Color Sense Test for Job and Learning Ability

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Color defectives have been considered to be handicapped persons in modern-day Japan. We studied color recognition of color detectives using various clolor materials and color-blindness test. At first, a traffic signal recognition were reviewed. There were no significant differences between the color defectives and the controls. It is a distinct advantage for color detectives that the actual color of the green traffic signal light is mostly blue-green in Japan. The second and third reviews were related to the Color Mate Test (CMT) and its comparison with other color vision tests. The CMT was developed specifically to know which children will require special color consideration in classroom activities, but the Ishihara Color Charts and the Farnsworth D-15 Test (Panel D-15) continue to be used with greater frequency. CMT is the most accurate measure of color discrimination ability in daily life, followed by the Panel D-15. The Ishihara test should be considered unsuitable for evaluating color discrimination ability in daily life. When there is a need to evaluate real-life color discrimination ability, evaluations using common colored objects are the most appropriate.

Key words: Color Vision Test, Farnsworth D-15 Test, Ishihara Color Chart, False Color Recognition in Daily Life, Color Mate Test (CMT)

1. Introduction

Color defectives have been considered to be handicapped persons in modern-day Japan. They have been prevented from entering some types of schools such as painting, textile design, medicine, military, and industrial design, and from applying for certain occupations, especially as technicians dealing with colors. From the international point of view, there is no other country which restricts persons with color-blindness more than Japan. A movement to ease restrictions on color defectives was started by the Nagoya Ophthalmologist Association for School Health (Takayanagi, 1989) and now has become active also in the school health field in Japan. In 1986, 47 out of 94 universities (50.0%) had restrictions for color-blind persons on entrance examinations among the national universities in Japan. However, the number decreased to 3 universities (3.1%) today. It may be a little dangerous, to diagnose color-blindness, much less, the degree of its strength only by ophthalmological tests, for the diagnosis may depend on the instruments which are used in the examination. Even if it should be possible to diagnose them, it would not always attest whether color-blind persons are suitable for the jobs or study fields they wish to be engaged in. In the first part of this paper, we study color recognition of traffic signals, an ability considered to be lacking in color-blinds when they perform certain tasks. We seek to determine whether color-blinds are significantly inferior to color normals in color recognition of red and green traffic signals in particular.

Color vision tests came into use in Japanese schools with the 1958 School Health Law, and the school version of the Ishihara Color Vision Test was universally used. Students who could not read the plates properly faced large barriers (Ishihara, 1989, 2003; Takayanagi and Miyao, 1993; Takayanagi, 1996a, 1996b, 1998; Takayanagi and Nagaya, 1999) in their subsequent education and employment (Fig. 1). The first author learned of this initially from school nurses after becoming a school ophthalmologist in 1973, but before that time opinions from people in the education field had been disclosed in surveys (Sumita, 1981, 1982, 1983a, 1983b, 1983c, 1983d).

The educational version of the Ishihara Test that were generally used in schools are a kind of pseudoisochromatic plate, used to screen out children with congenital color vision abnormalities; they are not a diagnostic tool. Color discrimination ability cannot be judged using this test.

When an “abnormality” is suspected with the use of pseudoisochromatic plates, a classification of “strong abnormality” or “not strong abnormality” is made by an ophthalmologist using the Panel D-15 test (Farnsworth Dichotomous Test). The Panel D-15 test uses 16 disks (caps) of 2 cm in diameter with two colors. One cap is the reference hue and the other 15 caps are arranged in order of their similarity to the reference cap, and based on this the color vision abnormality of people who take the test is classified as either “strong” or “moderate to normal.” People who are classified as “strong” fail the test, while those who are not classified as “strong” pass the test. Furthermore, depending on the arrangement pattern, those who fail can be classified as proton (P: 1st color vision abnormality; red color blindness) or deutan (D: 2nd color vision abnormality; green color blind-

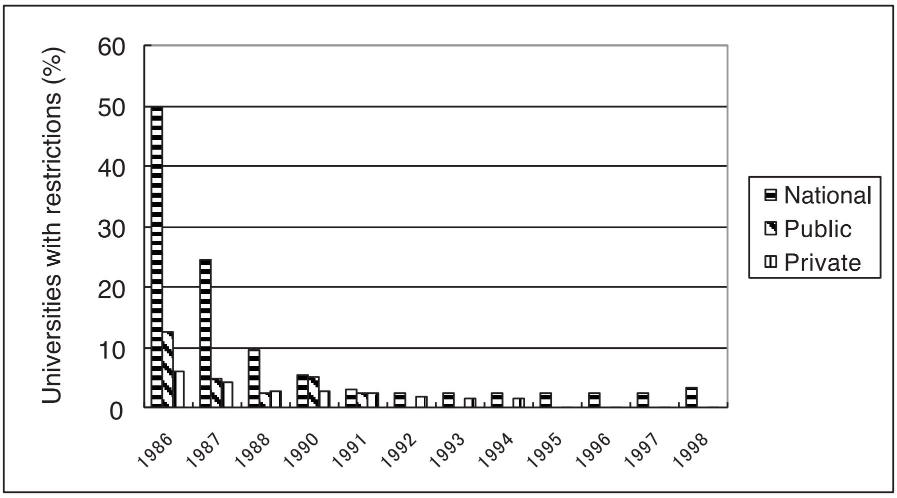

Fig. 1. The ratio (%) of national, public, and private universities which restrict the admission of color defective students.

