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INFLUENCE OF ACHROMATIC SURROUNDS ON CATEGORICAL PERCEPTION OF SURFACE COLORS*

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Abstract—Color samples selected from the OSA Uniform Color Scales set were seen isolated in a dark field, illuminated by hidden projectors. These appeared as self-luminous aperture colors when thus isolated. We employed a categorical color-naming procedure to assess color appearance. Achromatic surrounds of 33 min width, if adjacent to samples subtending about 2.2 deg, were sufficient to render normal categorical surface-color perception. As the size of surrounds decreased, color naming shifted from that normally observed in the surface-color mode to that appropriate to the aperture-color mode. For isolated samples, brown was almost never seen, being most often replaced by orange; a white border less than one-sixtieth the width of the color samples was sufficient to restore its perception in an otherwise dark field. The reflectance of the surround and the gap between test and surround stimuli were also examined and found to be important factors in surface color perception, whereas the overall luminance level was not.

Color vision   Categorical color perception   Surface color   Surround effects   Mode of perception   Brown

INTRODUCTION

Two modes of color perception, the surface-color and aperture-color modes, can be observed depending upon whether surfaces or isolated patches of color are presented (for summaries, see Evans, 1974; and Boynton, 1979). In the aperture-color mode, with no surround, a given spectral radiance distribution generally does not appear as it would in the surface-color mode. In the latter case, the color appears to be attached to a definite object in the visual scene and is influenced also by other colors in the visual field. However, such spatial influences are not limited to surface colors, but are also known to occur in otherwise isolated situations, where no surfaces are seen, and with as few as two colors (Fuld, Werner & Wooten, 1983; Werner, Cicerone, Kliegl & DellaRossa, 1984).

Two basic color sensations, brown and black, require surrounds for their production. Although it is convenient to use real color samples, as we have in this study, and as Bartleson (1976) did in his study of brown, their use is not required to study the perception of surface color. It is possible instead to produce the surface-color mode of viewing with self-luminous displays. For example, brown and black have been observed with simple center-surround configurations in Maxwellian view (Fuld et al., 1983; Werner et al., 1984), and Arend and Reeves (1986) studied the surface-color mode of perception using a CRT display. It is commonplace, furthermore, that blacks and browns are readily perceived in color TV images, most of which simulate complex scenes in which real objects are represented.

The converse, the perception of a real surface color as if it were not, is also possible to achieve. One classical way to obtain an aperture color using a reflecting color chip is to use a reduction screen. However, this necessarily introduces a surround field, which would be unsatisfactory for our purposes. We sought instead to achieve a texture-free reflecting sample, suspended in a dark void without visible means of support and spotlighted by a hidden source. In the experiments to be reported, we achieved this condition and thereby were able to gauge the perceived colors of reflecting samples seen without surrounds. For this condition, the samples appear as isolated, self-luminous aperture colors. The results from this condition served as a reference

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against which to compare changes in color appearance caused by introducing achromatic surrounds of various sizes, reflectances, and locations relative to the test field.

To assess the perceived color of an isolated field, one should use a method that does not require a comparison stimulus, the very presence of which is likely to affect the appearance of the test field (Bartleson, 1979; Fuld et al., 1983). Boynton and Olson (1987) developed a categorical color-naming procedure that meets this criterion. Their method of categorical color naming, also employed here, revealed 11 basic colors, ones that have been suggested as being physiologically basic as well (Ratliff, 1976). The method has also proved useful for assessing the color perception of color-deficient subjects (Montag & Boynton, 1987), color rendering (Boynton, 1987), and the color perception of observers who are native speakers of very different languages (Uchikawa & Boynton, 1987). To develop a fuller understanding of the properties of categorical color space, it is of interest and importance to study how the basic colors change with surround conditions.

EXPERIMENT 1

Method

Stimulus materials. The color samples, each 5.1 cm square, were selected from the 424 samples of the OSA Uniform Color Scales set (see Boynton & Olson, 1987, for references). The OSA colors are specified by L, j, g coordinates, which represent lightness, blue-yellow, and red-green axes respectively. From these, we chose 215 samples that include all of the even-numbered OSA lightness levels (L), which range from -6 to $+4$. In other experiments (Olson, 1988), we have shown that this so-called "half set" is sufficient to yield results that differ in no important way from those obtained with the full set of 424. Some of the color chips exhibited tiny artifacts at their edges that exposed their white substrate; these bright white specks were eliminated by careful application of black paint so that, when illuminated, only the appropriately colored surfaces of the samples were perceptible.

Apparatus. Fig. 1 illustrates the apparatus that we constructed for the present experiments. A test sample, placed by hand on a vertical, floor-mounted pipe open at its upper end, was illuminated by slide projectors from both sides, so that the specular component of reflection from the glossy OSA sample would be invisible to the subject. By means of suitably-shaped apertures placed in the slide planes of the projectors, light was permitted to escape past the sample only to the minimum extent necessary to ensure that the color sample was fully and uniformly illuminated. Precautions were taken to trap this light, as well as the specular reflection from the color samples.

