# Color category influences heterogeneous visual search for color

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Many previous studies have revealed chromatic characteristics of visual search using relatively simple stimuli. They suggested that color difference between a target and distractors was a crucial factor. However, it may not be applicable to natural environments that contain numerous colors. This study demonstrates the existence of a color-category effect on heterochromatic visual search. Color differences between a target and distractors were constant in the OSA uniform color scales; however, the search times varied widely. This suggests that color differences alone do not explain search performance. To clarify the mediation of a higher-order categorical color process, search times were analyzed using 11 basic colors. When the color category of a target was shared by a larger number of distractors, the search performance declined. However, when the color category of a target was not shared with distractors, the target was easily detected. The results suggest that heterochromatic stimuli could be segregated by categorical color perception. © 2005 Optical Society of America

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## 1. INTRODUCTION

Visual search is one of the visual functions frequently used to detect a target among distractors in a visual field. Many previous studies have revealed the characteristics of visual search using a relatively simple experimental paradigm, such as detecting a bluish target from greenish distractors.[1] Although the simplicity of distractors provides the simplicity of stimulus configuration (e.g., chromatic difference between a target and distractors), homogeneous distractors make the target salient by a discontinuity in a feature space (e.g., color) that defines the target. Bacon and Egeth proposed a feature search mode and a singleton search mode in the context of a visual search task.[2] They found that irrelevant singletons in a feature dimension different from the feature dimension defining the target (e.g., a color singleton distractor paired with a shape singleton target) resulted in attentional capture of the singleton distractor (singleton search mode). When heterogeneity of the stimulus along the target dimension was introduced, singletons in the distractor dimension did not capture the attention (feature search mode). In the singleton search mode, subjects could adopt a strategy in which the singleton in the stimulus display should be the target. Subjects did not need to search a particular feature. In the feature search mode, the target should be identified by a particular feature because discontinuities in the stimulus feature dimension prevent the target from popping out. Thus, the heterogeneity of distractors substantially influences the process of visual search.

Heterogeneity of distractors can be defined by various feature dimensions, such as shape, size, or texture.[3] Among them, color has been considered as one of the most important attributes in our visual system.[4–6] D'Zmura[7] and Bauer *et al.*[8–10] studied the chromatic characteristics of visual search. In a case in which the target chromaticity fell on a straight line along the two distractor chromaticities or the target fell inside the triangle formed by three distractor chromaticities in color space, the search time was an increasing function of the number of display items (i.e., set-size effect). When the chromaticity of the target was off the line connecting two distractors or outside of the triangle, the target was easily detectable, and the slope of the search time was essentially flat. They argued that the difficulty of heterogeneous visual search depends on whether a target is linearly separable from distractors within an appropriate color space.

Although the linear separability model is simple and also supports studies that use shape and size as the feature space,[11,12] it cannot be explained by low-level chromatic mechanisms (e.g., opponent-chromatic channels). The chromatic conditions tested by D'Zmura suggest the involvement of a higher-order chromatic mechanism. For example, let us consider a set of distractors that consisted of red and yellow and a target that was orange. If the search process were mediated by the red–green and the yellow–blue opponent mechanisms, it would be difficult to detect the target since the red-green channel would not be able to separate the orange target from red distractors and the yellow-blue channel would not be able to segregate the orange target from the yellow distractors. However, the orange target popped out in their experiment. Thus, the higher-order chromatic mechanism that combines the opponent channels should be involved in the heterogeneous visual search.

Many visual search experiments provide good evidence that higher-order chromatic mechanisms exist.[13–16] Nagy *et al.* investigated the interactions among opponent channels in visual search. They introduced variation in a channel signal (e.g., red–green) of distractors and analyzed the influences of such signal variability on the detectability of a target that was defined by the other chan-

nel (e.g., yellow–blue). Since the opponent channels are largely independent, the variation of distractors had little effect on chromatic visual search. However, this result was replicated even in the condition that a target and distractors were defined by diagonal directions in the opponent-channel chromaticity diagram. These results also suggest the involvement of higher-order color mechanisms beyond the opponent mechanism.

Recent physiological studies have revealed the existence of higher-order color mechanisms in the visual cortex.[17–20] Komatsu *et al.* found color-selective cells in the anterior part of the inferior temporal cortex of macaque monkeys. Each cell responded to a region in the color space. The size and location of the receptive field for each cell were largely independent of the luminance of the stimulus, and the population of cells covered nearly all of the color space. Xiao *et al.* also found systematically arranged color-selective cells in V2. The responses of these cells did not depend on luminance or spatial frequency. These findings suggest the existence of a color mechanism that combines low-level information and represents the color itself.

Berlin and Kay conducted a pioneer study demonstrating that well-developed languages contained 11 basic color terms (red, green, blue, yellow, orange, brown, pink, purple, white, gray, and black).[21] Boynton and Olson psychophysically investigated the basic color terms using a color-naming task.[22,23] Each of 424 samples from the OSA uniform color space was named with a monolexical term. The results showed that basic colors were used more consistently within subjects, with greater consensus among subjects, and with faster response times than nonbasic colors. These characteristics of basic colors were universal for different languages.[24] Such a universal categorization mechanism may be used in various visual processes,[25,26] and possibly in visual search.

