

New Color Vision Tests to Evaluate Faulty Color Recognition

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Purpose: To develop and assess new color vision tests to be used in evaluating faulty color recognition.

Methods: We developed new color vision tests to evaluate faulty color recognition. The two types of color vision tests, designed to assess faulty color recognition in color vision deficiencies, are based on principles that are different from those of the conventional color vision tests. In the first test plate, the subject is asked to choose either a red, green, or gray line from among 10 lines that are randomly colored red, green, gray, yellow, or blue. The score is the difference between the number of correct answers and the number of incorrect answers. In the second test plate, the subject is asked to identify a total of 10 red azalea blossoms, which are dispersed among numerous green leaves. Seventy-five persons with congenital color deficiencies and 20 subjects with normal color vision were examined using these new test plates.

Results: The scores differed significantly between dichromats and anomalous trichromats, and between anomalous trichromats and subjects with normal color vision.

Conclusions: The new tests are easy to use, sensitive, and have good reproducibility for use in discriminating subjects with color vision anomalies. These tests reveal the faulty color recognition that occurs unconsciously in persons with color deficiencies, and are useful in judging the quantification of color vision required in their daily life and occupations. **Jpn J Ophthalmol 2002;46:601-606** © 2002 Japanese Ophthalmological Society

Key Words: Color naming method, color vision deficiency, faulty color recognition, new color vision test.

Introduction

There are many reports regarding faulty color recognition in persons with color vision deficiencies.¹⁻⁹ However, most of the reports mention clinical findings or explanations of the phenomena, while factors related to faulty color recognition, such as its incidence, conditions, and characteristics are not included in the studies. Based on his clinical research, Hukami¹⁰ reported that it was difficult to determine testing conditions that could be applicable to the

clinical investigation of faulty color recognition. In our previous questionnaire, which was distributed to 375 university students with color deficiencies, 88% of dichromats and 39% of anomalous trichromats had various experiences in anomalous color recognition.⁷ This investigation also used a subjective examination method and many of the students were unaware objectively of their color recognition deficiencies. They could recognize a red feather on green leaves if they were told in advance to look for it. If they had not been told, they could not identify the presence of the red feather. This forced recognition of the red feather by referring to its presence indicates that the shape or volume factor, not color, plays an important role in this type of recognition. Therefore, persons with color vision deficiency can easily be un-

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Can you recognize green lines? If any, answer in line number.

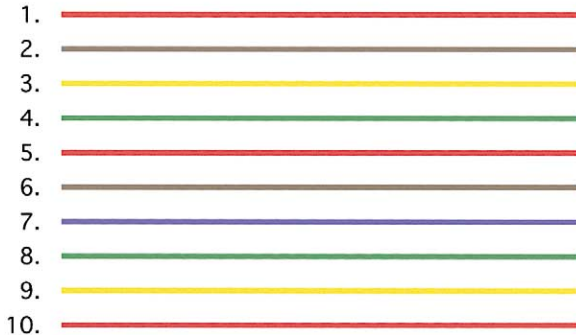


Figure 1. Test plate for Test 1. Lines 1–10 are parallel, 15 cm in length, with 1.0 cm between lines. Test subjects are asked to identify green lines; then, either red or gray lines.

aware of many things about the characteristics of their vision if they are not informed of the presence of the objects.

To investigate faulty color recognition in persons with color vision deficiency, it is important to consider problems related to color in their everyday lives. However, with the subjective method, it is difficult to identify faulty color recognition in persons with color vision deficiencies. It is well known that subjects with severe color vision deficiency cannot identify red blossoms surrounded by green leaves.

