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Influence of Basic Color Categories on Color Memory Discrimination

Two color-memory experiments were performed to investigate whether observers tended to confuse colors with a smaller color difference in memory or colors in a same color-category region. We made color stimuli on a color CRT. Color difference was determined by a simultaneous color discrimination experiment. Color-category regions were obtained by a categorical color-naming experiment using the 11 basic color names: white, black, red, green, yellow, blue, brown, orange, purple, pink, and gray. The results show that two colors with a certain color difference can be confused more easily when they are in a same color category than in different color categories, and that colors identified with memory tend to distribute within their own color-category regions or their neighbor color-category regions, depending on their positions in a color space. These findings indicate that color memory is characterized by the color categories, suggesting a color-category mechanism in a higher level of color vision. © *1996 John Wiley & Sons, Inc.*

Key words: color memory, basic colors, color category, color discrimination, color recognition.

INTRODUCTION

There are millions of colors surrounding us. Our visual system can discriminate colors of very slight differences when two colors are presented in good viewing conditions. Among various viewing conditions, simultaneous comparison with juxtaposed fields is necessary for precise color discrimination. We do not use, however, millions of colors in our daily situations. It seems that we use several color names and their combinations to represent the colors of objects in most cases. An important difference between the simultaneous color discrimination and our everyday color discrimination is whether memory is involved when two colors are compared. We always use some color memory, unless we can see two colors in the fovea at the same time. Colors may not be precisely retained in memory, and color-appearance difference may not hold the same in memory. Therefore, in order to understand our color vision in the common circumstances, it is important to investigate how colors are retained in memory and what the characteristics of color discrimination are when memory is involved.

Some research on color memory was performed as early as a century ago.[1] Since then, there have been quite a few studies on color memory, but only a few studies are particularly concerned with color discrimination using memory.[2–18] These studies employed a successive color-comparison paradigm, in which two colored stimuli were compared with some temporal delay. A test color was first presented for a short duration, then, some seconds later, a comparison color was presented. The observer, using memory, judged whether the comparison color was the same as or different from the test color, or adjusted the comparison color to make a match to the test color in memory. It was shown in these studies that the successive discrimination threshold was greater by a few degrees than the simultaneous discrimination threshold regardless of a temporal delay up to several minutes, and that color shift occurred in memory toward somewhat the more saturated direction. There are still many questions on color memory, for example, whether there are particular colors more accurately remembered than others, or whether and how colors interact with one another in memory. No general property on color memory has yet been revealed.

Colors within a certain color region tend to be categorized under a single color name in normal situations. For example, bluish red, yellowish red, bright red, and dark red are all categorized in a single "red," even though they

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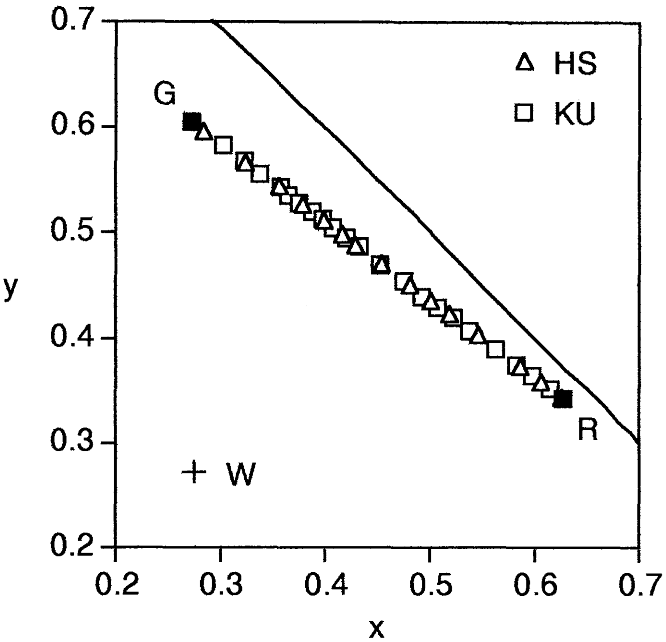

FIG. 1. CIE 1931 (x, y) chromaticity coordinates of stimuli obtained in the jnd setting in Experiment 1. Observer: HS (open triangles) and KU (open squares). R, G, and W indicate positions of red and green phosphors and the surrounding white, respectively.

appear obviously different. This implies that our visual system has the ability not only to discriminate small color difference, but also to perceive different colors as the same. Berlin and Kay[19] investigated 98 languages in the world and found 11 basic color names; white, black,

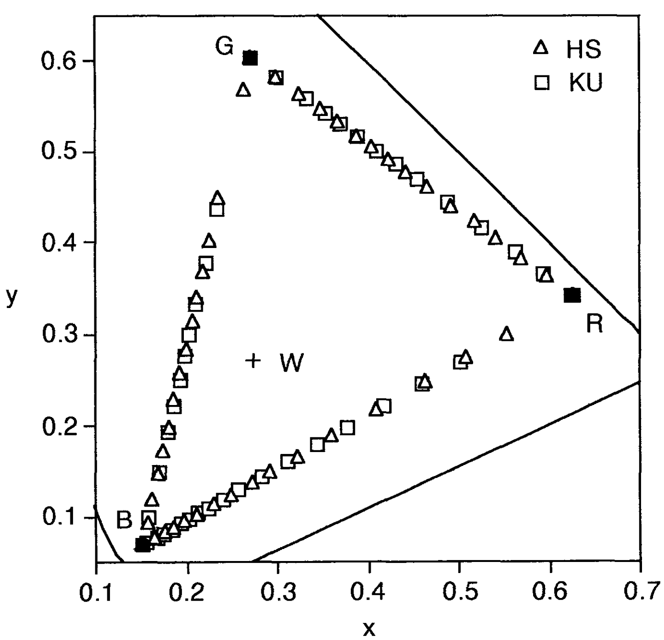

FIG. 2. CIE 1931 (x, y) chromaticity coordinates of stimuli obtained in the jnd setting in Experiment 2. Observer: HS (open triangles) and KU (open squares). R, G, B, and W indicate positions of red, green, and blue phosphors and the surrounding white, respectively.