A mirror was placed at a 45-deg angle above the test sample so that the square patch of color

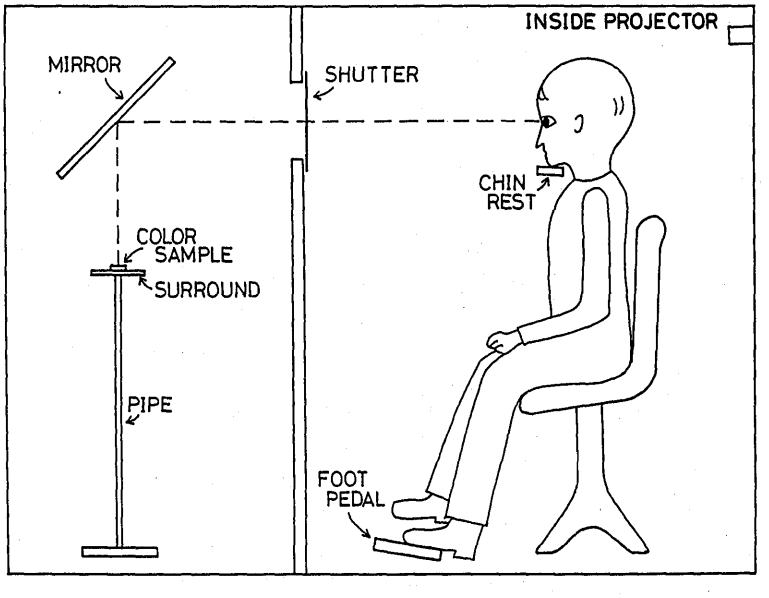

Fig. 1. Schematic view of the experimental arrangement. The projectors used to illuminate the color sample and its surround are approximately at right angles to the plane of the diagram and are not depicted.

was seen in a vertical orientation in a completely dark space, directly in front of the subject and without any visible means of support—a circumstance so unlikely for a real, reflecting surface that the naive subjects were fully convinced that they were seeing self-luminous colors, produced in some unknown way. Even for the three of us who knew otherwise, this illusion was difficult to escape. The subject, sitting in a lightproof booth and positioned by means of a chin rest, saw the test sample binocularly through a 18 × 17 cm opening in a black panel located 60 cm in front of his head. A black shutter blade, which when closed obscured the viewing aperture, blocked the subject's view of the between-trial activity of the experimenter, who removed and replaced color chips.

The shutter was controlled mechanically by the observer by means of a foot pedal. The test sample was seen at a distance of 133 cm, where it subtended 130 min of visual angle. Inside the subject's booth, a tungsten lamp dimly illuminated the front panel and shutter, providing a luminance of 0.5 cd/m^2, which was maintained to prevent full dark adaptation, which we have informally observed to interfere with central color perception (for example, green appears desaturated when the eye is fully dark adapted). Release of the foot pedal simultaneously opened the shutter and opened a switch extinguished the booth light.

For some conditions, a surround was introduced by means of a neutral gray card of 20-pct reflectance upon which the sample was placed. The spectral reflectance of this gray is flat within 0.05 log unit from 450 to 700 nm. The apertures in the slide plane of the projectors were suitably enlarged to accommodate the larger beam needed to fully illuminate the gray surround. Balance of the gray card upon the pipe, which otherwise would have been nearly impossible to maintain, was achieved by attaching a string to the bottom of the card. A weight, attached to the other end of the string, was dropped through the open end of the pipe, thus lowering the center of gravity of the card-string-weight combination, while also keeping it centered. The card was, however, free to rotate if disturbed; although considerable skill was developed by the experimenters (KU and HU) in the placement and removal of samples, we cannot claim perfect alignment of backgrounds and samples. The luminance of the gray surround card was 81 cd/m^2. This luminance level was kept constant for all surround conditions in Expt 1.

Procedure. Except that response times were not recorded, the categorical color-naming procedure of Boynton and Olson (1987) was used. All color samples were presented twice to each observer, first in a random order and then once again in the reverse of that order. Following the presentation of each color sample, the observer responded with any monolexemic (single word) color term that came to mind. No modifiers or hyphenated terms were allowed.

For 5 min at the beginning of each session, the observer was adapted to the dim illumination inside the booth. On each trial, the experimenter placed the test sample in position and signaled the subject, who released the foot pedal to open the shutter and extinguish the booth light. After responding (there was no time limit, but this seldom took more than 2 or 3 sec), the observer depressed the foot pedal to close the shutter and restore the illumination inside the booth. The experimenter recorded the response on the keyboard of a microcomputer programmed to indicate stimulus order and to record the responses in a form suitable for subsequent analysis, and then replaced the color sample for the next trial.

In addition to the no-surround condition, two sizes of square gray backgrounds were used upon which test samples were placed to provide surrounds having widths of 33 and 264 min. These will be referred to as the no-, small- and large-surround conditions.

Observers. Six observers were employed in the present experiments (see Table 1). HU, KU, and RMB (the authors) were experienced subjects, whereas KH, SG, and ED were naive. All were color normals as evaluated with the Farnsworth–Munsell 100-hue test. Three observers were native speakers of English, three of Japanese. Uchikawa and Boynton (1987) showed good correspondence, both in consistency of usage and in centroid locations of equivalent basic color terms, between speakers of these two languages. Here we report for the Japanese subjects the English equivalents of the basic color terms they used.