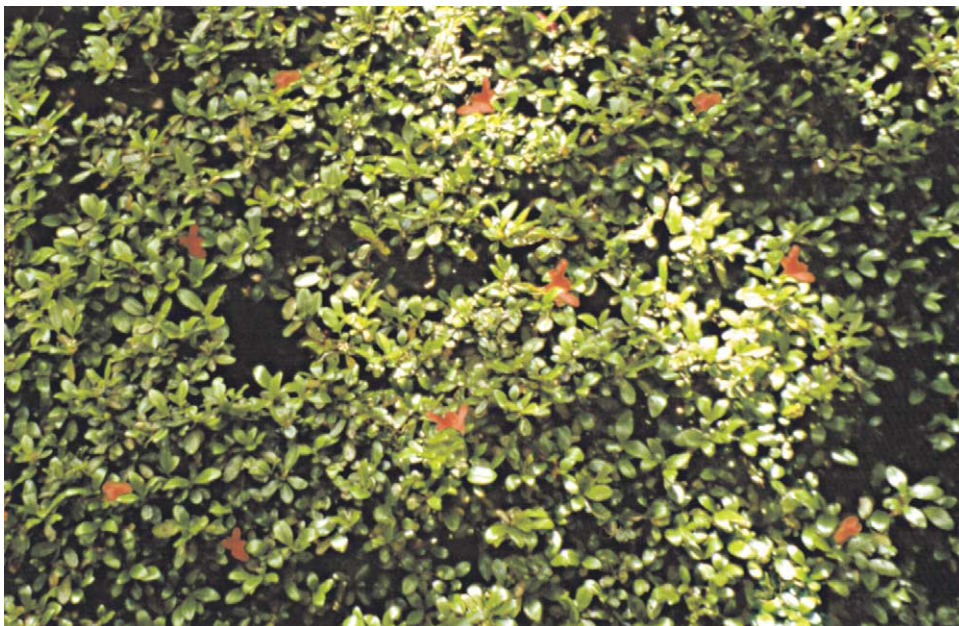


Figure 2. Test plate for Test 2. Subjects are asked to point out blossoms among leaves. Actual size: 18.2 × 11.8 cm.

Based on these phenomena, we developed novel test plates composed of pseudoisochromatic colors. The purpose of the current test plates for identifying color deficiency is to detect and classify the types of color deficiency. Therefore, these tests cannot be used to evaluate the color perception of persons with color vision deficiencies in the context of their social and occupational lives.

Materials and Methods

Subjects

The subjects were 75 persons with color vision deficiencies, comprising a total of 11 protanopes, 23 deuteranopes, 15 protanomals, and 26 deuteranomals, along with 20 subjects with normal color vision. The age range for the entire group was from 15 to 40 years. These 75 subjects with color deficiencies had been diagnosed by anomaloscope. The anomalous trichromats taking part in this study were limited to those who passed the Farnsworth Dichotomous Test Panel D-15. The subjects with normal color vision were defined as those who were able to pass all the test plates of the Ishihara Test Chart for Colour Deficiency (38 Plates, International Edition).

Methods

Test 1 is composed of three plates. In each plate, 10 lines are drawn, randomly colored either red, green, gray, yellow, or blue. Each line is 1.5 mm in

Table 1. Colorimetry Data (Test 1)

Color	XYZ-Y	Yxy-x	Yxy-y
Red	14.63	0.5040	0.3348
Green	16.08	0.2984	0.4640
Gray	14.12	0.3369	0.3531
Yellow	58.98	0.4540	0.4655
Blue	10.16	0.2000	0.1839

width, 15 cm in length, and set in a parallel position 10 mm from the next line. The subjects are asked first to decide whether there are any green lines among the 10 lines in the Test-1 plates. Then they are asked to choose either red or gray lines among the 10 lines in any of the 3 plates in Test 1 (Figure 1).

The three test plates are presented to the subjects for up to 15 seconds at a distance of 50 cm under a D65 light and 1,000 lx.

Test 2 consists of one plate that displays 10 azalea blossoms dispersed on a background of green leaves, produced using computer graphics (Figure 2). The conditions for this test are the same as for Test 1. The subjects are asked whether there are any blossoms, and then, to point them out.

The results are evaluated by calculating the difference between the number of correct answers and the number of incorrect answers for each test.

The specifications of the colors used were determined by spectrophotometer (CM-2022, Minolta, Tokyo) and the results are shown in Table 1. In Test 2, 10 randomly selected locations for blossoms among green leaves should be correctly identified. The results of this test are shown in Table 2. In the Commission Internationale de l'Eclairage chromaticity chart, red and green are plotted on the same isochromatic line for protanopes and deuteranopes. The neutral points that are confused with gray are plotted in the area identified as blue-green or green by persons with normal color vision (Figure 3).

Table 2. Colorimetry Data (Test 2)

Blossom	XYZ-Y	Yxy-x	Yxy-y	Leaf	XYZ-Y	Yxy-x	Yxy-y
1	36.74	0.4346	0.3630	1	25.1000	0.3424	0.4594
2	21.03	0.4531	0.3593	2	64.0000	0.3511	0.3958
3	24.19	0.4843	0.3588	3	10.6200	0.3143	0.4049
4	10.57	0.4919	0.3459	4	12.9400	0.3325	0.4389
5	22.25	0.4977	0.3653	5	20.5600	0.3159	0.4294
6	22.18	0.5021	0.3545	6	49.9700	0.3803	0.4521
7	19.79	0.5045	0.3490	7	39.4100	0.3613	0.4802
8	19.85	0.5069	0.3572	8	5.8400	0.3136	0.3765
9	11.54	0.5124	0.3435	9	17.9500	0.3045	0.4051
10	17.18	0.5162	0.3472	10	4.4100	0.3096	0.3540