red, green, yellow, blue, brown, purple, orange, pink, and gray, were used commonly in fully developed languages. These 11 basic colors can divide a color space into 11 regions, which are invariant for any language. Boynton and Olson[20,21] carried out experiments in which the observer responded with monolexemic color terms when presented with 424 color chips of the OSA Uniform Color Scales. They found that only 11 color names satisfied the definitions of the basic color names, and these 11 color names corresponded to the names proposed by Berlin and Kay. Uchikawa and Boynton[22] obtained the 11 basic color names of Japanese observers. They showed that each of the 11 basic color names described a fundamental color sensation that did not differ between Japanese and Americans. These results were interpreted to imply a physiological basis for categorical color sensation.[23]

Boynton et al.[17] investigated the effects of color category on color memory. They selected 55 test color samples in the region of the orange category in the OSA Uniform Color Scales. For each test sample, the nearest neighbors were selected and compared by successive comparison. The observer's task was to judge whether the test and the comparison were the "same" or "different." Their results showed that two different colors in the same color category were more frequently misjudged to be the same than two colors in different categories. This suggests that categorization occurs when colors must be remembered.

We remember many colors in our everyday lives. It might be the case that colors are categorized by a higher mechanism of color vision, and, as a result, colors in the same category are more easily confused in memory than those in different categories. In the present study, we aim to investigate whether colors are confused in memory on the basis of color difference in appearance or on the basis of categorical difference. If two colors with a certain color difference are confused equally in a color space, then we organize colors in memory based on color appearance. However, if colors with an equal color difference are not confused uniformly in a color space, but confused de-

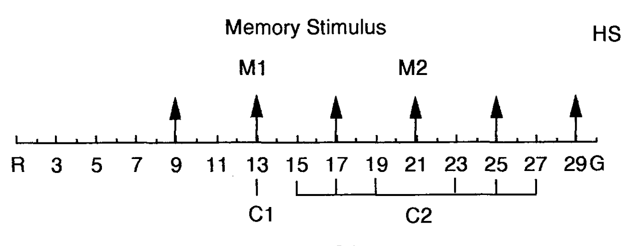

FIG. 3. An example of combinations of memory stimuli, M1 and M2, and comparison stimuli, C1 and C2, for the observer HS in Experiment 1. Six arrows indicate memory stimuli, and stimuli of 3–29 in two steps are variable comparison stimuli. R and G indicate stimuli of 1 and 30, which are the red and green phosphors.

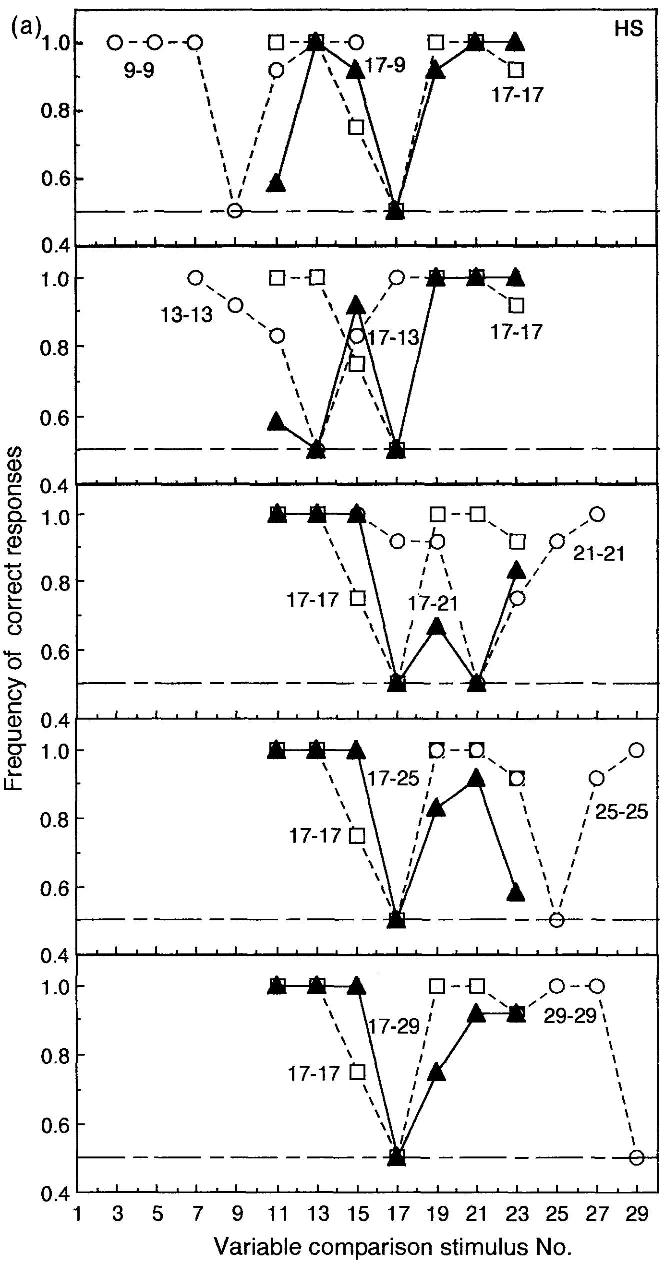

FIG. 4. Frequency of correct responses as a function of a variable comparison stimulus. Observer: HS. (a) Filled triangles: two memory stimuli are Nos. 17-9, 17-13, 17-21, 17-25, and 17-29. Open circles: two memory stimuli are Nos. 9-9, 13-13, 21-21, 25-25, and 29-29. Open squares: both of two memory stimuli are No. 17. (b) Filled triangles: two memory stimuli are Nos. 21-9, 21-13, 21-17, 21-25, and 21-29. Open circles: two memory stimuli are 9-9, 13-13, 17-17, 25-25, and 29-29. Open squares: both of two memory stimuli are No. 21.