Table 1. Sex, age, and language used by the observers of this study

	Observers					
	RMB	KU	Hu	KH	SG	ED
Sex	M	M	F	F	F	M
Age	62	36	35	34	19	20
Language	E	J	J	J	E	E

E: English; J: Japanese.

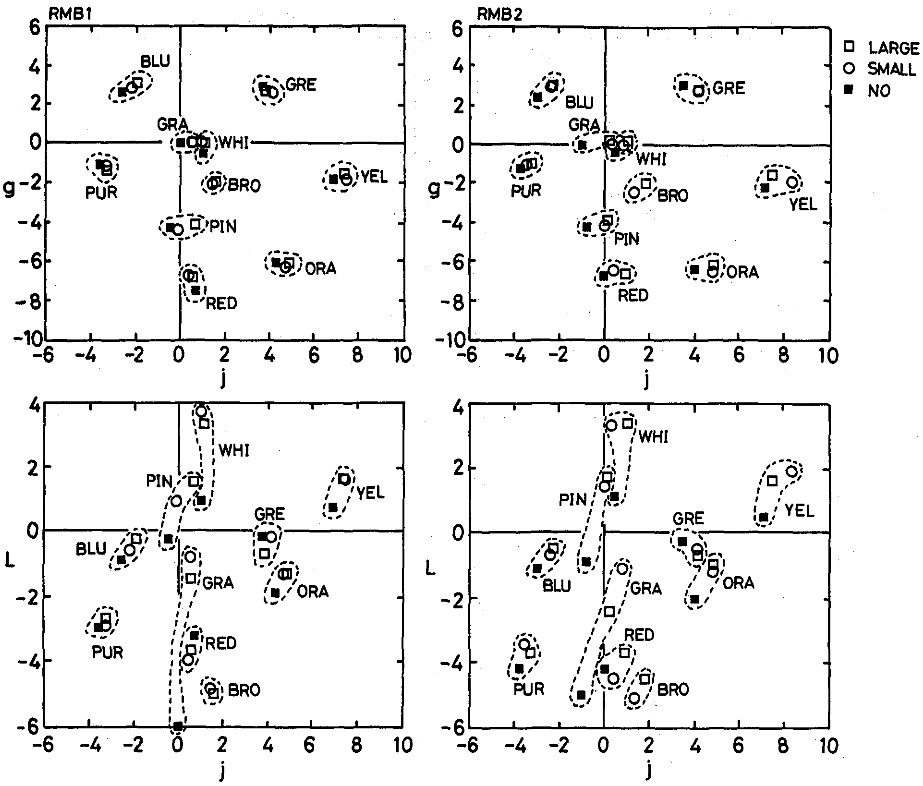

Fig. 2. Expt 1: centroid locations for the large-, small- and no-surround conditions. Centroids are computed by averaging the *L*, *j*, *g* values for all samples called by a particular name, weighted according to whether the name was used once or twice. Data are for subject RMB for two replications of the experiment.

Results and discussion

Centroids. As a check on reliability of measurement, subject RMB was examined twice. Figure 2 shows the centroid locations of the basic colors for these two replications, with the chromatic *j*, *g* locations represented in the top panels, and the achromatic *L* values plotted against *j* at the bottom. Different symbols are used to distinguish the three surround conditions. The correspondence between the two sets of data appears acceptable. Figure 3 shows the same type of plot for the average of the six observers, including RMB's first replication. Although examination of other individual plots (not shown here) reveals some minor idiosyncrasies, it is clear from a comparison of Figs 2 and 3 that RMB's data are representative of the mean data.

The *j*, *g* positions of most basic colors are little affected by the surround conditions used, except that no subject used the term brown in the no-surround condition. For most colors, *L* values moved significantly downward, consistent with an increased lightness caused by removal of the surround. A small but systematic

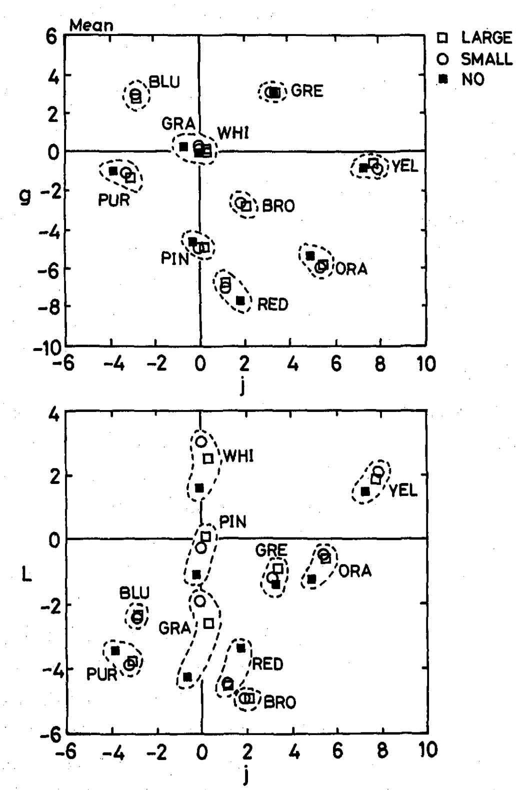

Fig. 3. Expt 1: centroid locations for the large-, small- and no-surround conditions. This is the same as Fig. 2, except that mean data for 6 subjects are shown.