Smallman and Boynton investigated the efficiency and the discriminability of basic colors in the visual search paradigm.[27,28] Targets coded by basic colors were well segregated from numerous distractors. It made no difference whether the target was cued by image or by name. These results seem to provide evidence that the basic colors play a substantial role in the basic visual processes, including visual search. However, they also showed that nonbasic color targets and distractors that were separated similarly to basic colors in the OSA space led to similar performance, with the exception that it was difficult to cue nonbasic color targets by name. Therefore, they concluded that basic colors segregated well only because they were widely separated in color space. Their results agree with the claim that visual search performance can be characterized by the color difference.[6,29,30] These authors used up to 14 chromaticities, including seven basic colors and seven nonbasic colors. These chromaticities were sparsely located in the OSA space so that the average color differences between neighboring basic colors were from 9.47 to 13.84 in the OSA unit.

These extremely wide separations might hide the advantage of basic colors over the simple color difference. Moreover, since the color differences were not strictly controlled, it is premature to attribute the segregation of stimuli to the color differences alone. Therefore, the role

of basic color categories in visual search is still an open question.

In this study, we demonstrate the effect of basic colors on a heterochromatic visual search. To clarify the role of basic colors in the visual search paradigm, color differences of stimuli must be precisely controlled. We adopted the OSA uniform color space and selected sets of 13 distractors that formed a spherical structure of radius 2 OSA units. A target was located outside ($2\sqrt{2}$ units from the center) the sphere. This arrangement enabled precise and systematic analysis of chromatic characteristics.

Another important issue is which process enables the categorical color perception. Color categorization is thought to be mediated by a color perceptual process that is inherently or empirically developed.[31–33] However, it is suggested that the memory enhances the color categorization.[34] Huttenlocher *et al.*[35] argued that categorization would arise from memory rather than from perception. Furthermore, some studies (e.g., Roberson and Davidoff[36]) suggest that categorical color perception is based on the linguistic labeling of color. It is beneficial to clarify the source of color categorization; therefore, we tested both cued and uncued conditions. The memory of a color should be involved in the cued condition, but a target color cannot be memorized in the uncued condition. If the categorical effect were observed even in the uncued condition, it would suggest that the color categorization is mediated by a color perceptual process and not by color memory or by linguistic labeling. If the color categorization were shown only in the cued condition, it would support the claim that it originates from memory or possibly from labeling.

## 2. METHODS

### A. Stimuli
To keep the color difference constant, the chromaticities of stimuli were selected from the OSA uniform color scales. The uniformity of the color space was confirmed by a preliminary experiment. Color differences of two pairs of adjacent OSA samples were evaluated by each subject. Significant distortion of scales was not observed.

Figure 1 shows an example of a set of 13 distractor chromaticities and four possible locations of a target. A set of distractor chromaticities consisted of a central chromaticity [e.g., $(L,j,g)=(0,4,0)$] and 12 chromaticities that were adjacent to the center and formed a sphere of radius 2 OSA units. The chromaticity of a target was located outside the sphere. The color difference between a target and the center of the distractors and between a target and the nearest distractor was $2\sqrt{2}$ and 2 units, respectively. A target was located at each of four chromaticities with respect to a set of distractors. Conditions in which a target was out of the OSA space were omitted. The centers of the distractor sets were allocated at 27 positions in the OSA space, shown in Fig. 2, to analyze the chromatic characteristics systematically. A total of 101 target–distractor chromatic conditions were obtained within the limitations of the OSA space.

The search display contained 64 color samples on an $8\times8$ grid. A color sample was a square (1.6 deg in visual angle). A target and 63 distractors (4 or 5 samples for each
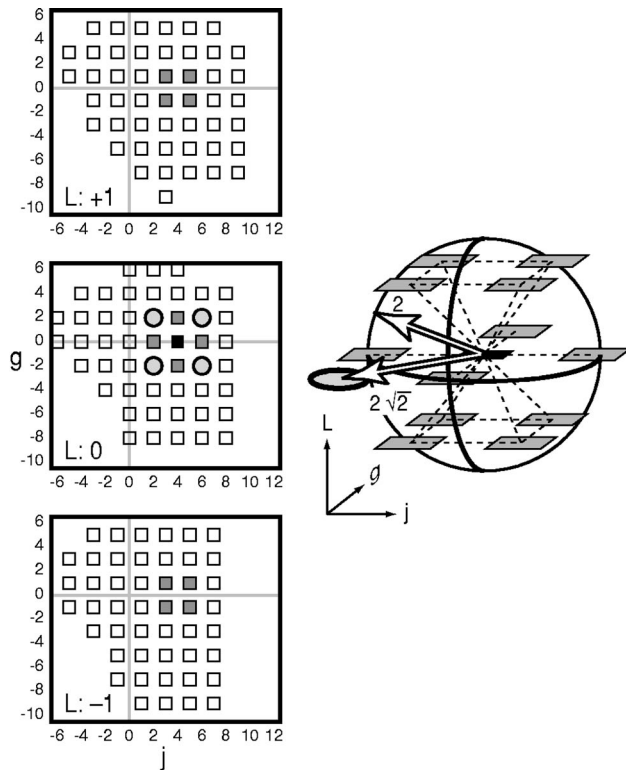
Fig. 1. Chromatic structure of stimulus in the OSA space. A set of 13 distractor chromaticities (squares) formed a sphere of radius 2 OSA units. A target was located at one of the four chromaticities (circles) that were $2\sqrt{2}$ away from the central chromaticity (black square) of distractors.
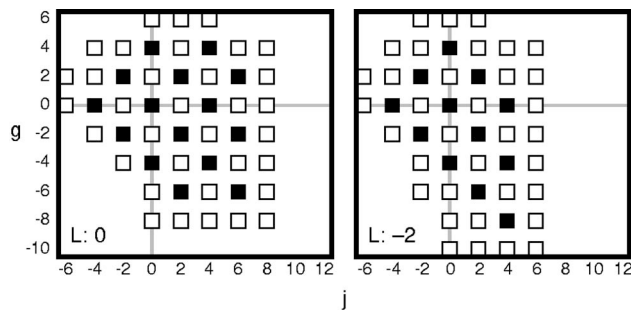


