

Trichromat-like Categorical Color Naming of Dichromats

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It has been shown that some dichromats can categorize colors using color names in quite similar manner to trichromats. The previous studies suggested some possible mechanisms to account for this trichromat-like categorical color naming ability, such as rod contribution, anomalous cone pigments, a nonlinear parallel chromatic channel or luminance cue. However none of them has not been able to fully explain the categorical color naming of dichromats. In this paper we tried to find out what observing conditions of color stimuli mostly affect the color categorization of dichromats to explore this naming mechanism. Dichromats and trichromats participated in the categorical color naming experiments, in which they named 424 OSA uniform color samples twice using only the Berlin and Kay's eleven basic color terms under various chromatic illuminants. They also observed OSA color samples, simulated on a CRT monitor, in various observing conditions, i.e., a small visual angle, a short duration, equal luminance and blurred edge. A trichromat could use the same color names for the same stimuli in almost all observing conditions whereas a dichromat showed some confusion of color names along the green-red direction under some illuminants and for some CRT stimuli. This confusion was greater with a small visual angle and with equal luminance. Individual differences were much greater for dichromats than for trichromats. Our results suggest that dichromats might not have the same color category mechanism, but have different mechanisms that determine their degree of deficiency. These mechanisms must yield barely visible differences, not enough to be used for color discrimination, but enough for color categorization.

1. Introduction

Dichromats are categorized into protanope, deutanope and tritanope depending on the L, M, and S cone lacked in the retina, respectively. Because of lacking a type of cone dichromats have the two-dimension (M, S), (L, S) or (L, M) cone space. A normal trichromat transforms L, M, S cone signals into a luminance and two chromatic (red-green and yellow-blue) channels whereas a dichromat transforms two cone signals into a luminance and a chromatic (yellow-blue or red-green) channel.

Since protanope and deutanope have only a chromatic (yellow-blue) channel they can discriminate colors only along a yellow-blue axis

in the chromaticity diagram. Therefore the number of colors dichromats can use ought to be quite limited. Their color names should be yellow, blue, white, black, gray and those mixtures.

Red, Green and yellow cannot be discriminated by protanope and deutanope since they do not have the red-green chromatic channel. However they can actually use these color names in their everyday lives. How do they manage to use red, green and yellow? This is the question we tried to answer.

Some previous studies reported the color naming characteristics of dichromats. Boynton and Scheubner (1967) and Jameson and Hurvich (1978) reported dichromats' use of red and

green hue names. On the basis of color naming characteristics of dichromats some possible mechanisms have been proposed to explain their color naming behavior. Montag and Boynton (1987) measured the categorical color space of dichromats by using the OSA uniform color samples and concluded that rods contributed signals to categorize surface colors. But later Montag (1994) reported that an anomalous third cone pigment, not rods, must contribute to the dichromats' color categorization. Wachtler et al. (2004) proposed a model with a nonlinear parallel channel.

The purposes of the present study are, firstly, to know how well dichromats allocated color names on colors not to be discriminated, and, secondly, to measure effects of various observing conditions on categorization of dichromats. The conditions included various chromatic illuminants, small size, short duration, equal luminance and edge blurring to remove chromatic aberration.

2. Experiment 1

Methods

We used 424 OSA uniform color samples as test stimuli. They are arranged at an equal color-difference interval in the OSA (L, j, g) space. The test color chip was placed on a gray table illuminated at 500 lx by the D65 illuminant. The light source was a LC projector.

The observer performed the categorical color naming using one of the Berlin and Kay's 11 basic color terms: white, black, red, green, yellow, blue, brown, orange, purple, pink and gray. He adapted to the test illumination for 3 minutes, then, randomly selected a color chip from a set of 424 OSA color chips. He named all 424 color chips in a session. Two sessions were repeated.

Four normal trichromats, three protanopes

and two deuteranopes participated in the experiments. They were all males.

Results

We firstly obtained the distributions of basic color names in three-dimensional OSA space. All trichromats showed clear division of the basic color regions, which confirmed the previous reports. Protanopes and deuteranopes showed some confusion of the basic color regions in the j (red-green) direction. There were large variations of categorical color naming among dichromats.

We used the centroid of a categorical color region in order to characterize the location of the basic colors in the OSA color space. The centroid was calculated by averaging the coordinates of all the color chips named with the same name weighted by two (when consistently named) or one (when inconsistently named). **Fig. 1(a)** shows the centroids of the basic color names in the j–g plane for trichromat NN. Each symbol represents the color category. The size of the symbol is proportional to the number of the color chips named for that color name. The centroids of trichromat well spread in the j–g plane.

Figs. 1(b), (c) and (d) show the centroids of dichromats. Protanope PS has similar distribution of centroids as the normal trichromat. Another protanope PY has narrow distribution in the r–g direction. Deuteranope DF's distribution is almost as good as the normal distribution.