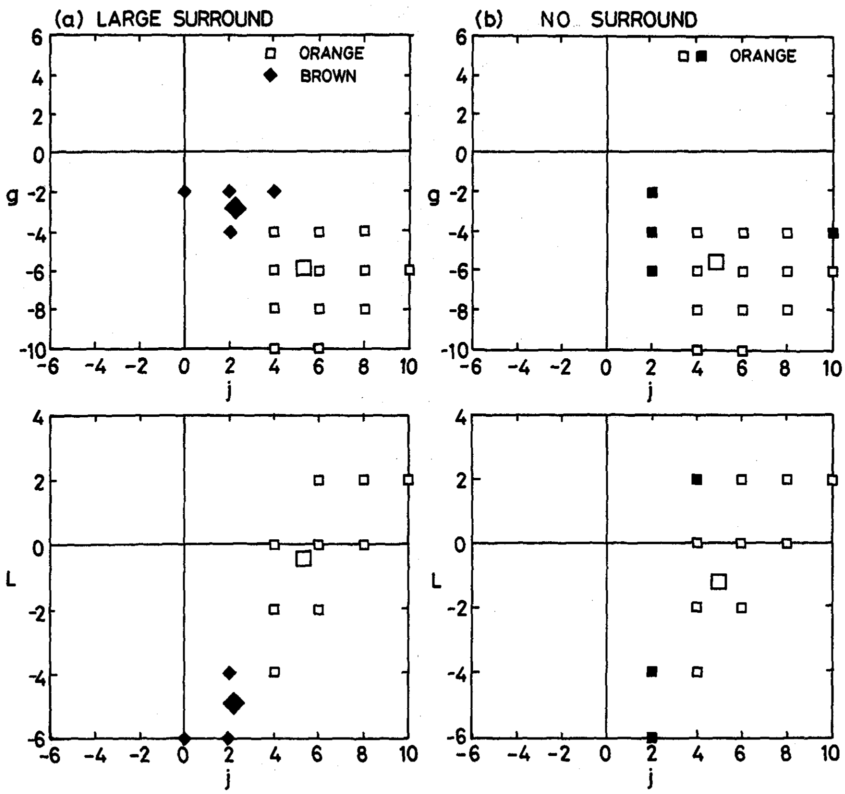

Fig. 4. Expt 1: distribution of color samples, projected into the *j*, *g* plane, that were named orange or brown more than six times (out of a possible 12 for all observers), for the large surround (left) and no surround (right) conditions. The large symbols represent centroid locations. The solid symbols in the right-hand panels represent locations where orange appears when the surround is removed.

shift in the *j*-direction is also observed for most colors. Both surrounds seem to show approximately the same effects.

Two Japanese observers (HU and KH) did not use *ao* (blue) in the no-surround condition, but instead used the nonbasic term *mizu* (light blue). Only two subjects used black, and then only when surrounds were present. Black, which is not plotted in Fig. 3, is poorly represented in the OSA set.

Figure 4(a) shows the distribution of color samples that were named orange and brown on more than 6 of a possible 12 occasions by all observers in the large-surround condition. The large symbols represent centroid positions of orange and brown replotted from Fig. 3. The orange and brown regions (open and solid symbols, respectively) are well separated in Fig. 4(a). Figure 4(b) shows the distribution of orange responses in the no-surround condition, where dark symbols indicate positions added when the surround is completely removed. As already noted, there is no brown response for this condition. It seems clear that the orange region of the large-surround condition expands into the previously brown region when the surround is removed.

Numbers of responses. Figure 5(a) shows, for RMB, the number of color-name responses for the three surround conditions, and Fig. 5(b) displays the equivalent mean data for six subjects. In the lower panels of the figure are shown the differences in numbers of responses relative to the large-surround condition. When the surround is removed, brown, purple, and blue responses decrease, whereas orange, pink, and white responses increase. But again there is only a small difference between number of responses in the small- and large-surround conditions, with the major effects being reserved for the no-surround condition.