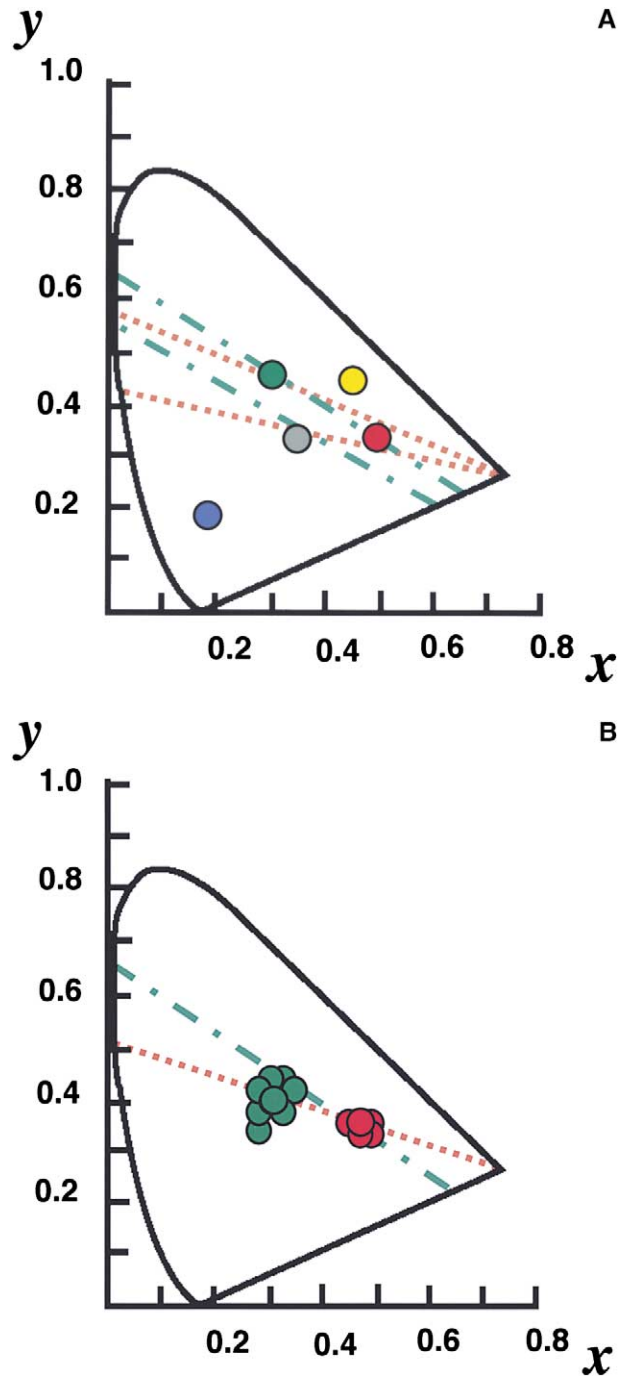


Figure 3. Colors used in Test 1 (A) and Test 2 (B) in Commission Internationale de l'Eclairage chromaticity chart. Isochromatic lines designate protanopes (broken lines) and deuteranopes (dotted lines).

For Test 1, the test plate was designed using a mixture of these easily confused colors to detect faulty color recognition in persons with color vision deficiencies. In Test 2, the red color of the blossoms and

the green color of the leaves, or the achromatic color of the background, were adjusted to align isochromatic lines.

Results

In Test 1, all the subjects with normal color vision correctly identified the green lines, thus obtaining 2.00 ± 0.00 as the mean score. On the other hand, the mean scores were 0.63 ± 0.81 for protanopes, 0.09 ± 0.29 for deuteranopes, 1.60 ± 0.63 for protanomals, and 1.50 ± 0.71 for deuteranomals (Figure 4A). The mean scores for the red line were 3.00 ± 0.00 for the normal color vision subjects, 1.99 ± 0.25 for protanopes, 2.35 ± 0.17 for deuteranopes, 2.67 ± 0.16 for protanomals, and 2.65 ± 0.17 for deuteranomals

(Figure 4B). The average number of correct answers for the gray lines were 2.00 ± 0.00 for the normal color vision subjects, 1.00 ± 0.24 for protanopes, 0.74 ± 0.18 for deuteranopes, 1.44 ± 0.19 for protanomals, and 1.08 ± 0.17 for deuteranomals (Figure 4C). For each line, for both protans and deuterans, there was a significant difference in the number of correct answers between the dichromats and the anomalous trichromats, and also between the anomalous trichromats and subjects with normal color vision ($P < .05$, Welch *t*-test).