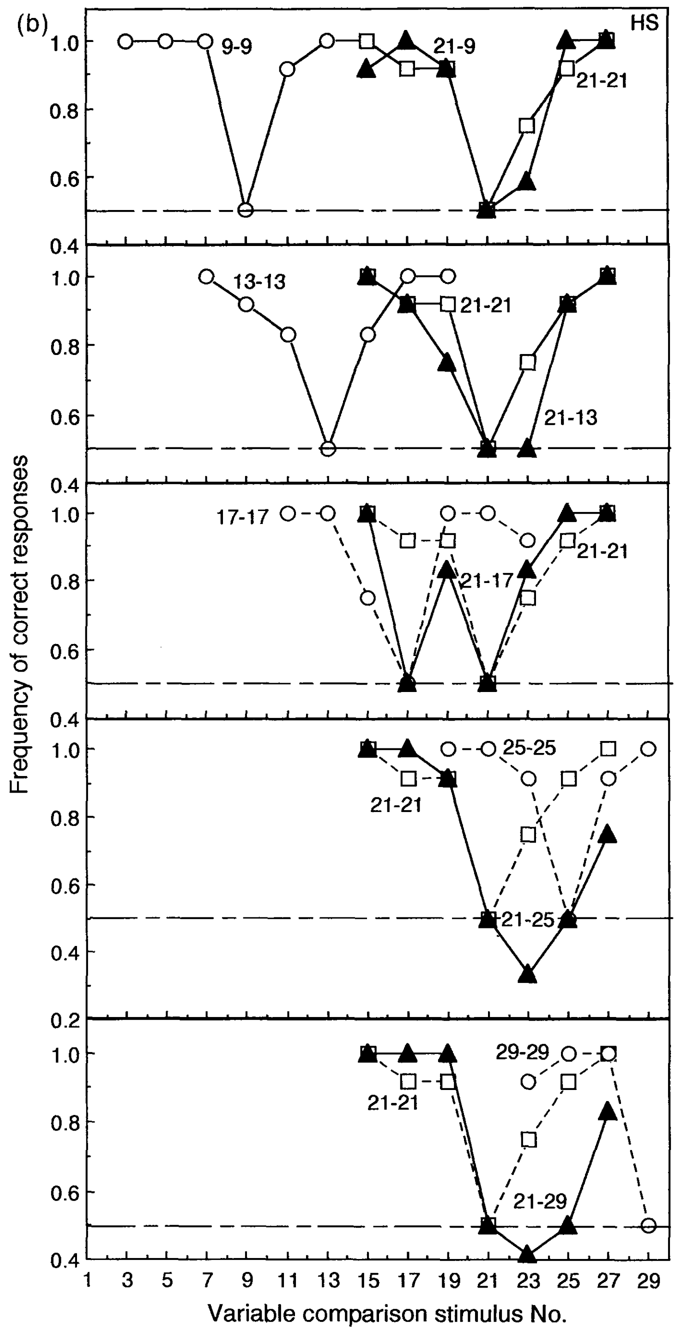

FIG. 4. *(Continued)*

pending on their positions in a color space, then color memory might be influenced by color category.

Most of the previous experiments employed a single test color and obtained results that indicated fairly accurate memory discrimination.[6,9–11,15–18] This might be, because the memory task was too easy to make colors confused in memory. We used two test colors in the present experiments to increase the observer's memory load. Two experiments were performed. In Experiment 1, we used a "same or different" discrimination judgment between test and comparison colors. In Experiment 2, an identification task was performed. The observer selected a color, which matched to a test color stored in memory, from a large number of comparison colors.

METHODS

Stimulus

We used a color CRT monitor to generate the stimuli. The CIE 1931 (x, y) chromaticity coordinates of the

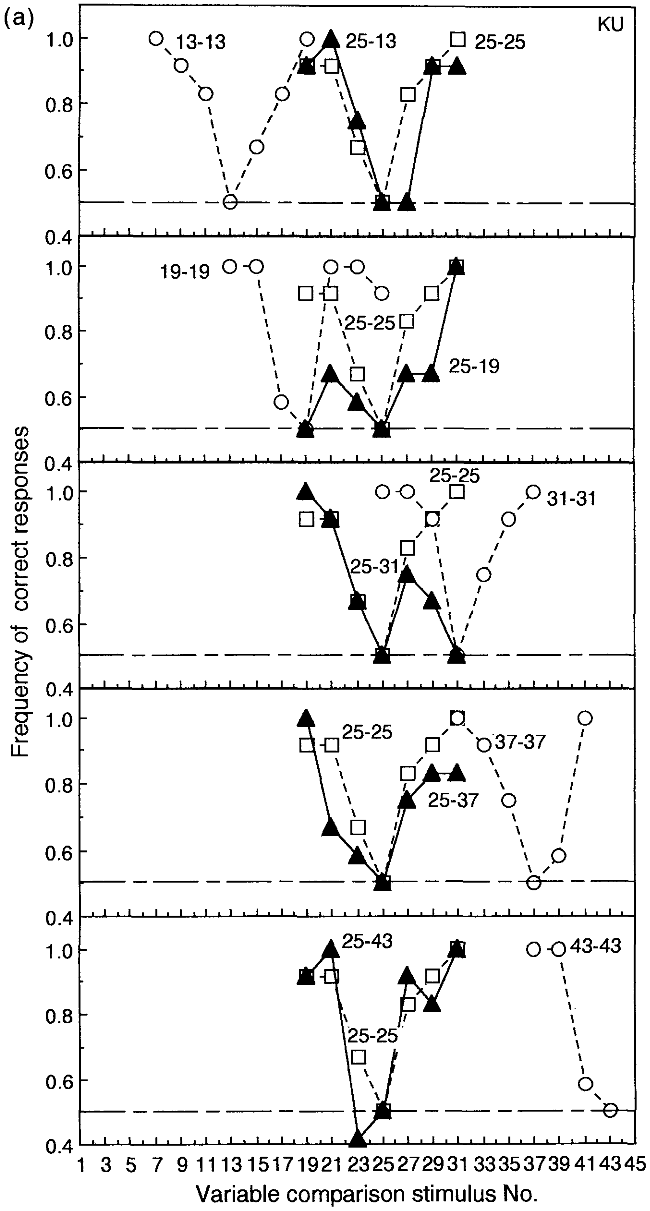

FIG. 5. Same as Fig. 2, but for observer KU. (a) Filled triangles: two memory stimuli are Nos. 25-13, 25-19, 25-31, 25-37, and 25-43. Open circles: two memory stimuli are Nos. 13-13, 19-19, 31-31, 37-37, and 43-43. Open squares: both of two memory stimuli are No. 25. (b) Filled triangles: two memory stimuli are Nos. 31-13, 31-19, 31-25, 31-37, and 31-43. Open circles: two memory stimuli are Nos. 13-13, 19-19, 25-25, 37-37, and 43-43. Open squares: both of two memory stimuli are No. 31.