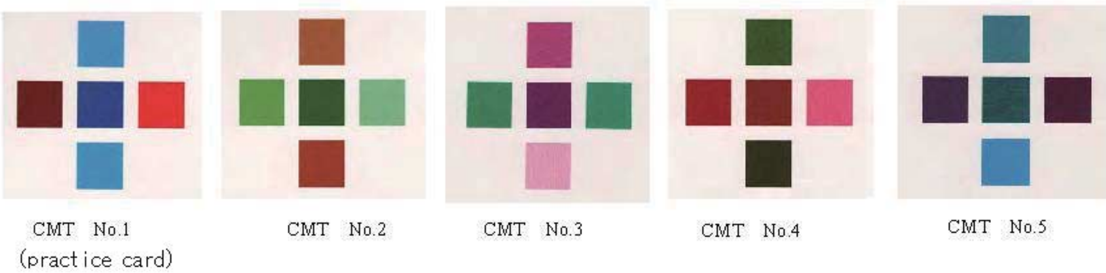

Fig. 2. Color Mate Test (CMT). The CMT has five cards, numbered 1 to 5, on which people are asked whether the "color mates" are aligned vertically or horizontally. The first card is a practice card in which red-brown colors are aligned horizontally and blue-green colors are aligned vertically for comparison. Even color blind students taking the test can easily see that the three colors "mates" on the practice cared are aligned vertically.

ness).

Even with the Panel D-15 test it is not possible to accurately estimate how people see color. An ophthalmologically accurate diagnosis is only possible with an anomaloscope test, with which diagnoses of protan, protanomalia, deutan, and deuteranomalia are made. The authors have proposed calling young students with color vision problems "color special." Even with the anomaloscope it is not possible to predict the specific color combinations that will be difficult to distinguish by people with abnormal color vision.

With the various color vision tests above, it is possible to make an ophthalmologically detailed diagnosis without overlooking even minor abnormalities. However, using ophthalmological diagnoses in educational settings to judge a child's or a student's "color vision abnormality" for the purpose of guidance for their future education. This logic has a history of leading to restrictions in the paths that are open to them.

From the perspective of school education, a specific example may be given of the need for teachers to understand what color of chalk on the blackboard or what color of printing in textbooks will be easy and difficult for students with color vision abnormalities to see. The authors have developed a new color test for schools, the Color Mate Test (CMT; Fig. 2), for this purpose (Kaneko, 1995a, b, c; Takayanagi and Kaneko, 1998; Kudo, 1999; Takayanagi, 2002). The CMT has five cards, numbered 1 to 5, on which people are asked whether the "color mates" are aligned vertically or horizontally. The first card is a practice card in which red-brown colors are aligned horizontally and blue-green colors are aligned vertically for comparison. Even color blind students taking the test can easily see that the three colors "mates" on the practice cared are aligned vertically. Depending on whether the student misses any of the next four cards, cards 2 through 5, it is possible to judge the degree to which the student will mistake colors in combinations that occur frequently in daily life.

The second and third parts of this paper described the utility of the CMT as a color vision test for school use by comparing it with other color vision tests. We also aimed to demonstrate that color discrimination ability tested using traditional ophthalmological color vision tests differs from that in actual society, and to discover future measures that will be needed for school education.

2. Traffic Signals and Colorblindness

Miyao *et al.* (1993) used 1) one hundred and ninety-one 7th-grade boys in Nagoya city, who were suspected of color-blindness and underwent a close examination for color-blindness by the city board of education, and 2) thirty-six age-matched junior high school students as controls,

Table 1. Numbers of color detectives and controls mistaking green for a red light, classified by the degree of color vision defects.

Type of color Blindness	Degree	Subject	Confusing colors	%
Protan	strong	33	0	0.0
Protan	mild	41	0	0.0
Deutan	strong	65	0	0.0
Deutan	mild	47	0	0.0
Total (color defectives)*		186	0	0.0
Control		36	1	2.8

*No significant differences between color defectives and control.

Table 2. Numbers of color defectives and controls mistaking red for a green light, classified by the degree of color vision defects.

Type of color Blindness	Degree	Subject	Confusing colors	%
Protan	strong	33	1	3.0
Protan	mild	41	6	14.6
Deutan	strong	65	4	6.2
Deutan	mild	47	1	2.1
Total (color defectives)*		186	12	6.5
Control		36	1	2.8

*No significant differences between color defectives and control.

who were diagnosed as normal trichromats using Ishihara's color-blindness test (international version).

In the ophthalmological examination for color-blindness, carried out by the members of Nagoya Ophthalmologist Association for School Health, the following criteria were used: 1) Ishihara's color-blindness test (international version) for the screening examination; 2) panel D-15 for the degree of color-blindness; and 3) an anomaloscope for the diagnosis. The examination by anomaloscope was always used for the 191 students suspected of color-blindness.

Then they carried out the experiment on traffic signal color recognition. An experimental traffic signal has been used for traffic safety education in Japanese elementary schools. It is made by Fuji Bosai Inc., and the light measures 70 mm in diameter. The luminance of red light is 965 cd/m^2 with a chromaticity by CIE 1931: ($x = 0.663$, $y = 0.313$); dominant wavelength: 615 nm. The green light luminance is 927 cd/m^2 and the chromaticity is: ($x = 0.217$, $y = 0.380$); dominant wavelength: 495 nm. These values ranged in between those of the blue and green lights. The luminance of the yellow light was 1990 cd/m while the chromaticity was ($x = 0.537$, $y = 0.443$); dominant wavelength: 585 nm. These values indicate that the yellow color was very close to the color of red. Traffic signals in use on the street in Japan have three different diameters; 450 nm, 300 nm, and 250 nm. Regulations call for the distance between the signal and the driver to be within 50 m so that the driver can recognize it without any problems. Here we used a similar experimental condition, with the visual angle in compliance with the above requirement, and a distance of 8 m for the examination. As for the test protocol, the traffic signal equipped 8 m in front for the examination. As for the test protocol, the traffic signal equipped 8 m in front of the subject flashed each of the red, blue, and yellow lights at random. The order and the interval of signal display were also at random; each color was displayed at intervals of 1, 1.5 or 2 seconds. The subject was instructed first to press the button when the red light came on. The second task was to press the button for the green light.