As already mentioned, all observers reported a self-luminous appearance of colors under the no-surround condition. Although the three naive observers had no idea that the isolated colors were chips illuminated by hidden projectors, the color chips appeared as surface colors for all observers under the small- and large-surround conditions. Therefore, it is likely that the differences in color naming responses

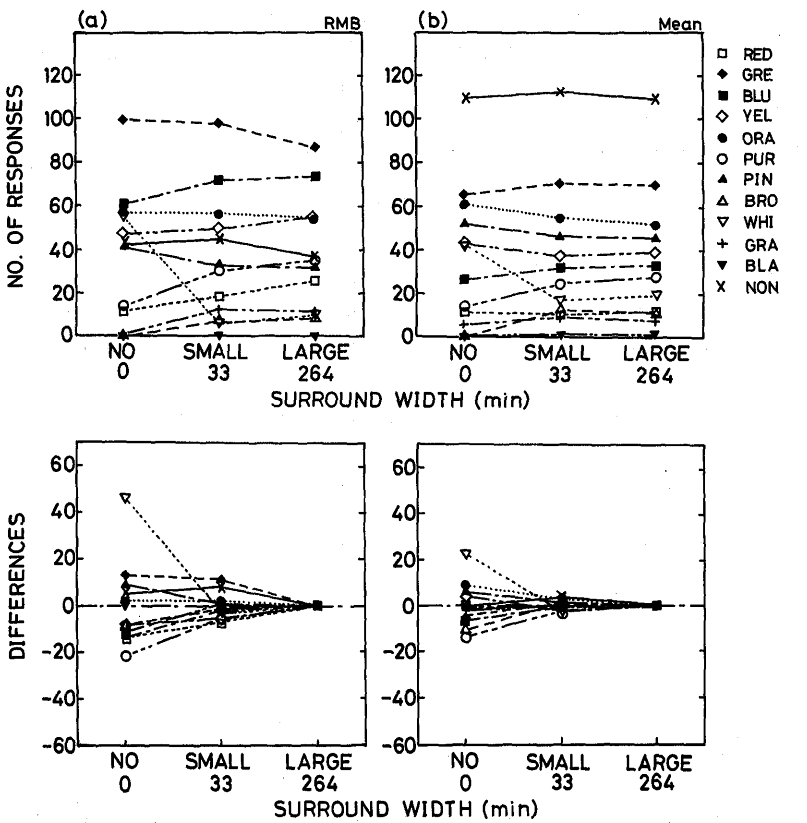

Fig. 5. Expt 1: the numbers of each of the basic color name responses used by subject RMB (upper-left panel) and for the mean of 6 subjects (upper-right panel). Nonbasic responses are grouped together to form one category. The lower panels normalize the upper values for the large-surround condition to show the response differences that pertain when the surround is made smaller (middle points) or eliminated altogether (leftmost points).

obtained with and without surrounds were caused not only by the presence of the surrounds, but also by the shift from the surface-color to the aperture-color mode of perception.

The number of times a basic color term is used consistently (named twice with the same basic color term within observers), divided by the number of total uses of the basic color term, defines a *consistency ratio*. These ratios are shown in Fig. 6. Each symbol represents the no-, small- or large-surround condition. The ratios are nearly the same for the small and large surround conditions, but those for the no-surround condition give the lowest values. It seems likely that the appearance of color chips is less stable, and that they are more difficult to name, in the aperture-color mode than in the surface-color mode.

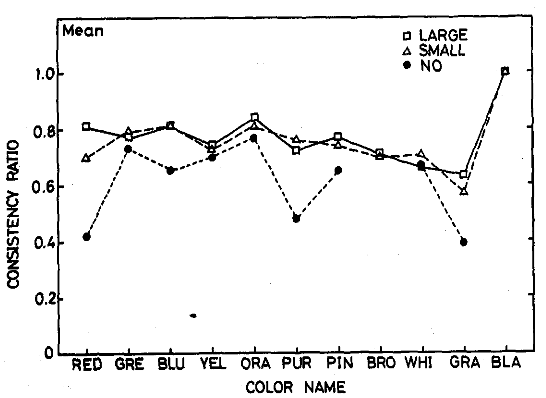

Fig. 6. Expt 1: consistency ratios for basic color terms, defined by the number of occasions on which color chips were named twice using a term, divided by the number of total uses of that term. Based on with-subjects data; mean of 6 subjects.

EXPERIMENT 2

In Experiment 1, as previously noted, brown was never seen in the no-surround condition. This indicates that its perception depends critically on having a surround present (Fuld et al., 1983). Except for black, about which we have little data, this property of brown is different from all of the other basic colors, including gray. The two surround widths differed little in