Fig. 2. Chromatic conditions. The central chromaticities of distractors were allocated at 27 coordinates (solid squares) systematically to cover various hues and saturations. Open squares represent the coordinates of the defined OSA samples.

of 13 distractor chromaticities) were presented randomly on a gray background $(L,j,g)=(-2,0,0)$, subtending 15.8 deg. Each sample was separated by a gap of 0.1 deg. Chromaticities and reflectances of original OSA samples were measured under a $D_{65}$ fluorescent light by use of a Topcon SR-2A spectrocolorimeter. The luminances of simulated OSA samples were calibrated so that the gray background $(L,j,g)=(-2,0,0)$ corresponded to 20.0 cd/m². Stimuli were presented on a Sony color monitor (GDM-2000TC) controlled by an Apple Power Macintosh 9500 computer. The subject viewed the monitor in a dark room at a distance of 100 cm with a chin rest.

## B. Procedure
The subject adapted to the gray background for 3 min at the beginning of each session. On each trial, a fixation point was presented until the subject pressed a mouse button. In the cued condition, the target sample was provided at the center of the gray background for 1 s. Following a gray blank of 1 s, the stimulus array was displayed until the subject found the target and pressed the button. This duration was recorded as the search time. Color samples were replaced by a black background to avoid afterimages, and the subject then indicated the target position using the mouse. When the subject could not respond with the correct target position, the trial was discarded and randomly interleaved later in the session. A trial that exceeded 60 s in duration was also canceled as a failure trial and interleaved later. A signal tone feedback for a correct response was given. There was an adaptation interval of 5 s between trials. In the uncued condition, the target cue was not shown prior to the search display. Thus, the subject could not memorize the color appearance itself as the target cue. Since each chromaticity of distractors was shared by multiple samples, the subject was instructed to find a single color sample as quickly and precisely as possible. The cued and uncued conditions were performed in separate sessions. Before collecting data, all subjects were given adequate practice sessions. For each target–distractor chromatic condition, 10 trials were repeated.

## C. Color Naming
Categorical color naming was performed in a separate session. Each of all 424 OSA color samples was presented randomly in the center of the gray background. This configuration was identical to the cue presentation frame, except that the duration time was not limited. Subjects named each sample by one of Berlin and Kay's 11 basic color names (red, green, blue, yellow, orange, brown, pink, purple, white, gray, and black). Three sessions were performed for each subject to confirm the consistency of naming. The color category of each sample named by each subject was used to analyze the search results.

## D. Subjects
Three males aged 23–29 years with normal acuity and normal color vision as tested by the 100-hue test participated in the experiment. Subject KY, one of the authors, was familiar with the experiment.

## 3. RESULTS
Figure 3 shows the histograms of the search times for each subject. In both cuing conditions, search times were widely distributed, ranging from less than 1 s to 60 s. The distribution of search times in the cued condition was shifted approximately 0.5 log s or more toward faster performance. The peaks of the distribution were less than 1 s in the cued condition for subjects KY and TT. The wide distribution of search times implies that search performance is not explained solely by the color difference.

Although facilitation by a target cue was evident, not all targets could be found instantaneously even if a target

cue was given. This means that the cuing effect was not the determining factor of the observed wide distribution in the search times. To clarify the influence of basic colors in visual search, the results were analyzed on the basis of the categorical color naming. Figure 4 shows the typical results. Bars indicate the average search times. The chromaticity, color name, and number of distractors sharing the same color name (referred to as the categorical set size) for each target are shown below the graph. A pie chart indicates the number of color names in a set of distractors whose central chromaticity is shown below.
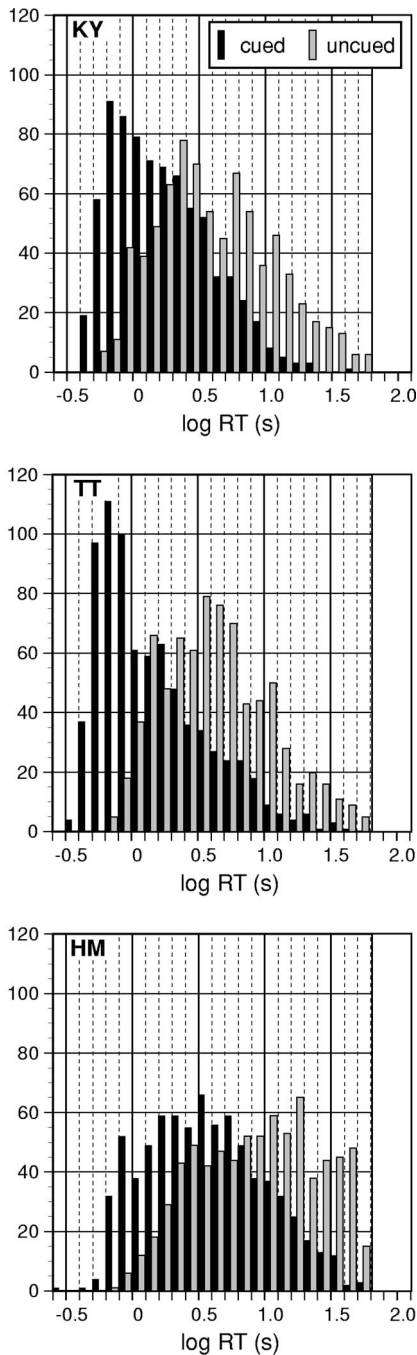