The authors compared the results by the types of color blindness. Having offered the same examination to 36 color normals as a control group, we compared the data with those of the color-blinds, and conducted Fisher's direct test.

They obtained the following results. Degree and diagnosis of color-blindness were cllasified. The classification by the degree of color-blindness is shown in Table 1. There were 33 (17.7%) strong protans, who failed the panel D-15 portion of the test. and 41 (22.0%) mild protans, who passed the same test. There were 65 (34.4) strong deutans who failed panel D-15, and 46 (24.7%) mild deutans who passed it. In total, 186 subjects were diagnosed as color-blinds and 5 subjects as normal trichromats from close examination. The diagnosis classification by anomaloscope was shown in Table 3. There were 33 (17.7%) protanopes (P), 3 (1.8%) extreme protanomats (EPA), and 38 (20.4%) protanomats (P1), against 60 (32.3%) deuteranopia subjects (D), 19 (10.2%) extreme deuteranomaly students (EDA), and 33 (17.7%) deuterano-maly subjects.

Tables 1 and 2 show traffic signal recognition classified by the degree of color defectiveness based on the Panel D-15 test. All the color-blind subjects, who were instructed to press the button on recognizing a green light, correctly pressed the button. One mistake was seen among the normal trichromats in the control group. When the subjects

Table 3. Numbers of color defectives and controls mistaking green for a red light, where diagnosis was classified by anomaloscopy.

Type of color Blindness	Subject	Confusing colors	%
Protanopia	13	0	0.0
Extreme protanomaly	3	0	0.0
Protanomaly	38	0	0.0
Deuteranopia	60	0	0.0
Extreme deutaranomaly	19	0	0.0
Deutaranomaly	33	0	0.0
Total (color defectives)*	186	0	0.0
Control(Normal trichromat)	36	1	2.8

*No significant differences between color defectives and control.

Table 4. Numbers of color defectives and controls mistaking red for a green light, where diagnosis was classified by anomaloscopy.

Type of color Blindness	Subject	Confusing colors	%
Protanopia	13	1	3.0
Extreme protanomaly	3	0	0.0
Protanomaly	38	6	15.8
Deuteranopia	60	4	6.7
Extreme deutaranomaly	19	1	5.3
Deutaranomaly	33	0	0.0
Total (color defectives)*	186	12	6.5
Control	36	1	2.8

*No significant differences between color defectives and control.

were told to press the button for a green light but a red light was actually displayed, 12 (6.5%) out of 186 color defective students mistakenly pressed the button (Table 2). However, we could not find a significant difference between the color defective subjects and color normal controls. Among the error-rates indicated for each degree and type of color defectives in Table 2, the mild protan subjects made mistakes most frequently; 6 subjects out of 41 (14.6%). There was no significant difference between the mild protans and color normals.

Tables 3 and 4 give the results of traffic signal recognition among various color defectives diagnosed by anomaloscope. The subjectss were to press the button when the traffic signal was red as shown in Table 3. No color defective subjects pressed the button when presented with the green signal instead.

The diagnostic classification in Table 4 indicates that 6 out of 38 (15.8%) protanomats (PA) made mistakes. Fisher's direct test, however, proved no significant difference in the numbers of subjects who made mistakes between each diagnosed type of color-blind and the control group of normal trichromats.

The road traffic control system of Japan largely conforms to those of Western countries, where traffic signals are red, yellow, and green (The Survey Task Force on the Color Distribution of Traffic signals Lights, 1989).

In Japan, the green light of the traffic signal is called "blue" in the Japanese language, because the general public called it "blue" when the first automobiles were introduced in the country. Even today, "blue" is the legal term for a traffic light, which is in fact green.

In modern days, use of polycarbonate filters has made quality control possible in terms of the chromaticity of the signal. The standard value of the color of the green light has been set on the border of the chromaticity of the blue in Japan.

Recently LED lights for green color for the trafic signals are widely used in Japan. However, signals which use glass filters are still used, and more or less different depending on the signals. The Green light chromaticity for the trafic signal is within the "blue green" color area.

The report (International Society For Traffic Safety, Inc., 1988) on the recognition of traffic lights by the color-blind was published by the International Society For Traffic Safety, Inc. (Tokyo), which carried out laboratory experiments. Lights of each color were displayed in the same position of the visual field; thus, no positional information of the signal was given. There was little difference in the simple response time to each traffic light of no matter what color among the normal trichromats and the mild deutans. Among the serious color-blind, however, both the protanopes and the deuteranopia subjects showed a longer response time than color normals. Under the same condition in the present study, the protans most often confused the red (without a background light) for the green (with background light) light, while yellow was rarely confused.

On the other hand, the deutans most frequently confused the yellow, and then, the red and green lights.

In the laboratory experiment, where lights of each color were displayed in a different position of the visual field, thus, positional information of the signal was given, the simple response time was not much influenced by the difference of target light colors among the mild color-weak subjects and color normals. On the contrary, there was a remarkable delay in the response time of the strong protans to red and green colors. The report also stated that among the strong deuteranopia subjects, the response time was longer for any color.