All color samples were plotted in the (L, M, S) cone space. For normal trichromats the color samples appeared to be well divided into the 11 basic color categories when plotted in the (L–M, L+M–S, L+M+S) space, that is, the opponent-color (r–g, y–b, w–b) space.

For protanope PS the color samples were not divided into the color categorical regions when plotted either in the (M, S) or in the (M+S,

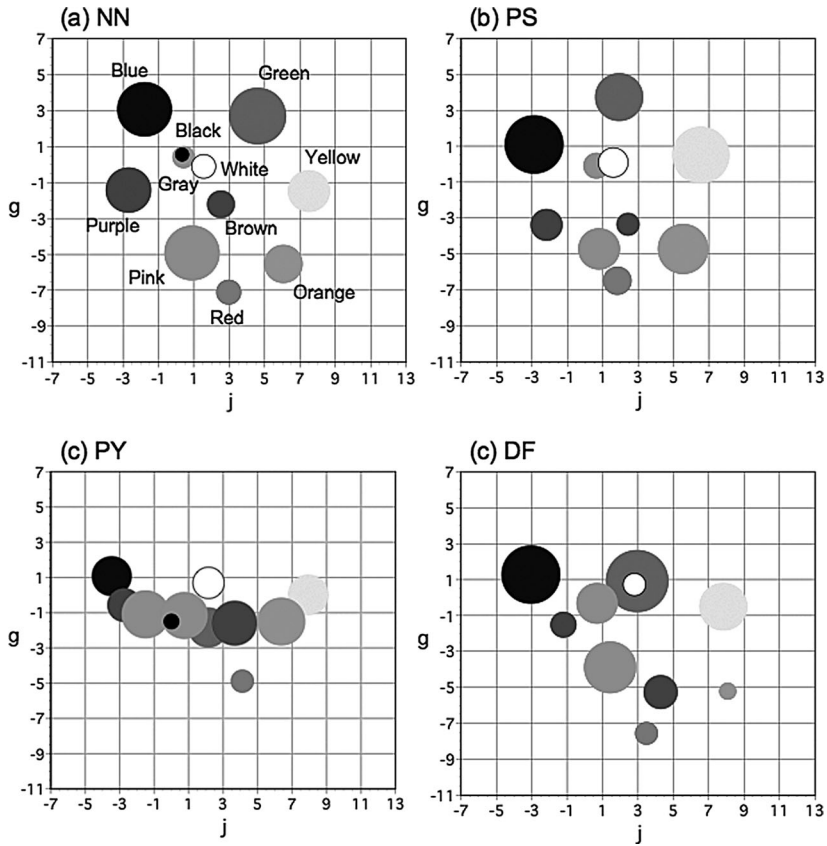


Fig. 1. Centroids of the basic color names in the j - g plane. Each symbol represents the color category. The size of the symbol is proportional to the number of the color chips named for that color name. (a) Normal trichromat NN, (b) Protanope PS, (c) Protanope PY, (d) Deuteranope DF.

M-S) plane, but instead well divided when plotted in the (L-M, L+M-S, L+M+S) space, which means he needs three variables as if he could have an anomalous type of cone. For protanope PY the color samples were well divided into the basic color categories in the (M+S, M-S) plane whereas they were not clearly divided in the (L, S) plane for deuteranope DF. This means that PY needs only 2D cone space and might use luminance cue to name colors, but DF might have an extra dimension in the cone space.

3. Experiment 2

Methods

We used four illuminants: B0, 25000 K, 3000 K

and R0 along the daylight locus and four illuminants: R1, R2, G1 and G0 in the r - g direction in addition to the 6500 K white. The LC projector produced these illuminants. B0, R0, G0 illuminants were the blue, red and green primary colors, respectively, of the projector. R1, R2 and G1 lay on a confusion line passing through the 6500 K white. This confusion line was obtained to average two confusion lines of protanope and deuteranope. R2 was on the line connecting R0 and B0, and G1 on the line connecting G0 and B0. R1 was on the middle between R2 and 6500 K.