Fig. 3.    Histograms of search times for correct trials in the cued condition (black) and in the uncued condition (gray). The three panels show the results from three subjects.
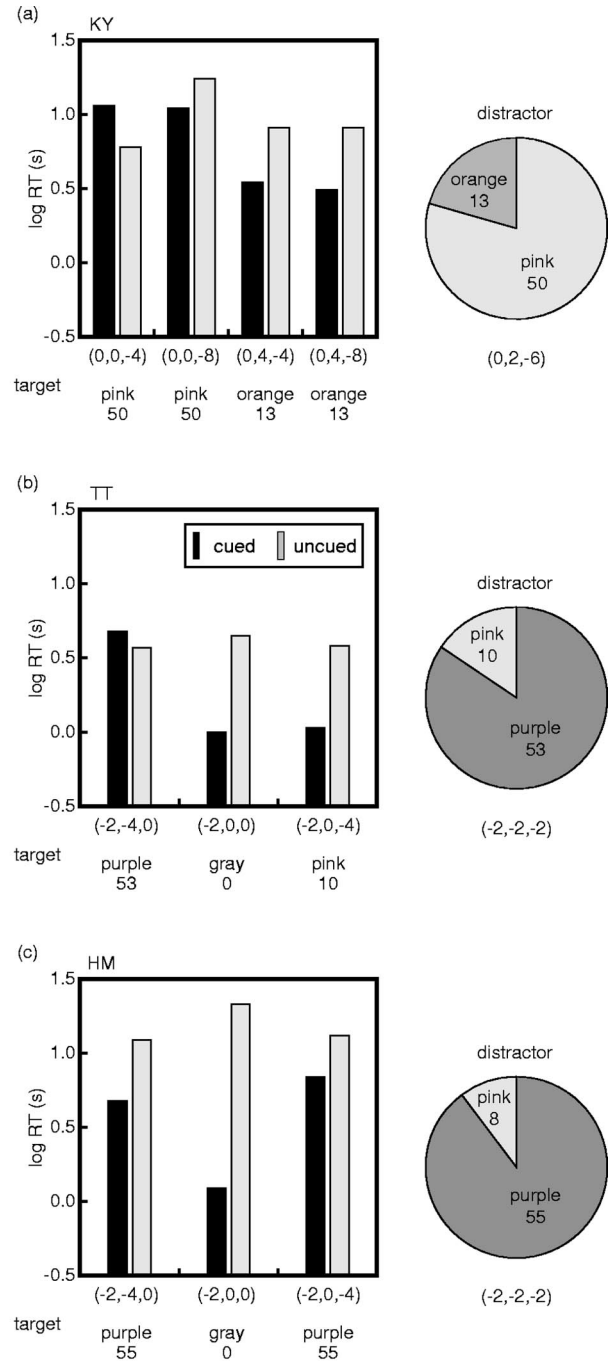


Fig. 4.    Average search time and basic color categories. Typical results are shown for three sets of distractors. Bars: average search times of targets in the cued condition (solid) and in the uncued condition (gray). Labels indicate the OSA UCS coordinate, the color name, and the categorical set size of the target (the number of distractors sharing the same color name). Pie charts: the number of color names in the set of distractors. The central chromaticity of the set is shown below.

Figure 4(a) demonstrates a distractor set whose central chromaticity was $(L,j,g)=(0,2,-6)$. According to the total of 63 distractors in the set, 50 distractors were named as pink, and 13 distractors were named as orange by subject KY. The leftmost column of a bar graph represents the search times for target $(L,j,g)=(0,0,-4)$, which was named as pink, and so on. Even though all search times in

the uncued condition were approximately 1.0 log s, the targets perceived as orange were easily detectable (about 0.5 log s) in the cued condition. However, the facilitation by a target cue was weak for the pink targets. Figures 4(b) and 4(c) represent identical chromatic conditions for subjects TT and HM. Both subjects named the distractors as almost purple. It is obvious that a cue was effective for a target perceived as gray or pink. For a target perceived as purple, a cue was less effective. From Fig. 4, it was expected that a target whose categorical set size was small would be detectable faster by a target cue. However, a target whose categorical set size was large was relatively difficult to search even if a target cue was provided.