The result of the experiment proved that the color confusion was not significant at all (only one of strong deutan subjects was mistaken) and if color-blind persons are given the positional information, the mistakes will markedly decrease. The International Association for Traffic Safety also gave the test of the traffic light recognition on the video-screen under the driving simulation. According to the report of the test, almost all color-blind persons correctly recognized the traffic lights on the video screen. Thus, 5 color-blind subject underwent this experiment and made only 3 mistakes out of 180 trials. As for the traffic signals recognition under the same condition, only one subject made a mistake. The report described an actual field driving test on the road in the 4th experiment. The results were as follow. 1) Color-blind persons who had color recognition problems in the laboratory experiment did not have difficulties in recognizing the color of a traffic signal which was not far from them. 2) From a distance, however, they noticed and recognized the signal more slowly than normal trichromat persons.

Factors preventing recognition of a green light were bright back light, confusing shadows, glare from the sky, white or gray colored buildings, green roadside trees in the background and white glare from mercury lamps at night. A red traffic light, on the other hand, was difficult to see with direct sunlight, bright back light, dark buildings or dark green trees in the background. A yellow traffic light was difficult to discern in direct sunlight. 4) For protans, a red light was seen to be dark and ambiguous. On the other hand, deutans had trouble a green traffic light. 5) Color-blind tended to be more careful about the movement of cars around them and paid more attention to traffic signals than color normals. Our experiment corresponds to the Laboratory Experiment in the previous report. The experiment proved that even under the most difficult conditions for color-blinds to recognize colors, there was no significant difference in recognition ability for experimental traffic signal between the color-blind subjects and the control subjects with normal trichromatism.

All of the color-blind subjects showed an outstanding ability to recognize a green light without any mistakes in the present study. They made numerous mistakes, however, when faced with a red light. This is attributed to the fact that the red light has close chromaticity to the yellow light of the traffic signal. It might be believed that color-blind persons make mistakes because they confuse red green lights. However, the present experiment attested that the color-blind subjects showed no confusion when they saw a green light. Consequently, it is presumed that the errors of color-defectives with a red light occur due to the confusion between red and yellow lights.

It would be worthwhile to empirically attest this presumption in the future by including yellow lights in the experiment. When color-blind persons actually drive, they identify the color of the signal by the order or layout of lights on the traffic signal. Even if they confused red for yellow, this is at least less dangerous than mistaking them for green in terms of safety. Steward and Cole (Steward and Cole, 1989) studies everyday tasks of color vision defectives and found that nearly 90% of the dichromats and up to two-thirds of the anomalous trichromats reported difficulties in performing everyday tasks that involve color. Their study also showed that nearly one-half of the dichromats and one in five of the anorma-lous trichromats difficulty with traffic lights, and similar proportions reported color difficulties in their present jobs. These rates of color-blind people who find it difficult to recognize traffic lights are relatively low, just as in our results'. Vingrys and Cole (1988) reviewed the evidence related to color standards in transport industries and concluded that a strong case can be made for their retention in public transport. Though this conclusion seems rational, the diagnosis and the degree of the strong color defects cannot be always correct, for they depend on the instruments used for the examination. The test to evaluate the strength of color-blindness should be practised by using actual traffic lights.

Kuyk *et al.* (1966) carried out an experiment on the ability of protan color defectives to perform color-dependent air traffic control tasks. They concluded that severe protans cannot perform color-dependent air traffic control tasks reliably, while the performance of moderate protans is better.

Kuyk *et al.* (1987) also studies the ability of deutan color defectives to perform simulated air traffic control tasks. Deutans who performed all tasks as well as normals were classified as mild defects. Moderate deutans performed only the large disc (1 degree) colornaming tasks as well as normals, and could not perform the same task with the smaller disc (0.1 degree), whereas severe deutans performed none of the tasks as well as normals. D-15 relative error score was the single best predictor of performance on the task (r-square = 0.602). It was concluded that mild deutan color defectives have sufficient color vision to safely perform several critical air traffic control tasks, while moderate and severe deutans failed to respond correctly.

Iinuma (1975) carried out a color naming test using an actual Japanese traffic signal in which each of the three colored lights was presented randomly. He classified the mistakes subjects made, reporting that most of the errors were due to the confusion of a red light with a yellow light irrespective of the types of color-blindness. The second cause of mistakes was due to the confusion of a yellow light with a red light. Iinuma confirmed that there was no mistaking of a green traffic light. Iinuma's results completely correspond with the present findings.

Nathan *et al.* (1963) found no significant correlation between the response time to the signal and the degree of color-blindness by using an anomaloscope.

Kinney *et al.* (1979) revealed that there was no distinct relationship between the degree of color-blindness and the average performance to judge correctly the colors of navigation lights (red, green, and white) presented to the subject at night under realistic sea conditions among 81 color defective men and 24 color normals. Actually, the similar result to Kinney's was obtained from the present experiment: the protanomaly subjects made more mistakes than the protanopia subjects did. Conversely, Ohta (1975) found a significant relationship between the findings from the color-blindness test using color light, e.g. anomaloscope or lantern test, and the error-rates of color recognition for color signal. He also indicated that recognition of a color signal was independent of the result of color-blindness test batteries using color paints.

Ichikawa *et al.* (1976) wrote that the threshold distance to finding out the existence of traffic signals was approximately 100 m in either of color-blinds or color normals. The threshold distance for the deutans was slightly shorter. The fixation duration per one trial of about 0.5 second was no different for color defectives or color normals.

Ichikawa and Tani (1969) also found no significant difference in traffic accident rate between color normals and color defectives in Japan.

As we mentioned previously, color defectives can recognize the color of the signal by the order or layout of the actual traffic light. Besides, color defectives usually can distinguish obscure colors readily in daily life.