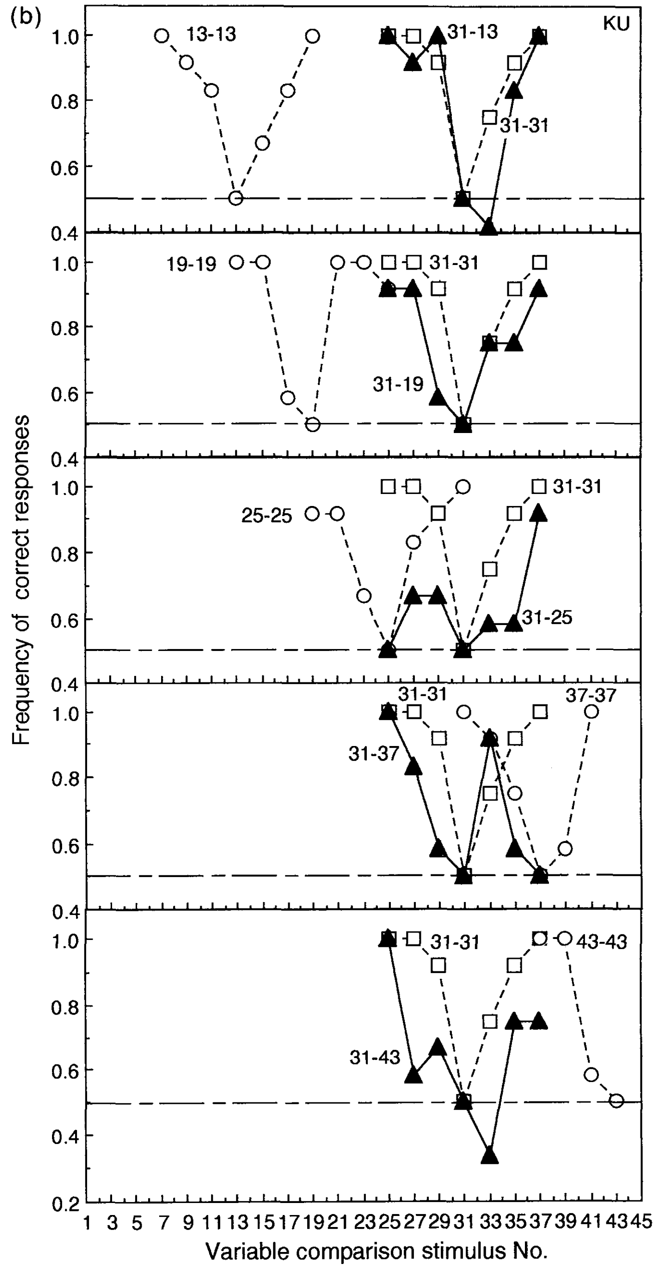

FIG. 5. (*Continued*)

green (G), red (R) and blue (B) phosphors of the CRT were (0.271, 0.603), (0.626, 0.342), and (0.152, 0.069), respectively. In Experiment 1, only the R and G phosphors were used, so that the stimuli changed on the line between the R and G points in a chromaticity diagram. In Experiment 2, two combinations of the three phosphors were used in order to make stimuli on the three sides of the hue triangle RGB.

The memory stimulus, a square subtending 2.1° of visual angle, was presented at the center of the CRT screen. The surrounding was a white square subtending 12.3° × 16.2°, whose chromaticity coordinates were (0.273, 0.272) and luminance was 15 cd/m^2. In Experiment 1, the comparison stimulus was of the same size as the memory stimulus and presented in the same position. In Experiment 2, all comparison stimuli were arranged in four color palettes. A color palette consisted of 46 stimulus squares, arranged in a 6 × 8 matrix without the upper and lower left corners. A stimulus square subtended 1.6° × 1.6° visual angle and there was a gap of 0.26° between the edges of neighbor stimulus squares.

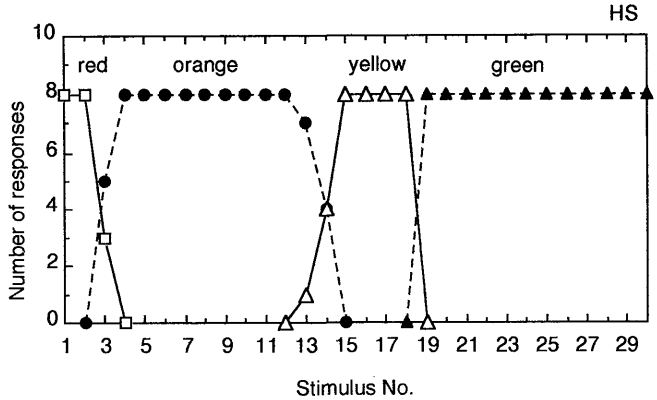

FIG. 6. Number of color-naming responses for stimuli in Experiment 1. Color names are shown along each response curve. Observer: HS.

Observers

Two male observers with normal color vision, HS and KU, 23 and 38 years of age, respectively, participated in all experiments.

Procedure

In the first preliminary experiment, a brightness matching was performed between the stimuli and the surrounding white for each observer in order to make all stimuli equally bright. These stimuli were chosen in small appropriate steps on the *RG* side of the *RGB* hue triangle in Experiment 1, and on the three sides, *RG*, *GB*, and *BR*, in Experiment 2. The observer adjusted luminance of each stimulus so that the stimulus appeared equally bright to the surrounding white. This brightness matching was repeated six times for each stimulus. The mean luminance values of these stimuli were used later to calculate a luminance value for an equally bright stimulus by interpolating those luminances.