Faulty recognition of the green line as gray was 82% in dichromats (protanopes at 64% and deuteranopes at 91%), and 27% in anomalous trichromats (protanomals at 3% and deuteranomals at 23%). The gray line could not be identified by 44% of the

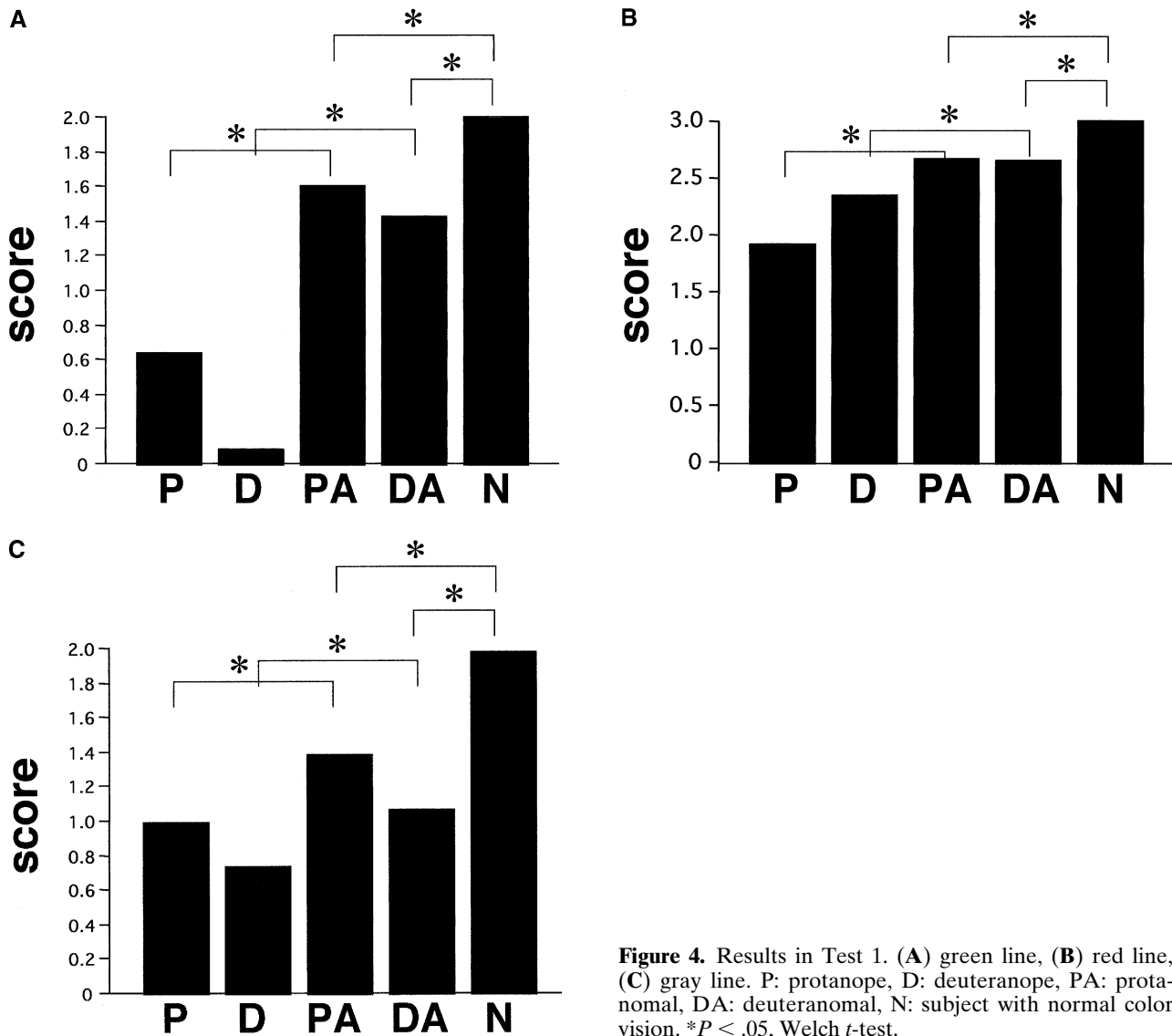


Figure 4. Results in Test 1. (A) green line, (B) red line, (C) gray line. P: protanope, D: deuteranope, PA: protanomalous, DA: deuteranomalous, N: subject with normal color vision. * $P < .05$, Welch *t*-test.

dichromats (protanopes at 27% and deuteranopes at 52%), and by 24% of the anomalous trichromats (protanomals at 13% and deuteranomals at 31%).