The procedure was the same as in Experiment

1. All observers participated in Experiment 2.

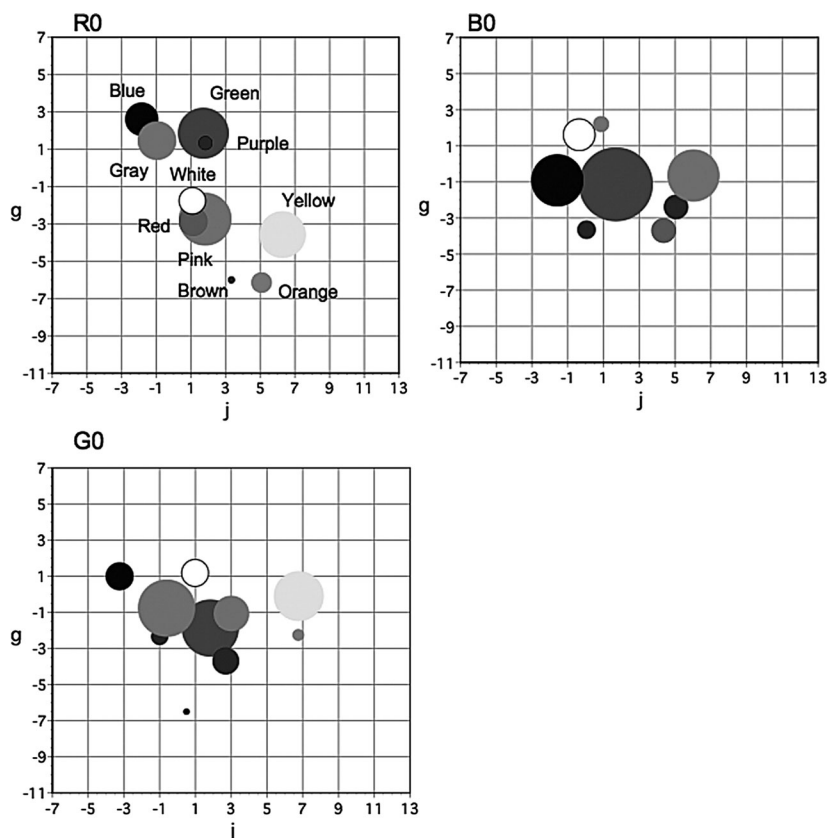


Fig. 2. Centroids of the basic color names in the j - g plane under R0, B0 and G0 for deuteranope DF.

Results

The centroid positions of trichromats in the j - g plane were almost invariant under all illuminants, indicating that trichromats had good color constancy. Protanope PS showed the centroid positions similar to those of trichromats, which again suggested he might have had an anomalous type of cone. Deuteranope DF showed bad color constancy under R0, B0, G0, R1 and R2. **Fig. 2** shows his centroid distribution of the basic color names in the j - g plane under R0, B0 and G0.

DF's color samples were well divided in the (L, S) cone space under highly saturated chromatic illuminants, indicating that he lost color constancy. DF seems not to use the same cue as PS. DF might have neural anomaly

whereas KS has cone anomaly.

4. Experiment 3

Methods

The OSA color samples were simulated on a CRT display. In the control condition the stimulus was 2.6 deg and presented steadily as in Experiments 1 and 2. The stimulus size was 30 min in diameter in the small-size condition and the stimulus was presented for 200 ms in the short-duration condition. In the equal luminance condition the stimuli were equated in luminance to the reference white of 10, 25 and 40 cd/m^2 by flicker photometry for each observer. In the blurred edge condition the stimulus changed in luminance with the Gaussian shape so that the stimulus did not have chromatic aberration on

the edge.

The color naming procedure was the same as before. Trichromat NN and protanope PS participated in this experiment.

Results

These distributions of the basic color names were the same in all conditions for trichromat NN. His color naming was stable, not dependent on conditions. However protanope PS's color naming was found more confused than that when using the real color chips in the control condition, but still his color categories were separated along the r-g direction (**Fig. 3**). In the small-size condition his color naming was much more confused so that red and gray spread along the r-g direction as shown in Fig. 3. The characteristics of trichromat-like categorical color naming were still prominent in other conditions.

In the equal luminance condition trichromat NN showed clear distinction of categorical regions. Protanope KS still used color categorical color names, but they spread along the r-g direction and not restricted in categorical regions. We took color samples on the confusion loci. The colors on a line are of equal luminance and do not have difference in M cone response. They should not be discriminated by protanopes. KS confused all equal-luminance colors but red. Why red was still categorized? This is still to be solved. KS

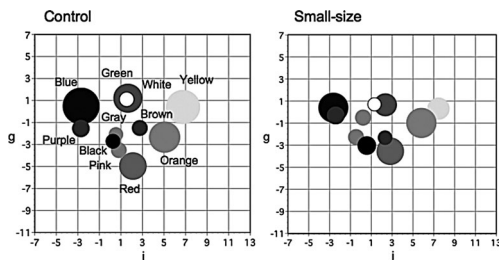


Fig. 3. Centroids of the basic color names in the j-g plane in the control and small-size conditions protanope KS.

might have a third anomalous cone.

5. Conclusions

(1) There were quite large variations of categorical color naming among dichromats.

(2) Protanope PY might use luminance cue since his categorical regions were well separated in 2D cone space.

(3) Deutanope TF might have a nonlinear neural channel since under chromatic illuminants the categorical regions were separated in 2D cone space. His color constancy was weaker than normal trichromats. He could not have utilized von Kries type of adaptation for color constancy.

(4) Protanope KS might have an anomalous third cone since his trichromat-like categorization was only lost in restricted stimulus conditions, e.g. small field.

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