In the second preliminary experiment, we carried out a color discrimination in the juxtaposed condition to set stimuli of equal color difference. Two square stimuli of the same size of 2.1° × 2.1° visual angle were simultaneously presented with the horizontal separation of 1.6° between their edges. The left stimulus was the reference and the right was the test. In a trial, the observer adjusted color difference of the test stimulus so that the test and the reference stimuli were just noticeably different (jnd). The brightness of the two stimuli were kept equal by a computer using the brightness matching data. In the next trial, this test stimulus became the reference in the left field and a new test stimulus was presented in the right field. As a result, a series of color stimuli in jnd discrimination steps were obtained for each observer on the *RG* side in Experiment 1 and the three sides of the *RGB* triangle in Experiment 2. Figures 1 and 2 show these colors in the CIE 1931 (x, y) chromaticity diagram, respectively.

We verified color difference of two neighboring colors in the series of stimuli obtained in this jnd setting. The two colors with a jnd difference were presented in the juxtaposed condition. The observer estimated color difference between these two colors with a number. We assigned 1, as a reference, to the color difference of the first pair of colors in these series of stimuli. The standard deviation of color difference for all pairs of the jnd stimuli turned out to be 0.060 for HS and 0.063 for KU. This confirmed that the stimuli were quite uniformly arranged in color difference steps.

In Experiment 1, two memory stimuli M1 and M2 were successively presented for a duration of 1 s with an inter-stimulus interval (ISI) of 1 s. The observer memorized these two stimuli. Then, 2 s later, two comparison stimuli C1 and C2 were presented for 1 s duration with an ISI of 1 s. One of comparison stimuli, called here a fixed stimulus, either C1 or C2, was set equal to either M1 or M2. The other comparison stimulus was used as a variable stimulus. Suppose here that C1 was a fixed stimulus set equal to M1, and C2 was a variable stimulus being different from both M1 and M2. The observer responded by indicating which comparison stimulus, C1 or C2, was the same as M1 or M2. In this case, the correct answer was C1.

If the observer can precisely store M1 and M2 in his memory, he can recognize that C1 is the same as M1. But if the observer confuses M1 and M2 in his memory, he might not be sure that C1 is correct when the variable comparison stimulus C2 is chosen between M1 and M2. In this way, it is possible to know whether M1 and M2 are confused in memory in a particular region of a color space in which they are selected.

In Experiment 1, a total of 30 and 45 stimuli for HS and KU, respectively, were provided along the *RG* side of the hue triangle *RGB*. These stimuli consisted of the series of colors obtained in the second preliminary experiment plus the colors newly selected in half-distance between the two neighboring colors in this series. No. 1 was the red-phosphor (R) stimulus and No. 30 for HS and No. 45 for KU was the green-phosphor (G) stimulus. Six stimuli: from No. 9 to No. 29 in 4 steps for HS and from No. 13 to No. 43 in 6 steps for KU, were chosen as memory stimuli. For each memory stimulus, six variable comparison stimuli were provided in 2 steps, three toward the *R* direction and three toward the *G* direction on the *RG* line. For two memory stimuli placed on the ends of the *RG* line, only three variable stimuli were provided in either of the *R* or the *G* direction. Figure 3 shows an example of combinations of memory stimuli, M1 and M2, and comparison stimuli, C1 and C2, for the observer HS. Six arrows represent all memory stimuli used for HS, and Nos. 3–29 stimuli in 2 steps are variable stimuli. In this example, C1 is set to be equal to M1 and C2 is a variable stimulus.

Ten combinations of memory stimuli were tested for each observer. They were Nos. 17-9, 17-13, 17-21, 17-25, 17-29, 21-9, 21-13, 21-17, 21-25, and 21-29 for HS,

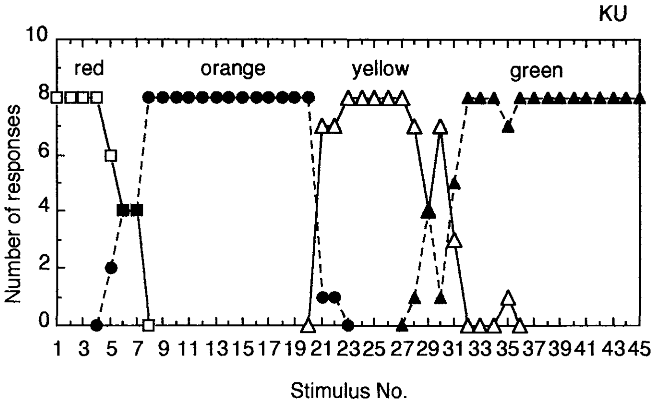

FIG. 7. Same as Fig. 6, but for observer KU.

and Nos. 25-13, 25-19, 25-31, 25-37, 25-43, 31-13, 31-19, 31-25, 31-37, and 31-43 for KU. A total of twelve trials were run for each variable comparison stimulus to calculate the frequency of correct responses. It should be noted that we selected two memory stimuli, Nos. 17 and 21 for HS and Nos. 25 and 31 for KU, called test memory stimuli, which were paired with all other five memory stimuli.

In Experiment 2, two memory stimuli M1 and M2 were successively presented for a duration of 1.5 s with an ISI of 1 s. Then, 1 s later, a tone signal of a single beep or double beeps was presented to indicate either M1 or M2, respectively. The observer recalled either M1 or M2, indicated by the tone signal, and started selecting a comparison stimulus C that was matched to the memory stimulus in his memory.

A total of 91 and 85 stimuli were prepared for observer HS and KU, respectively, in the preliminary experiment. We selected 18 test memory stimuli along the *RG*, *GB*, and *BR* sides of the hue triangle *RGB* for each observer. For each test memory stimulus a total of 11 pairs: 10 pairs with other memory stimuli and a pair with itself, were used. A total of 198 pairs were presented at random for 16 times per each pair (a total of 3168 trials). Since all 91 (HS) and 85 (KU) stimuli were used as memory stimuli paired with some test memory stimuli, it was impossible or very hard for the observer to know which stimulus was one of the 18 test stimuli during the experimental sessions.

