stimulus should be much higher to be perceived in the aperture-color mode. In this case, local contrasts and average luminance are important. Further study is required to elucidate these points.

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