Takayanagi *et al.* (1987) reported that color defective people had a superior ability to discriminate the colors compared to color normals. With reference to a green light, although used one in this experiment was the middle between the green and the blue, there is a wide range between green and blue lights of Japanese traffic signals. While most "green" traffic lights in Japan are blue-green, if the light is made blue, both protan and deutan color defective persons will have no difficulty in distinguishing a "green" light. The chromaticity of a red light can also be arranged so that color defective persons may not have any color confusion.

Miyao *et al.* (1991) proposed conditions for the chromaticity of a red light on cathode ray tube (CRT) displays. Dominant wavelengths above 600 nm in color CRTs should be avoided in routine work presentation because of less sensitivity in protanopias, while the American National Standard Institute (ANSI, 1988), recommended that pure red (long wavelength: dominant wavelength above 650 nm) in CRT displays should be avoided, because protanopes are noticeably less sensitive at those wavelengths. Correspondingly, it is an advantage for color defectives that the actual color of the "green light" is blue-green in most cases in Japan. From the present findings, the chromaticity of the red and yellow traffic lights should be improved so as to prevent confusion between those two colors.

Recognition ability of color defectives using traffic signals were reviewed. All the color defectives in the experiment, who were supposed to press the button on recognizing a red light, never pressed the button mistakenly for a green light. On the contrary, 12 out of 186 color defectives (6.5%) mistakenly pressed the button for a red light in a task in which they were supposed to press the button for a green light. There was, however, no significant difference between the cases and the color normal controls. It is advantage for color defectives that the actual color of the "green traffic light" is mostly blue-green in Japan. Thus we recommend that the chromaticity of the red and yellow traffic lights be improved so as to prevent confusion.

3. The Utility of the CMT as a Color Vision Test

3.1 Comparison of CMT and various other color vision test

The Law of School Health was amended in 1995 so that the color vision test is done only once, when children are in the fourth grade of elementary school, considering adaptability to the test. At that time the law stated that the purpose of the color sense test was to determine whether a child would be hindered in school activities, not to detect congenital abnormalities. It also says that a mild color vision defect that does not interfere with schoolwork should not be considered a disability. However, at that time the main test for color vision in school health checkups and in school nurses' offices was the school version of the Ishihara test. Therefore, Takayanagi *et al.* (2010) conducted a survey to compare existing ophthalmological tests and the CMT, which was developed to be uses as a reference for whether or not children would be hindered in school education due to their color vision.

In 2000 and 2001, regular school health checkups were conducted for 59,309 boys and 55,293 girls who were second-year middle school students in a major city. At that time screening was done for color sense using the school version of the Ishihara test. It was recommended to students suspected of having a color sense problem and their parents that the students take a second test for color sense at an ophthalmological clinic associated with the Ophthalmologic School Doctors Association of the city. The test would be paid for by the board of education. A total of 1,017 students (0.95% of the total number of students) underwent a second test at an ophthalmological clinic, including 915 boys (1.5% of all boys) and 102 girls (0.18% of all girls). Informed consent was received from the students and their parents. These 1,017 students were the subjects for Study 1. The number of students who were suspected of having a color sense problem and recommended to take a second test among the total number of students could not be identified because it has not been made public. It is known that when using the Ishihara test the percentage of students suspected of having a color sense problem is about 4.5% of boys and about 0.2% of girls. Therefore, taking the students who were suspected of having a color sense problem and who were recommended to receive a second test as a parameter, the percentage that took the second test is estimated to be about 33% for boys and 50% for girls.

Three tests were used for the students who were examined a second time: the school version of the Ishihara test (Ishihara test), the Panel D-15 test, and the CMT. With the Panel D-15 test, students were dichotomized into Pass and Fail groups, and those in the Fail group were further classified as proton (P) and deutan (D). In this way, students were divided into three groups, a pass group (Pass group), proton group (P group), and deutan group (D group). The mean number and standard deviation of mistaken answers

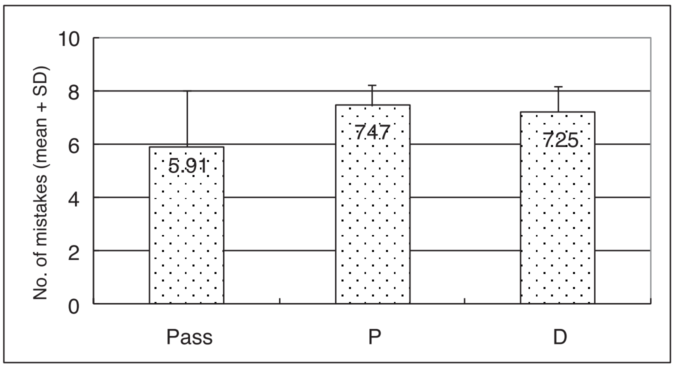

Fig. 3. The mean number and standard deviation of mistaken answers on the Ishihara test for each group classified by the result using Panel D-15 test.

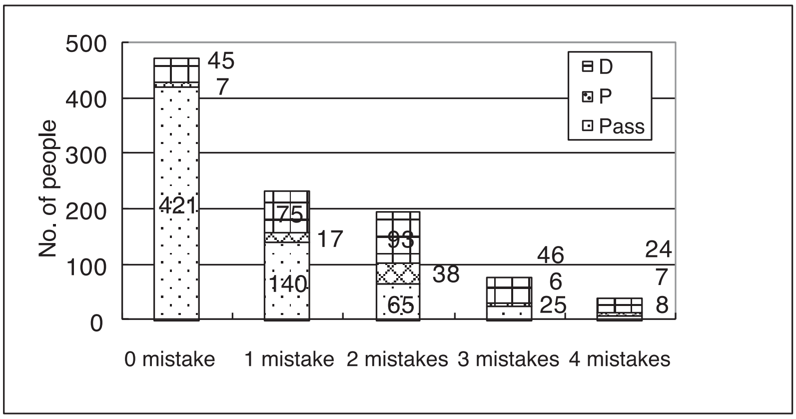

Fig. 4. The number of people in the Pass group, P group, and D group from the Panel D-15 for the mean number of errors on the CMT.