All average search times as a function of the categorical set size are plotted in Fig. 5. The abscissa indicates the categorical set size (the number of distractors sharing the same color name as the target). The categorical set size 63 means that the target and all distractors were named as a single color category. The categorical set size 0 means that the color category of the target was not included in the distractors. Search times were entered into a cuing $\times$ categorical set-size analysis of variance for each subject. Significant main effects were revealed for the cuing $[F(1,100)=56.02(\text{KY}),62.67(\text{TT}),36.28(\text{HM}),p<0.05]$ and the categorical set size $[F(63,100)=2.39(\text{KY}),2.59(\text{TT}),1.85(\text{HM}),p<0.05]$. Significant positive correlations [for the cued condition: $r=0.455(\text{KY}),0.526(\text{TT}),0.375(\text{HM}),p<0.001$; for the uncued condition: $r=0.396(\text{KY}),0.491(\text{TT}),p<0.001$] were observed between the search time and the categorical set size, except for the uncued condition of subject HM ($r=0.185,p=0.094$). These correlations indicate that the search performance was reduced as the categorical set size increased, although the total set size was constant in all conditions. This categorical effect was obtained even in the uncued condition.

In the cued condition, a target cue was displayed on the gray background. Subjects sometimes reported that the appearance of some targets seemed different from the presented cue. It is known that the color appearance could be influenced by the simultaneous color contrast. It is plausible that the distractors surrounding the target induced the color shift of the target appearance. Thus, the perception of the target among distractors might not co-

incide with the appearance of the cue on the gray background. Then, it is possible for the shift in color appearance to change the color category of the target. If a change in color category occurs, it could have an influence on the search performance. To clarify the interactions between the categorical shift and the search performance, color-naming tasks were repeated with surrounding distractors.
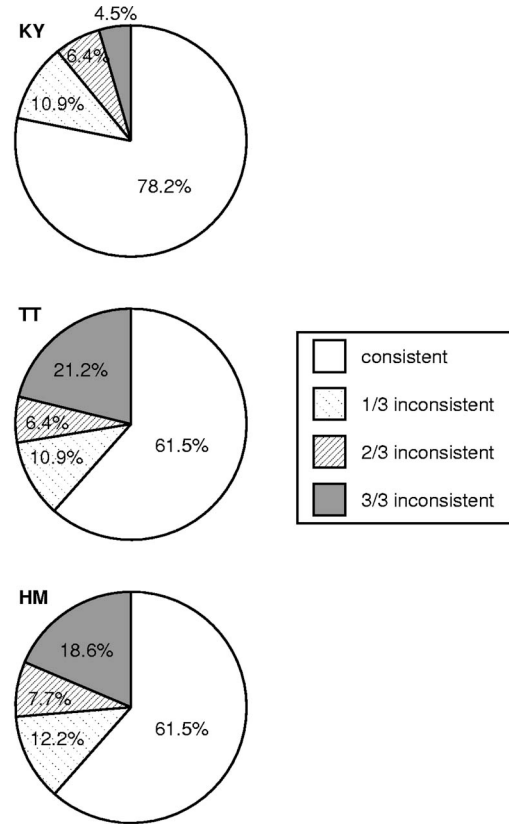


Fig. 6. Perceived categorical color changes induced by surrounding distractors. The ratio was calculated by comparing categorical color naming with surrounding distractors and one without distractors. Both color-naming tasks were performed three times in separate sessions. Open region: both color names were completely consistent. Dotted region: one third of the color names were inconsistent. Lined region: two thirds were inconsistent. Solid region: both color names were fully inconsistent.
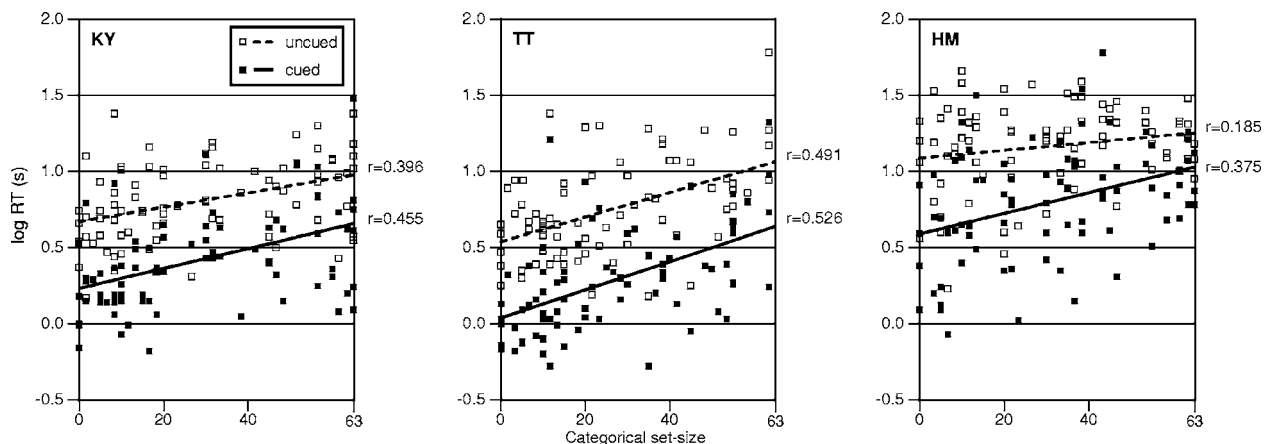