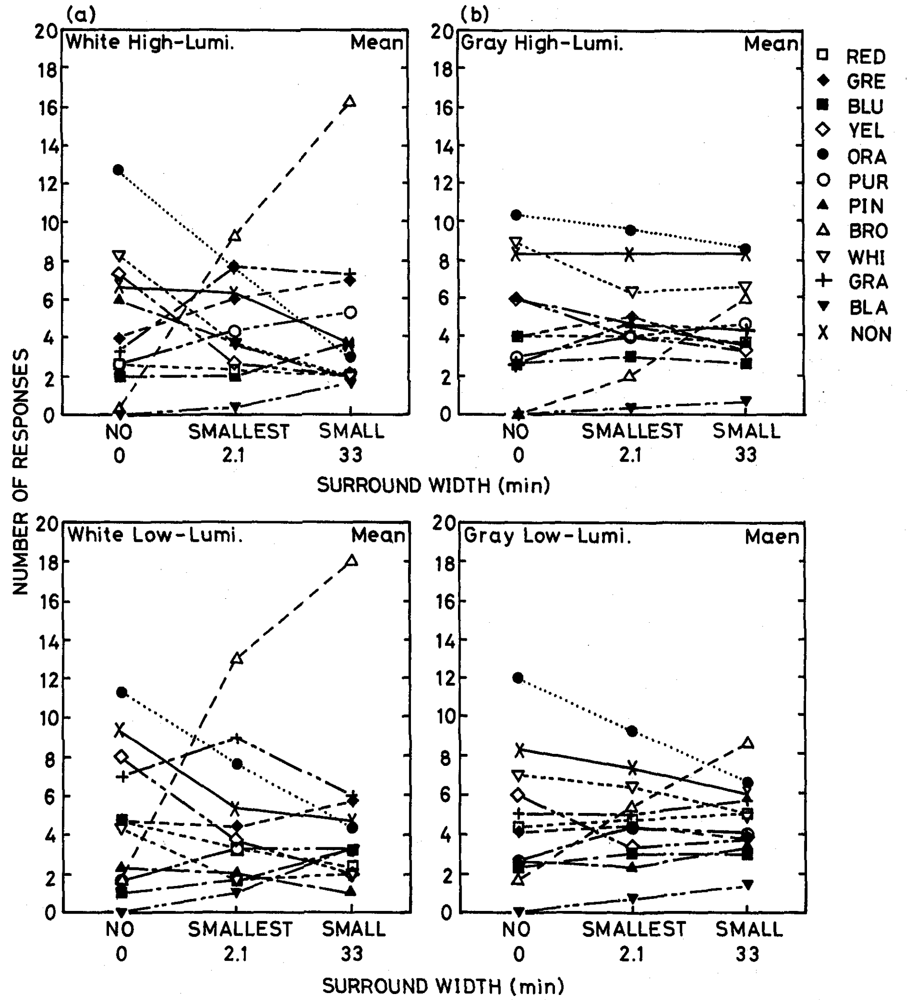

Fig. 7. Expt 2: mean results (3 subjects), where the width of the surround was varied under four conditions: high luminance (upper panels), low luminance (lower panels), white surrounds (left-hand panels), and gray surrounds (right-hand panels).

their effects. Experiment 2 introduced a much narrower surround width and also examined the influence of white surrounds and lower overall luminances.

Method

Changes in conditions from Experiment 1. In Expt 2, we used white surrounds of 75 pct reflectance, as well as the 20 pct gray surround of Expt 1. The spectral reflectance of the white is almost flat, similar to that of the gray. In addition to the 81 cd/m^2 luminance level of the gray surround card, a level of 8.1 cd/m^2 was achieved by placing 1.0 neutral-density filters over the projector lenses. These conditions were used in all possible combinations. To compensate for the larger number of conditions, as well as to focus attention on the perception of brown, the number of test samples was reduced to 28. Eight of these were selected from the brown region of Expt 1. To provide an appropriate context, as well as to gauge (though necessarily more crudely) the effects of the new conditions upon other colors, two samples were added from each of the other 10 basic-color regions. Only three subjects (RMB, KU, and HU) were used.

Achieving very narrow surrounds. Two widths used, in addition to the no-surround condition, were 2.1 min and 33 min. The latter is the same as the small width of Expt 1, and was achieved in the same manner as before, by placing the samples upon gray or white backgrounds; again it will be designated as "small." The very narrow 2.1-min surround, designated as "smallest," could not be reliably achieved by placing samples against a background just barely larger than the samples. Instead, strips of gray (or white) paper were precisely glued to the outer edge of each of the 28 samples; during the experiment, these were placed on the pipe, just as in the no-surround condition of Expt 1. Of course, the strips reduced the area of the samples slightly, but this effect is almost surely negligible.

Results

Because the results for the three subjects were again quite similar, only the mean data are presented. Figure 7(a) shows the numbers of basic and nonbasic color names, for the high (upper panel) and low (lower panel) luminance levels when white surrounds were used. All responses using nonbasic color names are combined into a single nonbasic category (NON). When the surround was white, brown responses increased and those of orange decreased, even when the smallest surround was used. The use of gray surrounds (Fig. 7b) revealed the same tendency, but the changes were much less profound, and were generally consistent with the data of Expt 1.

The results show, not unexpectedly, that the appearance of surface colors depends much more on the luminance ratio between test and surround (even when the surround is very narrow) than upon their absolute luminances. Gray may be an exception. Unlike brown, the perception of gray does not require a surround. A careful examination of Fig. 7 for the two no-surround conditions differing in luminance (which actually were identical and constituted a replication), shows that reducing the luminance of the isolated stimuli increased the number of gray responses.

Figure 8 shows the centroid locations of the basic colors in the condition of white surround and high luminance for the average of the three subjects. Since only 28 test samples were used in Experiment 2, more sampling errors are involved in the shifts of centroids than for those of Experiment 1 where 215 test samples were employed. Nevertheless, comparing Figs 3 and 8, there are consistent shifts from the no-surround to small-surround conditions.