Table 5. A comparison of the CMT and Panel D-15 test results.

	Panel D-15 test: Pass	Penel D-15 test: Fail	Total
CMT: Pass	421	52	473
CMT: Fail	238	306	544
Total	659	358	1,017

on the Ishihara test and CMT were compared for each of the three groups from the Panel D-15 test. The statistical analysis was done using the SPSS version 17 statistical software package. The data for the three groups was tested using one-way analysis of variance, and the χ^2 test was used to test the distribution of data between the groups.

3.1.1 Comparison of results of Panel D-15 test and Ishihara test Judging from the Panel D-15 test, there were 659 students in the Pass group, 75 students in the P group, and 283 students that D group (total 1017 students). The mean number and standard deviation of mistaken answers on the Ishihara test for each group are shown in Fig. 3. The number of mistaken answers on the Ishihara test was 5.9 ± 2.13 (mean $\pm$ standard deviation) in the Pass group, 7.47 ± 0.77 in the P group, and 7.25 ± 0.96 in the D group. A statistically significant difference was seen between the groups in a one-way analysis of variance ($p < 0.001$).

3.1.2 Comparison of results of Panel D-15 test and CMT Figure 4 shows the number of people in the Pass group, P group, and D group from the Panel D-15 for the mean number of errors on the CMT. The number of errors on the CMT was 0.57 ± 0.95 in the Pass group, 1.85 ± 1.02 in the P group, and 1.75 ± 1.16 in the D group. A statistically significant difference was seen between the groups in a one-way analysis of variance ($p < 0.001$).

Students who gave all correct responses on the CMT were classified in the CMT Pass group, and those who made one or more mistakes in the CMT Fail group. A comparison of the CMT and Panel D-15 test results is shown in Table 5, with P and D together taken to be the Panel D-15 Fail group. Of the students in the Pass group with the Panel D-15 test, 421 (63.9%) were in the CMT Pass group and 238 (36.1%) were in the CMT Fail group. Of the students in the Panel D-15 P group, 7 (9.3%) were in the CMT pass group and 68 (90.7%) were in the CMT Fail group. Of the students in the D group, 45 (15.9%) were in the CMT Pass group and 238 (84.1%) were in the CMT Fail group. The percentage of those in the Fail group on the Panel D-15 test who were judged to be Fail with the CMT only was 85.5%. In contrast, the percentage of those in the Panel D-

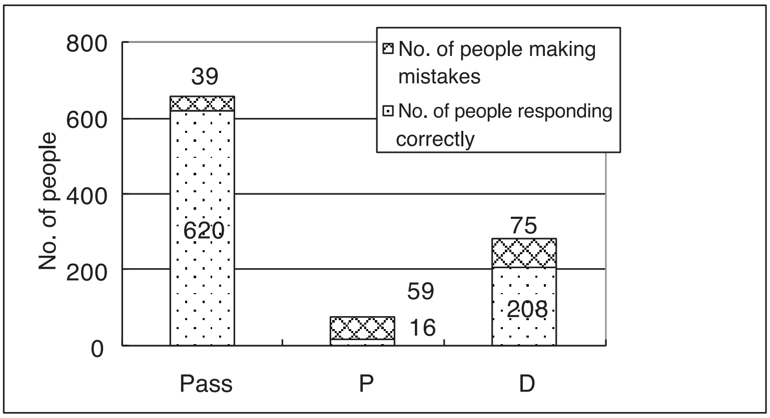

Fig. 5. The results and comparisons of mistaken responses on CMT card 2 and the Panel D-15 test.

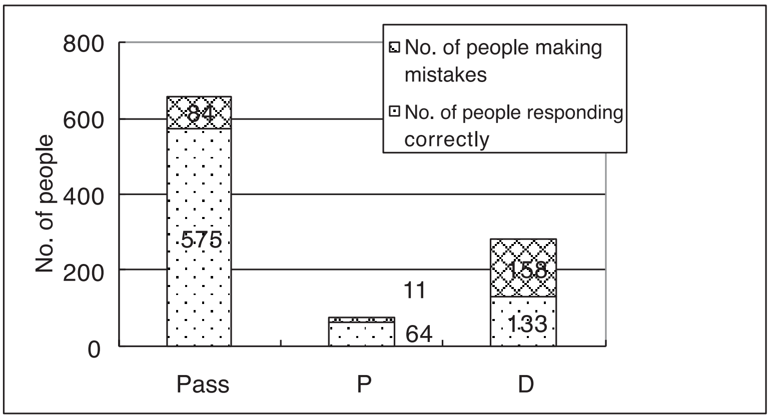

Fig. 6. The results and comparisons of mistaken responses on CMT card 3 and the Panel D-15 test.

15 Pass group who were judged to be Pass with the CMT was 63.9%. In other words, even among those who were Pass with the Panel D-15, 36.1% were Fail with the CMT.

3.1.3 Comparison of the results of each for each of the CMT cards and the Panel D-15 test Figures 5–8 show the results and comparisons of mistaken responses on each CMT card (cards 2–5) and the Panel D-15 test. For CMT card 2 (Fig. 5), correct responses were given by 620 (94.1%) of the Panel D-15 Pass group and incorrect responses were given by 39 (5.9%). In the P group, 16 (21.3%) responded correctly and 59 (78.7%) made mistakes. In the D group 208 (73.5%) responded correctly and 75 (26.5%) made mistakes. Significant differences in distribution were seen between the groups with a χ^2 test ($p < 0.001$).