Fig. 5. Average search times against the categorical set size. Open symbols: uncued condition. Solid symbols: cued condition. Regression lines and correlations were calculated for the uncued condition (dashed line) and for the cued condition (solid line).
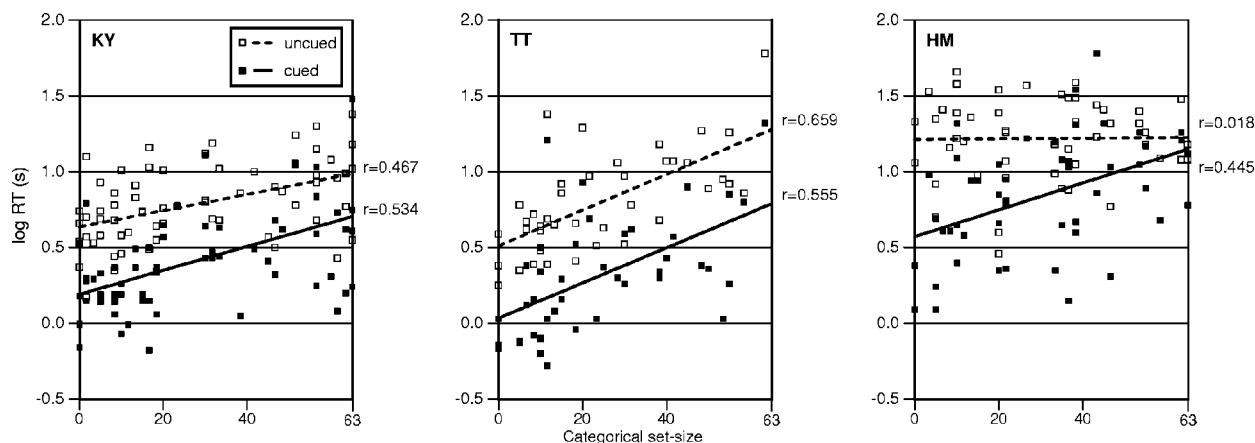
Fig. 7. Average search times against the categorical set size of the consistent color-naming conditions. Open symbols: uncued condition. Solid symbols: cued condition. Regression lines and correlations were calculated for the uncued condition (dashed lines) and for the cued condition (solid lines).

The experimental condition was identical to the original color-naming task, except that a target was presented in one of the four central cells of the $8 \times 8$ matrix filled with distractors. The cell was indicated prior to each trial. The combinations of chromaticities of a target and distractors were identical to the search condition. However, since the target cell was restricted to the central region of the matrix, the spatial arrangement of distractors was not identical to search trials performed previously.

Figure 6 shows the ratio of the categorical changes between the original and the additional color naming. It was presumed that over 60% of the targets for subjects TT and HM and about 80% for subject KY were perceived as the same color category as the provided cues, even if a slight change in the color appearance might have occurred. However, in subjects TT and HM, approximately 20% of the targets seemed to be perceived as quite different color categories from the target cues. Categorical changes for subject KY were relatively small.

Since a large part of color-naming results with distractors were consistent with the original color-naming results, the categorical set sizes of Fig. 5 did not change drastically. However, those for inconsistent color-naming conditions might not reflect the actual categorical perception. To clarify the categorical influence more rigorously, average search times only in the consistent color-naming conditions are plotted in Fig. 7. It clearly demonstrates that correlations between the search time and the categorical set size increased in all conditions [for the cued condition: $r = 0.534(\text{KY}), 0.555(\text{TT}), 0.445(\text{HM}), p < 0.001$; for the uncued condition: $r = 0.467(\text{KY}), 0.659(\text{TT}), p < 0.001$], except for the uncued condition of subject HM ($r = 0.018, p = 0.905$).

## 4. DISCUSSION

We measured the search time for the detection of a chromatic target in the presence of heterochromatic distractors in order to reveal the function of basic colors in the visual search paradigm. Although the color differences among a target and distractors were carefully kept constant, the search performance was influenced by the categorical color perception of stimuli. In the condition that the color category of a target was shared by a larger number of distractors, the search performance was reduced. On the other hand, when the color category of a target was not shared by the distractors, the target was instantaneously detectable. The correlation between the search time and the color category was observed both in the cued condition and in the uncued condition.

Contrary to the claim of Smallman and Boynton,[27,28] our results could not be explained solely by the color difference in the OSA uniform color space. Although they concluded that basic colors segregated well because of their separation in the color space, the color differences were not strictly controlled. In our experiment, the chromatic relations among a target and distractors were strictly controlled in the OSA space. However, the search times were widely distributed, as shown in Fig. 3.

The OSA uniform color space we adopted was constructed to maintain the uniformity of color differences through psychophysical experiments.[37] The uniformity was confirmed by a preliminary experiment. It is also supported by a recent study.[38] However, it could be claimed that the color differences in the OSA space might be violated in the CIE coordinate because the OSA coordinate and the CIE coordinate were nonlinearly related.