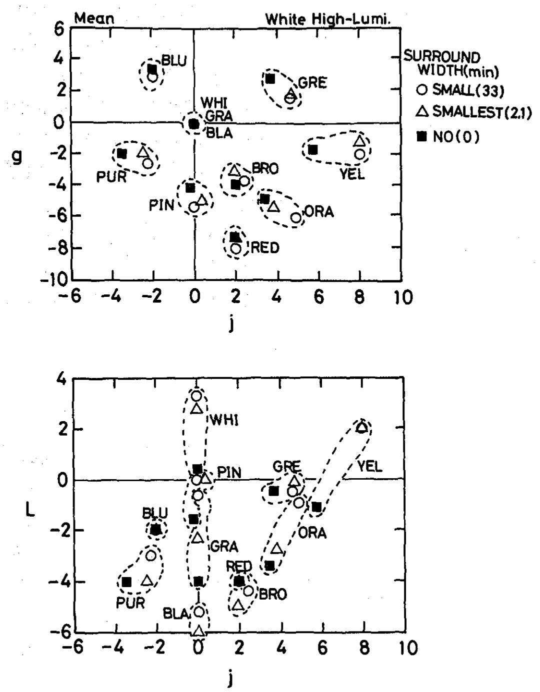

Fig. 8. Expt 2: centroid locations of mean data for small-, smallest- and no-surround, for the white, high-luminance condition.

sections, each of 33 min width, which were positioned to yield two gap distances (17 min and 66 min). The surrounds were glued to a large glass plate for support. Samples were placed by hand upon the glass. The same three subjects were used as in Expt 2, with the same variations in luminance and surround reflectance.

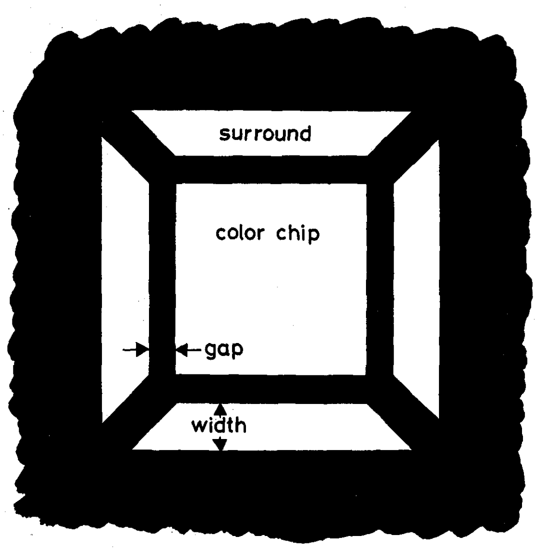

Fig. 9. Configuration of stimuli in Expt 3, where the surround of fixed width was removed under various conditions to form gaps of various widths between the color sample and the surround elements. The small gap is depicted here.

EXPERIMENT 3

The third experiment was designed to investigate the effect of introducing a gap between the color samples and the surround. As illustrated in Fig. 9, the surround for this experiment was constructed from four identical trapezoidal

Despite repeated cleaning, dust specks were sometimes visible upon the glass surface. Although their influence is probably not important, the specks might have influenced aperture-color perception in a no-surround condition. For that reason, and also because we had examined it so thoroughly in Expt 2, the no-surround condition was eliminated. Otherwise, the same subjects, color samples, illumination levels, and surround reflectances were employed as in Expt 2.

Results and discussion

Consistent results were obtained once again for the three observers, so only mean data are shown. Figure 10(a) shows the results for the white surrounds, Fig. 10(b), for gray surrounds. In each figure, the upper panel depicts results for the high luminance condition and the lower panel represents the low luminance condition. The infinity sign on the abscissas of the figures represents the no-surround condition, based on data taken from Expt 2, averaged for the two replications associated with the white- and gray-surround conditions of that experiment.

Figure 11 shows the centroid locations of the basic colors in the condition of white surround and high luminance for the average of the three subjects as shown in Fig. 8. Centroids for the no-surround condition (indicated by the infinity sign) have been replotted from those of Fig. 8.

When Figs 7 and 10, and Figs 8 and 11 are compared, it is evident that increasing the gap at constant surround width in this experiment produced effects similar to decreasing surround width with no gap in Expt 2. As gap distance increases, the responses of brown decrease and those of orange and white increase. The white surround has by far the larger effect, one which is still clearly visible for the larger gap, whereas the gray surround has lost most of its force even