All stimuli were used as comparison stimuli. Because the 91 (HS) and 85 (KU) comparison stimuli could not fit in the CRT screen at the same time, we used four separate color palettes, in which the comparison stimuli were arranged in the *RGB* hue order.

We performed a categorical color naming[20,22] for all stimuli used in Experiments 1 and 2 in order to obtain categorical color names of the stimuli. In this categorical color naming, the color names that the observer could use were restricted to the 11 basic color names. These naming experiments were done after the memory experiment in Experiment 1. The color-naming trials were repeated eight times for each stimulus. In Experiment 2, the naming experiments were carried out before the memory experiment, so that we could select test memory stimuli in and between categories for each observer. The color-naming trials were repeated six times for each stimulus. In Experiment 2, each observer determined focal colors that best represented color appearance of the categories in the color palettes.

RESULTS AND DISCUSSION

Experiment 1

Figures 4(a) and (b) show the frequency of correct responses for observer HS obtained in Experiment 1. The abscissa represents variable comparison stimulus from red (No. 1) to green (No. 30). In each panel of Figs. 4(a) and (b), different symbols show results in different combinations of two memory stimuli M1 and M2. Filled triangles represent conditions for pairs of two different

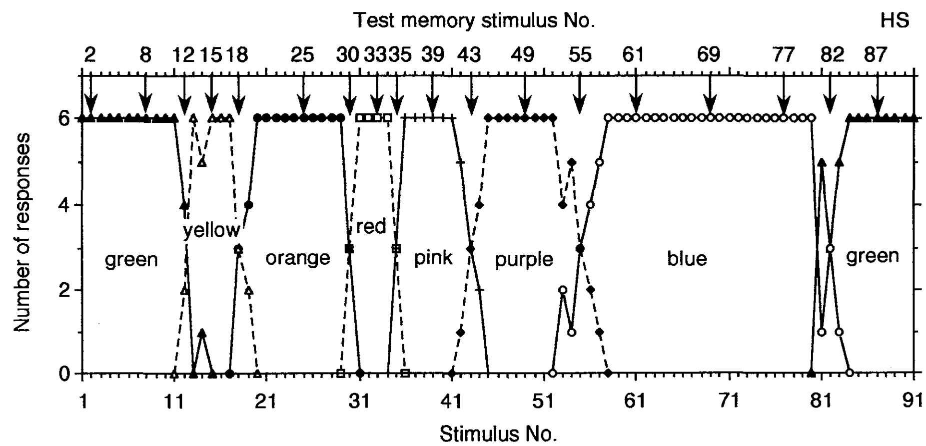

FIG. 8. Number of color-naming responses for stimuli in Experiment 2. Observer: HS. Arrows indicate positions of test memory stimuli.

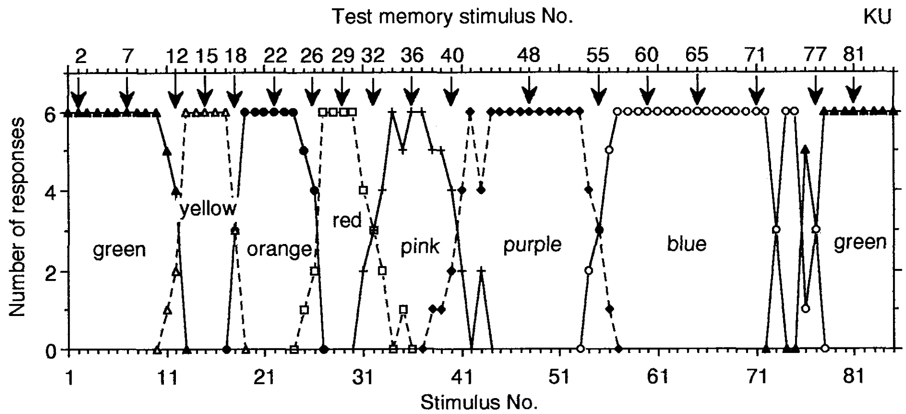

FIG. 9. Same as Fig. 8, but for observer KU.

memory stimuli; 17-9, 17-13, 17-21, 17-25, and 17-29 in Fig. 4(a); and 21-9, 21-13, 21-17, 21-25, and 21-29 in Fig. 4(b). Note that a stimulus in a pair was always 17 in Fig. 4(a) and 21 in Fig. 4(b). Open squares and open circles represent control conditions, in which two memory stimuli M1 and M2 were equal. These control conditions provide the frequency of correct responses without confusion stimulus. The stimulus numbers of the pairs are shown in the figures.

Figures 5(a) and (b) show results for observer KU. The abscissa represents variable comparison stimuli from red (No. 1) to green (No. 45). Filled triangles show conditions of 25-13, 25-19, 25-31, 25-37, and 25-43 in Fig. 5(a); and 31-13, 31-19, 31-25, 31-37, and 31-43 in Fig. 5(b). Other symbols indicate the control conditions.

Although a variable comparison stimulus (C1 or C2) was not set equal to the fixed comparison stimulus (C2 or C1) in the experiment, the frequency at the positions of C1 = C2 on the abscissa should be 0.5 since both C1 and C2 would be correct answers. Therefore, we put the value of 0.5 at the positions of C1 = C2 on the abscissa. Similarly, when C1 and C2 were not equal but C1 = M1 and C2 = M2, or C1 = M2 and C2 = M1, both C1 and C2 were also correct answers. In this case, we put 0.5 for these points.

In Fig. 4(a), it is shown that the curves of filled triangles almost coincide with an envelope curve of open circles and open squares. This indicates that two different memory stimuli M1 and M2 were precisely remembered in the same way as the control conditions of no-confusion stimulus. Therefore, there seems to be no confusion effect of the two memory stimuli in Fig. 4(a).