Previous experiments reported by Bauer et al.[8] were performed principally on the basis of the CIE coordinate. They showed that the search times were affected by the distance between a target and the line that segregates the target and distractors. To check whether the discrepancy between color coordinates was the primary reason for the large variability of the search times (whether the distance from the separation line in the CIE coordinate determines the search time), we recomputed the chromaticities of the OSA color samples in the CIE u′v′ diagram and plotted the average search time as a function of the color difference between a target and the separation line in the u′v′ diagram (Fig. 8). The separation line was deduced by connecting two of the nearest distractors. The distances from the separation line were slightly distributed. Weak negative correlations [for the cued condition: $r = -0.221(\text{KY})$, $-0.230(\text{TT}), -0.218(\text{HM}), p < 0.01$; for the uncued condition: $r = -0.243(\text{TT}), p < 0.001$] were observed between the search time and the color difference in the CIE coordi-

nate. Significant correlations were not found in the uncued condition of subjects KY ($r=-0.111, p=0.139$) and HM ($r=-0.046, p=0.540$). This result suggested the possibility that the color difference in the CIE coordinate influenced the search performance.

To estimate the respective influences of color categories and color differences in the CIE coordinate, we entered the categorical set size and the color difference as independent variables into the stepwise multiple regression model. The analysis showed that the categorical set size was significant [in the cued condition: $p<0.001$(KY), $p$



Fig. 8.   Average search times plotted against the color difference in the CIE u′v′ diagram. Average search times against the color difference between a target and the separation line that segregates a target and distractors are shown for three subjects. Open symbols: uncued condition. Solid symbols: cued condition.

$<0.01$(TT), $p<0.01$(HM); in the uncued condition: $p<0.001$(KY), $p<0.001$(TT)], except for the uncued condition of subject HM ($p=0.933$). The color difference was found to be significant in the cued condition of subject KY ($p<0.01$) and in the uncued condition of subject TT ($p<0.05$); it was not significant in the other conditions [in the cued condition: $p=0.062$(TT), $p=0.072$(HM); in the uncued condition: $p=0.191$(KY), $p=0.444$(HM)]. Although the possibility that the variation of color differences in the CIE coordinate affected the search time is not excluded, the contribution of the color differences is relatively smaller than that of the color categories.

Regardless of the color space, color categories and color differences are generally correlated. It might be assumed that chromaticities that share a common color category would be closer than chromaticities that do not. This could cause the impression that the categorical set size influences the search performance. This notion is similar to the conclusion by Smallman and Boynton[27,28] that basic color categories are easily segregatable due to the relatively wide separation of chromaticities. It should be emphasized that, in our experiment, chromatic differences were strictly controlled in the OSA uniform color scales, irrespective of the color categories. Regardless whether or not an adjacent pair of color samples shared a common color name, the chromatic difference between them was constant. Moreover, color names were chosen by color-naming tasks. It was quite possible for an identical color sample to be named differently by each subject [e.g., the target $(L, j, g) = (-2, 0, -4)$ was named as pink and purple, as shown in Figs. 4(b) and 4(c), respectively]. In this case, the categorical set size should vary with respect to the given color name, even though the chromatic differences between the target and distractors were completely identical. Therefore, the generality of correlation between the color category and the color difference did not change our conclusion.

In our experiment, color categories were explicitly irrelevant to performing visual search, since the chromaticities of stimuli were chosen systematically in various hues and saturations. It was not a particularly efficient strategy to segregate stimuli by 11 basic colors. It might be most effective to calculate the chromatic centroid of distractors and isolate the furthermost chromaticity from the centroid. Nevertheless, subjects segregated the heterogeneous stimuli on the basis of the 11 basic colors. Our findings may capture the essence of basic colors in the visual search paradigm.

The process of color categorization has been controversial. It is considered that the color categorization is mediated perceptually;[31–33] however, some studies propose that the categorization is based on memory[35] or linguistic labeling.[36] In this study, we adopted both the cued and uncued conditions to clarify this issue. Regarding color memory, it has been reported that color memory would enhance the categorization by basic colors.[34] It might be argued that the memory for a target cue enhanced the categorical segregation of stimuli so that the search performance depended on the categorical set size. However, the significant correlation between the color category and the search time was obtained also in the uncued condition. The color memory was not involved in the uncued
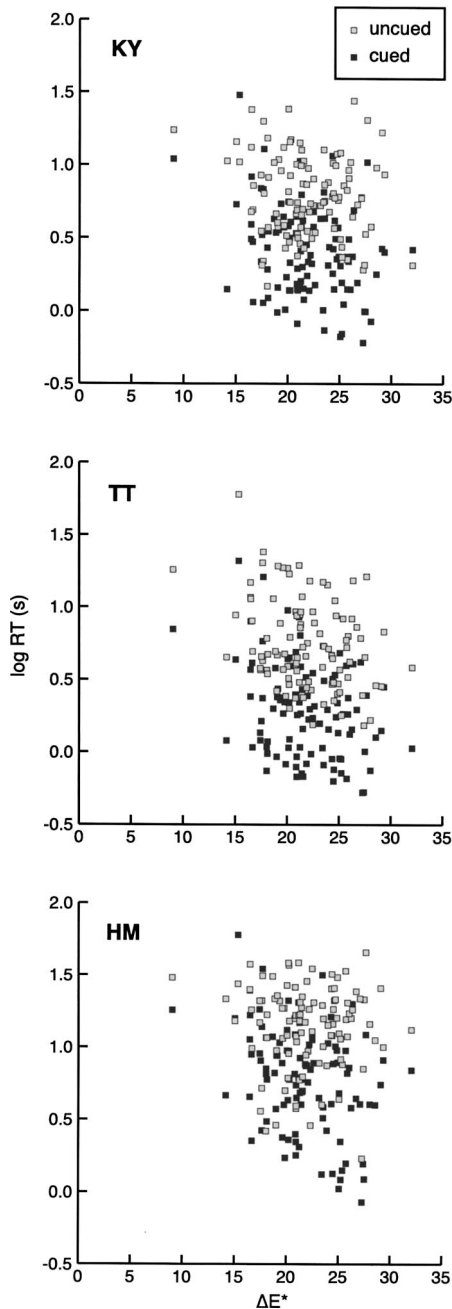
condition because a target cue was not presented. This category effect cannot be explained by color memory. Since the correlation coefficients were substantially higher in the cued condition, categorical enhancement by color memory might contribute to the segregation based on basic colors but cannot account for all the results.