With card 3 (Fig. 6), 575 people (87.3%) in the Panel D-15 Pass group gave correct responses and 84 people (12.7%) gave mistaken responses. In the P group, 64 people (85.3%) responded correctly and 11 (14.7%) made mistakes. In the D group, 133 people (47.0%) responded correctly and 150 (53.0%) made mistakes. Significant differences in distribution were seen between the groups with a χ^2 test ($p < 0.001$).

With card 4 (Fig. 7), 542 people (82.2%) in the Panel D-15 Pass group gave correct responses and 117 people (17.8%) made mistakes. In the P group, 59 people (78.7%) responded correctly and 16 (21.3%) made mistakes. In the D group, 171 people (60.4%) responded correctly and 112 (39.6%) made mistakes. Significant differences in distribution were seen between the groups with a χ^2 test ($p < 0.001$).

With card 5 (Fig. 8), 529 people (80.3%) in the Panel D-15 Pass group gave correct responses and 130 people (19.7%) made mistakes. In the P group, 24 people (32.0%) responded correctly and 51 (68.0%) made mistakes. In the D group, 127 people (44.9%) responded correctly and 156 (55.1%) made mistakes. Significant differences in distribution were seen between the groups with a χ^2 test ($p < 0.001$).

3.1.4 Evaluation of ophthalmological color tests It is thought that an accurate diagnosis of color vision abnormality can be approached ophthalmologically only after using several test instruments, including an anomaloscope. Therefore, “colorblindness,” “color vision anomaly,” and “color vision abnormality” are not simple to judge. In the past, however, “diagnosis” was done without sufficient thought using mistaken methods. What led to this mistaken notion in society was probably the color vision test in school health, which was mandatory in compulsory education.

Past manuals for the Ishihara Test said that if a person who was strongly colorblind were mistakenly allowed to become a doctor, pharmacist, or chemist, it would not only

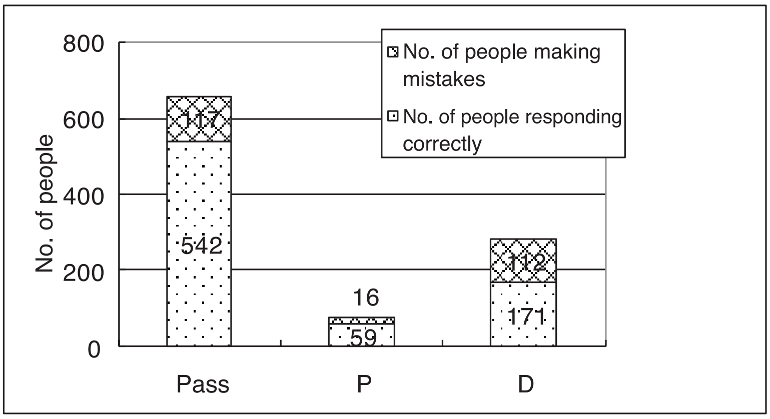

Fig. 7. The results and comparisons of mistaken responses on CMT card 4 and the Panel D-15 test.

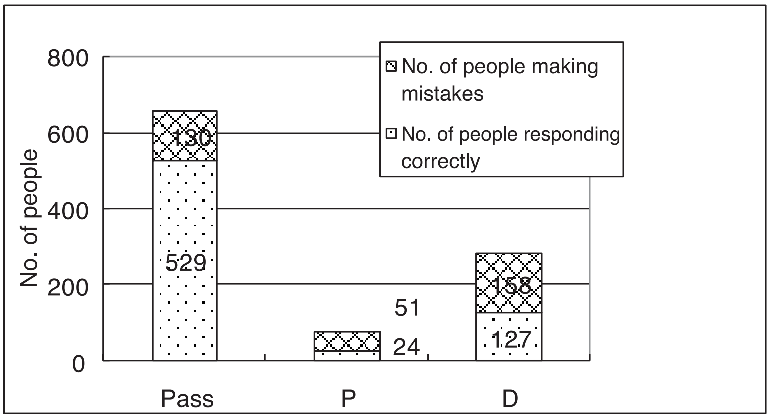

Fig. 8. The results and comparisons of mistaken responses on CMT card 5 and the Panel D-15 test.

be detrimental to that person throughout his life, but also may cause harm to others (Ishihara, 1989). This resulted in many young people being blocked from their preferred path, from advancing in the fields of science, engineering, and medicine to not being hired in many workplaces or unable to obtain desired qualifications.

Tokyo Medical University Department of Ophthalmology (1957) published the TMC Test, in which the guide lists occupational adequacy in detail. Suitable occupations for people with abnormal color vision are ranked A to D. Occupations ranked A are related to human life, and it is written that even people with mildly impaired color vision should not be hired as doctors, pharmacists, public health workers, or nurses. Rank B includes occupations in which a person with people with color vision abnormalities may cause major errors in performing their work, such as Self-Defense Force personnel, policemen, and Japan Coast Guard personnel. Rank C occupations are those in which people with color vision abnormalities may feel some difficulty in performing their work. They include middle and high school teachers. Finally, Rank D occupations are those that people with color vision abnormalities can perform acceptably. Five hundred two occupations are listed, including ticket scalper and horse race handicapper. Anyone who makes a mistake on pseudoisochromatic plates such as in the Ishihara test or TMC is considered to have "abnormal color vision," and is viewed as having a risk in real life from false color recognition.