It is important to see the categorical color names of these memory stimuli. Figure 6 shows categorical color-naming results for observer HS. The abscissa represents test stimuli and the ordinate represents the number of color-naming responses. We know, in Fig. 6, that Nos. 9 and 13 are orange, No. 17 is yellow, Nos. 21, 25, and 29 are green. No. 17 is the only yellow stimulus and is categorically different from all other memory stimuli.

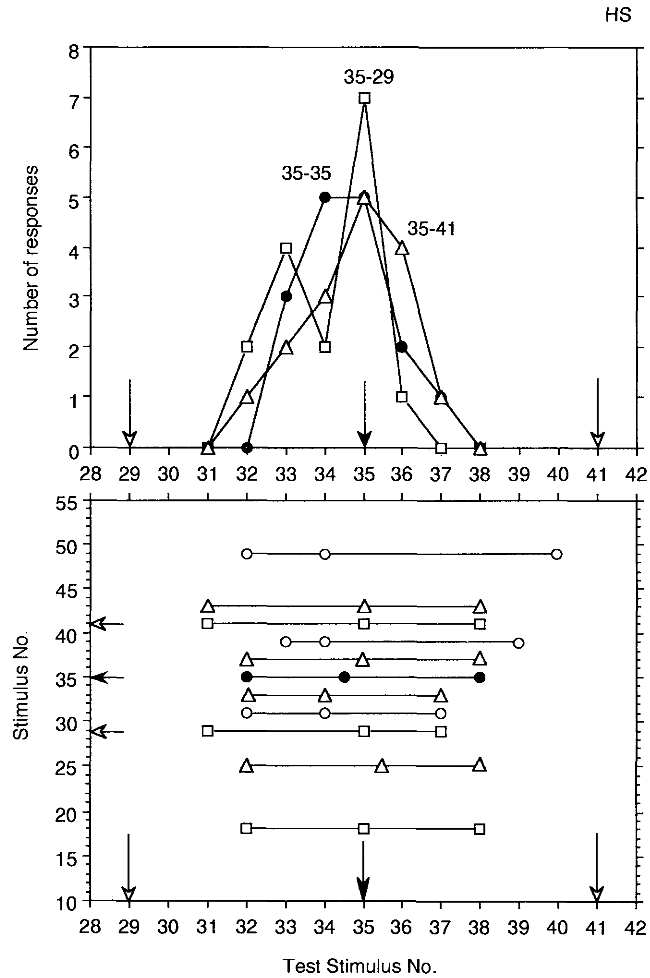

FIG. 10. An example of response distributions for a test memory stimulus. Test memory stimulus: No. 35. Observer: HS. Top panel: response curves for three pairs of memory stimuli are shown. Filled arrow indicates the test memory stimulus. Open arrows indicate two memory stimuli paired with the No. 35 stimulus. Bottom panel: Different symbols indicate peak positions and distribution ranges for all pairs of memory stimuli. The ordinate represents positions of a memory stimulus paired with No. 35 stimulus.

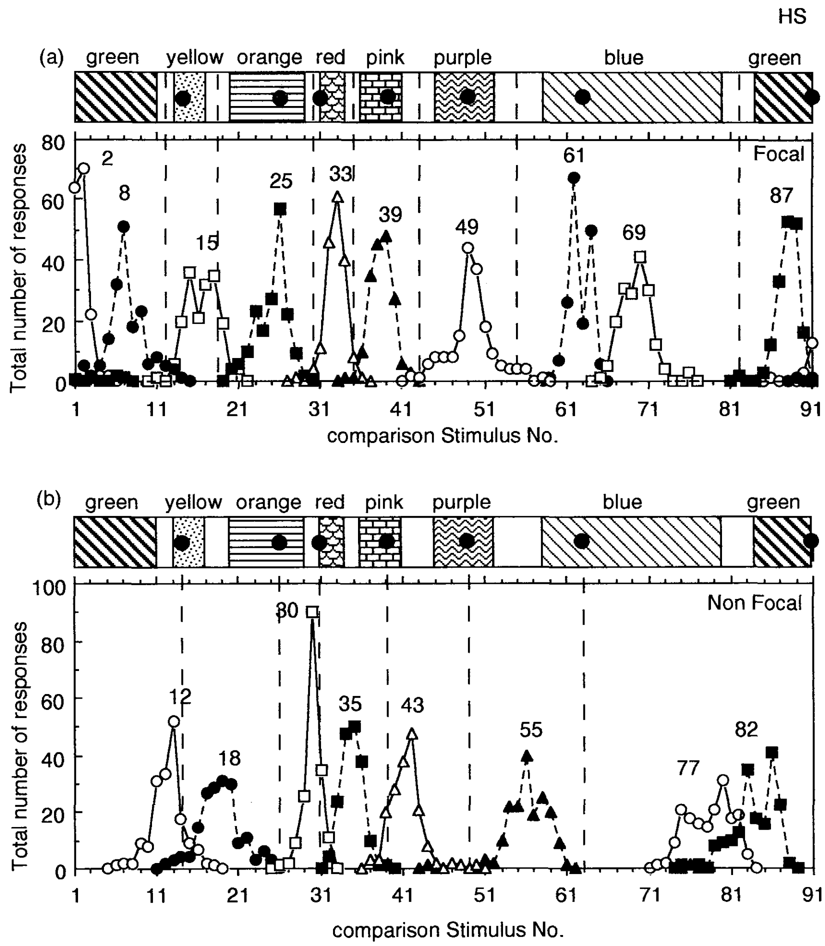

FIG. 11. Distribution of total numbers of selecting comparison stimuli for a test memory stimulus. Numbers in the figure indicate test memory stimuli. Categorical color regions are shown on the top of each panel. Filled circles indicate the focal-color positions in each region. (a) Test memory stimuli were selected near focal colors. (b) Test memory stimuli were selected between categorical regions. Observer: HS.

This might explain why No. 17 was not confused with any other memory stimuli.