The linguistic labeling theory assumes that categorical segregation is based on comparisons of verbal labels of stimuli. Since stimuli in the same category have identical labels, they are confounded. On the other hand, stimuli in different categories have different labels, so these stimuli can be discriminated. Roberson and Davidoff[36] found that the discrimination performance was lower for stimuli in the same color category than for those in different categories; however, both performances were equivalent in the verbal interference condition. In our experiment, the color-naming task, which requires verbal labeling, was performed; however, it was executed in a separate session from the visual search sessions. In addition, 64 color samples were presented in a search task. It was difficult to put verbal labels on 64 samples in a short time and to compare them. Furthermore, it was impossible to put a verbal label on a target in the uncued condition until a subject detected it. Our results do not support the linguistic labeling theory. Instead, our findings correspond to the claim that color categorization is mediated by the perceptual process.

In this study, the color categories were analyzed on the basis of the 11 basic color terms proposed by Berlin and Kay.[21] Although we found the relation between search performance and basic colors, there remains the question of whether the 11 basic color terms are the optimal categorization. Previous studies reported the advantage of 11 basic colors in color-naming tasks,[22–24] but the terms might not be optimal in visual search tasks. Even if the 11 basic colors were optimal, the categorical segregation might change dynamically depending on the chromatic distribution of stimuli. This issue warrants further empirical investigations. Optimal color categories used in visual search may be revealed by other naming tasks, such as nameability scores,[39] or cluster analysis based on search times.

In the visual search paradigm, several studies suggest that a target is processed in the feature space, which segregates the target from distractors such as shape, size, orientation, or color.[40–42] Wolfe proposed the guided-search model, in which a target is searched by a combination of preattentive and focused attentional processes. The candidates for the target are extracted by a rapid, preattentive parallel process; then, the target is identified by a slower, serial process of focused attention. Although color is one of the most important features in visual search, it was chromaticity that was used as the metrics of the color feature space. Our results indicate that color categorization could contribute to the visual search process.

To illustrate the relation between the color categories and the search performance, we hypothesize that the color search process is mediated by the 11 basic color categories in the guided-search model (see Fig. 9). In the first stage, stimuli are segregated rapidly based on the color category of a target if a target cue is given. When a cue is
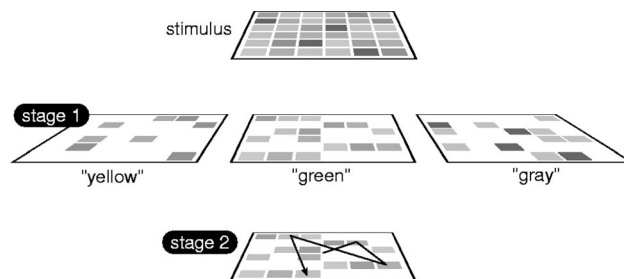


Fig. 9. Proposed search process. Stage 1: color stimuli are segregated by their basic color categories. Stage 2: the target is searched among the selected category. The number of stimuli in the selected category is supposed to produce the set-size effect.

not provided, a color category is assumed to be selected involuntarily. In the second stage, the target is searched serially within the selected color category until it is found; otherwise, the subject chooses another color category. Search performance would depend on the selection of the color category in the first stage, the set size of the selected category in the second stage, and when to give up the search within a category.

As shown in Fig. 5, when a target color category occupies a smaller part of distractors, the target can be found rapidly if the color category is properly selected according to the cue or by chance in the uncued condition. When a target color category occupies a larger part of distractors, search performance is reduced by the set-size effect, even if the color category of a target is known prior to the search. Although this hypothesis needs to be tested more quantitatively, it accounts for the relations between search performance and basic colors.

The supplementary experiment suggested that categorical perception is relatively consistent against surrounding distractors. Correlations in the consistent color-naming conditions were higher than those for all conditions that included inconsistent color-naming results. Since the ratio of categorically changed conditions was not adequate for quantitative analysis, it was difficult to obtain significant influences induced by the categorical change. However, it was observed that the cuing effect for the target whose color category was changed by surrounding distractors was less effective or even worse in several conditions. These results may be interpreted as the incorrect selection of a color category in the model. For instance, when a target is perceived as yellow in a cuing frame, the subject should select the yellow category in the first stage. However, if the target is categorized as brown in a search task, it should not be found in the yellow category. This hypothesis will require further study.

The categorization of visual stimuli is one of the most important mechanisms of the visual system.[25,26] While the metrics of color differences are also important in color discrimination or color-matching tasks, categorical color perception may mediate efficient visual information processing involved in our daily lives via *a priori* knowledge and concise representations of color distributions (e.g., basic colors) in the world.

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