In Test 2, the average numbers of correct answers were 10.00 ± 0.00 for subjects with normal color vision, 1.72 ± 1.42 for protanopes, 1.00 ± 2.07 for deuteranopes, 7.27 ± 3.58 for protanomals, and 8.42 ± 2.42 for deuteranomals. In both protanomals and deuteranomals there were significant differences in the scores between dichromats and anomalous trichromats, and also between anomalous trichromats and subjects with normal color vision ($P < .05$) (Figure 5). In dichromats, 38% (19% for protanopes and 48% for deuteranopes) could not identify the blossoms at all, and 12% (19% for protanopes and 9% for deuteranopes) pointed out an incorrect location for the blossoms.

Discussion

The tests in this study include the colors of red, green, and gray, which are often incorrectly recognized by persons with color vision deficiencies, based on the theory of isochromatic lines for dichromats.¹¹ These tests were developed to evaluate a person's color discrimination ability in his daily life. The results indicated that dichromats showed more faulty color recognition, especially in the discrimination between green and gray or the identification of a small red dot on a green background, both of which are difficult for them. Anomalous trichromats showed less faulty

color recognition than dichromats; however, they did show errors, which means they need to recognize their color vision characteristics.

It is noteworthy that the difficulty with category gray recognition and the faulty recognition of gray as green occurs not only in dichromats but also in anomalous trichromats. The faulty color recognition between gray and green among dichromats was reported in our previous study on color naming tests with color plates.⁸ These results can be explained in that it is difficult for persons with color vision deficiencies to discriminate blue-green, which is close to the neutral points for achromatic colors. Because dichromats are weak in discriminating colors with low saturation, they tend to recognize colors with low saturation as green throughout their lives. Anomalous trichromats have similar characteristics in color perception, although it is not as strong as in dichromats. It is true that faulty color recognition often occurs in their everyday lives among persons with color vision deficiency.

Restrictions in academic and social fields have been greatly eased for persons with color vision deficiency and they are able to work in many occupational areas. However, it does happen that persons with color vision deficiency have to change their occupations due to faulty color recognition. It is possible that minor cases of faulty color recognition that can be accepted in daily life might be potentially fatal in some occupations. Therefore, persons with color vision deficiencies should be aware of their true color perception before choosing a suitable occupation. Faulty color recognition is a very important factor in practical life. It is difficult to realize the differences in color recognition not only for persons with normal color vision but also for persons with color deficiencies. These new color vision tests can facilitate a better and more practical understanding of color recognition for persons with all levels of color perception.

The pseudoisochromatic color test presented here is an easy and sensitive examination method. Furthermore, the examinees themselves are able to realize the characteristics of their color perception with this test. The specifications for the colors used in the test plates were calibrated by spectrophotometer and the test plates have good reproducibility. Comparing the test colors with colors in practical life can be useful in judging the quantification of color recognition required in many occupations.

Identification of isochromatic lines differs depending on the type of color deficiency, and different color specifications used in a test give different re-

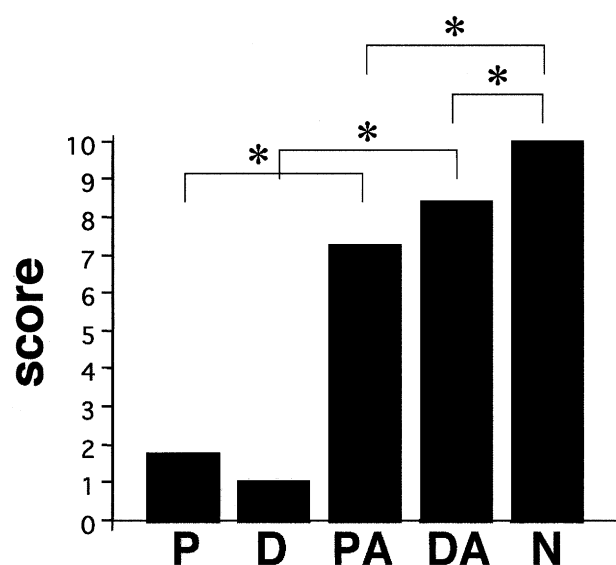


Figure 5. Results in Test 2. * $P < .05$, Welch t -test. P: protanope, D: deuteranope, PA: protanomal, DA: deuteranomal, N: subject with normal color vision.

sults. In this study, protanopes gave a better than average number of correct answers compared to deuteranopes. These results can be explained by the difference in isochromatic lines between the two tests. This indicates that the determination of color perception is the principle of this test.

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