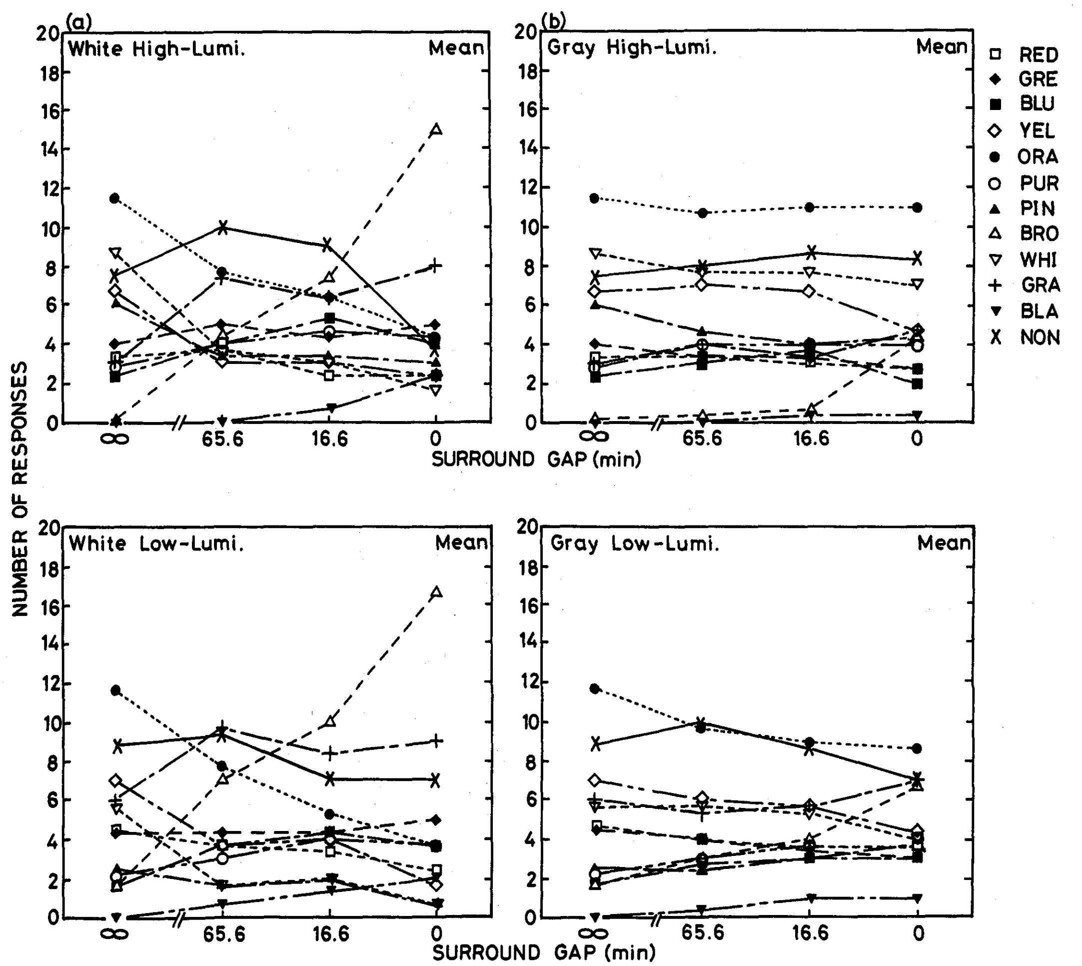

Fig. 10. Expt 3: mean results (3 subjects) for various gap widths. The arrangement of panels according to conditions is the same as for Fig. 6.

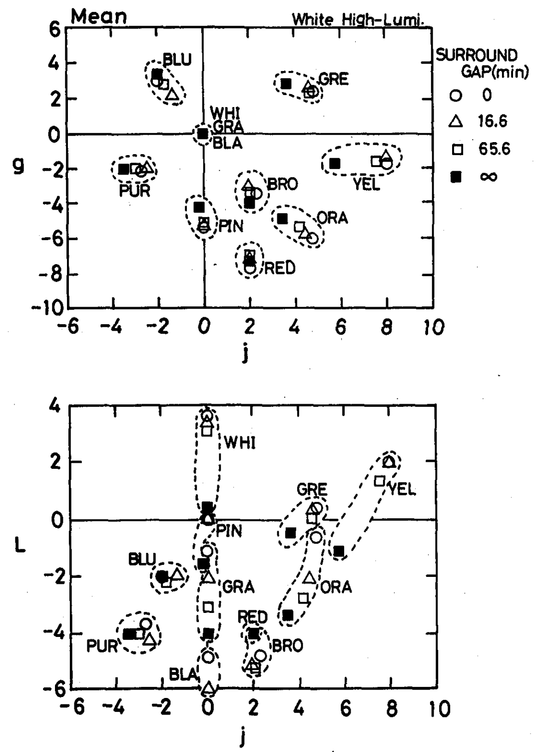

Fig. 11. Expt 3: centroid locations of mean data for various gap widths, for the white, high-luminance condition.

for the smaller gap. As in Expt 2, the two luminance levels yield very similar results.

SUMMARY

Color samples seen in isolation appear as aperture colors. Adding a surround causes them to appear as surface colors. Aside from becoming darker in appearance, most colors change rather little in hue. The exceptions are brown and orange. Although there may be argument about whether brown and orange are different hues, they belong to different basic color categories. Brown is almost never seen in isolation; under such a condition samples normally called brown tend instead to appear as orange. As the size of the surround decreases or the gap between the test and surround increases, the influence of the surround is diminished. White surrounds are much more effective than gray ones. A tiny white surround less than one sixtieth of the width of a 2.2 deg test stimulus, if placed adjacent to it, yields substantial effects and is sufficient to render the perception of brown for some color samples. Except to decrease reports of gray, and to increase perceived lightness, increasing the overall level of luminance has little effect upon color perception, whether or not surrounds are present.

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