In Fig. 4(b), filled triangles of 21-25 and 21-29, shown in the two bottom panels, have minima at No. 23. They are different in shape from the envelope curve of open circles and squares. The minimum values at No. 23 in both panels are lower than the chance level of 0.5, which means that the observer responded yes with confidence when the variable comparison stimulus was No. 23. In these conditions it was obvious that the observer confused two memory stimuli in his memory, and No. 23 appeared as a memory stimulus although it was not presented. It is shown in Fig. 6 that all stimuli of Nos. 21, 23, 25, and 29 are categorically green. This seems to suggest that when two memory stimuli were in the same category they could be confused in memory. It should be noted that, in the top three panels in Fig. 4(b), Nos. 9 (orange), 13 (orange), and No. 17 (yellow) were not confused with No. 21 (green), although Nos. 13 and 29 had the same discrimination step 8 from No. 21, and Nos. 17 and 25 had the same discrimination step 4 from No. 21.

In Fig. 5(a), this kind of confusion did not take place, probably because, as shown in Fig. 7, No. 25 was in the yellow category, but none of the other memory stimuli is in the same category; Nos. 13 and 19 are in orange, No. 31 is in yellow/green, and Nos. 37 and 43 are in green. In Fig. 5(b), No. 31 was common for all panels. No clear confusion effect was observed in this figure, except for a weak effect in the bottom panel. It seems that, because No. 31 was just on the border of the yellow and green categories, neither yellow nor green, it was not confused with yellow or green memory stimuli.

Experiment 2

Figures 8 and 9 show categorical color-naming responses of observers HS and KU, respectively, in Experiment 2. The 18 test memory stimuli, indicated by arrows, were selected in and between these categorical regions. For each test memory stimulus, 11 variable memory stimuli were chosen in the same category, neighbor categories, and between these categories.

In Experiment 2, combinations of two memory stimuli did not show any systematic effect on the distribution of selecting test colors. An example is shown in Fig. 10.

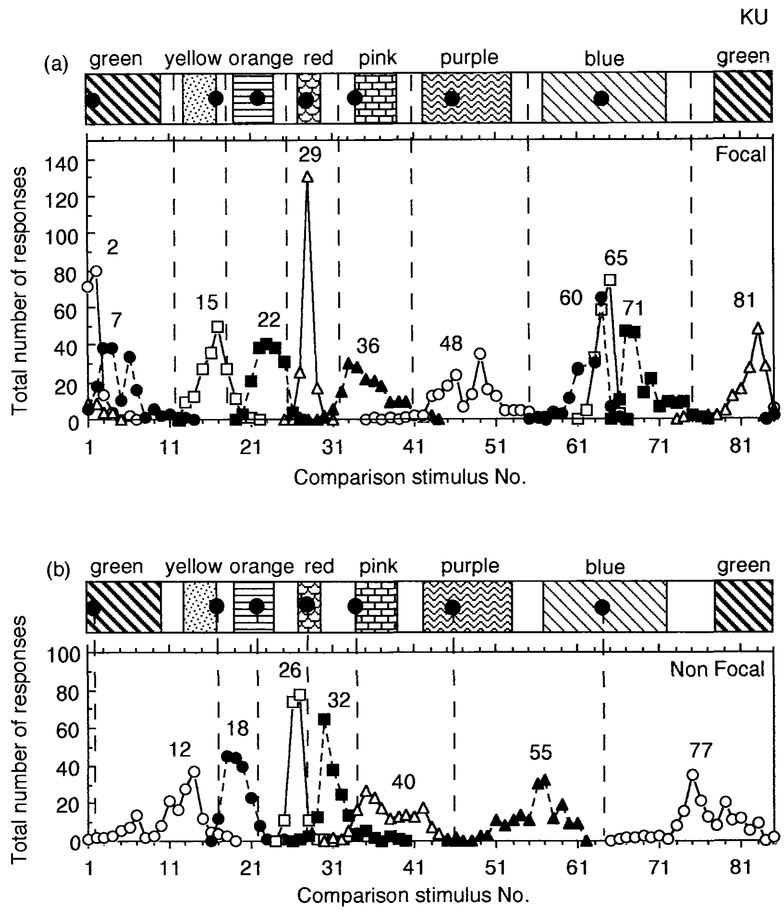

FIG. 12. Same as Fig. 11, but for observer KU.

In this figure, the test memory stimulus is No. 35, which is located between red and pink categories. The top panel shows three curves of responses for pairs 35-29 (open square), 35-35 (closed square), and 35-41 (open triangle). These three curves coincide well on the peak position and in the distribution range. In the bottom panel, the peaks and distribution ranges are shown by symbols and horizontal lines for all paired memory stimuli. These peaks and ranges do not differ systematically.

All other test memory stimuli yielded similar tendencies for their distributions. This would indicate that no clear confusion effects took place between memory stimuli. This tendency of the results seems inconsistent with that of Experiment 1. A possible reason might be the task difference between Experiments 1 and 2: the "same or different" judgment was required in Experiment 1, but an identification task was employed in Experiment 2. The identification task would be less sensitive to the slight memory effect, yielding a large response distribution for a test memory stimulus.

We combined all responses collected for a test memory stimulus, and showed this combined distribution in Fig. 11 for observer HS and Fig. 12 for observer KU. The distribution for a test memory stimulus near the focal color is shown in the top panel, and the distribution between categories is shown in the bottom panel. Numbers in the panels indicate test memory stimuli. Categorical color regions are also shown on the top of each panel. They were determined in Figs. 8 and 9 as regions that were consistently named the same basic colors all six times. Filled circles in the categorical regions indicate the focal-color positions.

In Figs. 11 and 12, some significant characteristics of the distribution of responses are found. First, the distribution range for each test memory stimulus is not the same. Second, the distributions of colors near focal colors, shown in the top panels, extend within their categorical color regions. Third, the distributions of colors between categorical regions, shown in the bottom panels, extend approximately to the focal-color positions, except in blue-green region for HS.

These characteristics imply that color variation in memory is determined not by color difference based on simultaneous color discrimination, but by the width of the categorical color region. A color near its focal color in a color category can vary only in the color category region. A color in a border region between two color categories tends to be confused only with colors in the neighbor categories. It is concluded that proximity of colors in memory is completely different from that in appearance, and that the color memory is characterized by the basic color categories.

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