Cole and Orenstein (2003) performed a color naming test with 10 color surface samples of fabric or painted samples of typical colors, and compared the results with those using the Panel D-15 test. Their subjects were 102 people aged 11–65 years with abnormal color vision among patients examined by an optometrist, who were compared with a control group of the same number of people with normal color vision who were matched for age. They found that 40% of all subjects with abnormal color vision did not make mistakes in naming the colors. They considered people who made more mistakes than the people with the worst results among those with normal color vision in naming colors to be "true positives" in false color recognition. After identifying these true positives, they calculated the sensitivity and specificity of the Panel D-15 test. Among the false color recognition group (true positives), the percentage (sensitivity) of people who failed the Panel D-15 test (positive: abnormal value) was 80%. The percentage of people who passed the Panel D-15 test (negative: normal values) among those who did not show any false color recognition (true negatives), in other words the sensitivity, was 69%.

According to Cole and Orenstein (2003) if people who mistake 16 or more of the 24 plates on the international version of the Ishihara test are taken to be positive, all the peo-

Table 6. Comparison of the results with the Ishihara test, Panel D-15, and CMT, and the false color recognition of objects used in daily life. Tests for false color recognition were done with 2 tasks that are typical of problems in color discrimination in daily life: 1) discrimination of colored pencils (Coupy Pencils®) from 12 colors painted on the outside of the pencils (white, black, brown, pink, purple, blue, aqua, green, yellow-green, yellow, orange, red), and 2) the colors (same 12 colors) of the plastic insulation covering electrical wires 2 mm in diameter that are used for electrical wiring codes (color codes).

Color pecils

	False color recognition	No false color recognition	Total
CMT: Fail	2	21	23
CMT: Pass	0	16	16
Total	2	37	37

Sensitivity: 100%; Specifity: 43%.

Color pecils

	False color recognition	No false color recognition	Total
Panel D-15 test: Fail	2	27	29
Panel D-15 test: Pass	0	10	10
Total	2	37	37

Sensitivity: 100%; Specifity: 27%.

Electrical wire color code test

	False color recognition	No false color recognition	Total
CMT: Fail	6	22	28
CMT: Pass	2	16	18
Total	8	38	46

Sensitivity: 75%; Specifity: 42%.

Electrical wire color code test

	False color recognition	No false color recognition	Total
Panel D-15 test: Fail	7	30	37
Panel D-15 test: Pass	1	8	9
Total	8	38	46

Sensitivity: 88%; Specifity: 21%.

ple in the false color recognition group tested positive by failing 16 or more of the plates (sensitivity 100%). Among those who did not have mistaken color recognition (people who had better color naming results than the worst results among the people with normal color vision), the percentage of people that were negative by failing 15 or fewer of the plates was 41% (specificity). From this result, the Panel D-15 test has a sensitivity of 80% and specificity of 69% in determining whether or not a person has false color recognition. Thus, it does not seem to be an adequate test.

As mentioned in the Results, the percentage of people who failed the Panel D-15 test who are judged to be in the Fail group with the CMT only was 85.5%. The percentage of people who passed the Panel D-15 test who are judged to be in the Pass group with the CMT only was 63.9%. Thus, 36.1% were Pass with the Panel D-15 test and Fail with the CMT. Thus, of the 1,017 people suspected of having problems with color vision from the Ishihara test, 659 were Pass on the Panel D-15 test (Pass rate 64.8%) and 473 were Pass on the CMT (Pass rate 46.5%). A simple comparison of the Pass rate shows that the Pass rate is lower with the CMT than with the Panel D-15 test.

4. Comparison of False Color Recognition of Objects Used in Daily Life and Color Vision Tests with the CMT and Other Tests

In the former section, the Ishihara test, Panel D-15 test, and CMT were compared each other. Next, the relation with false color recognition in daily life should be studied. Here the relationship between each color test and false color recognition in daily life with subjects who were examined at the ophthalmology clinic of one of the authors (Y.T.) was investigated.

The Ishihara test, the most widespread test of color vision, has an extremely high sensitivity when screening people who are suspected of having problems with color vision. With the Ishihara test, however, it is impossible to make judgments at the level of false color recognition in daily life. The CMT, which tests color combinations that are difficult to distinguish, was developed with the purpose of identifying children who will need special considerations for school study, and determining the kinds of measures that will be necessary. In tests of occupational suitability, the Panel D-15 has been used relatively more often. In Study II, therefore, Takayanagi *et al.* (2010) compared the results with the Ishihara test, Panel D-15, and CMT, and the false color recognition of objects used in daily life.

The subjects were 47 males who underwent tests with the school and international versions of the Ishihara test, the Panel D-15, anomaloscope, and CMT during color vision consultations at a single ophthalmology clinic from April 2005 to June 2009. Their mean age was 29.9 ± 16.9 years. The reasons for their consultations varied, including wanting to take a civil servant's test on which there were restrictions on abnormal color vision, and being told at school that they were color blind. All the tests could not be given to all the subjects, and so there are some missing values for some tests. Informed consent was obtained from the subject or, in the case of minors, the subject's parents, for participation in these tests, analysis of results, and publication.

Tests for false color recognition were done with 2 tasks that are typical of problems in color discrimination in daily life: 1) discrimination of colored pencils (Coupy Pencils®) from 12 colors painted on the outside of the pencils (white, black, brown, pink, purple, blue, aqua, green, yellow-green, yellow, orange, red), and 2) the colors (same 12 colors) of the plastic insulation covering electrical wires 2 mm in diameter that are used for electrical wiring codes (color codes). Each subject was taken to be a true abnormal or not depending on whether they named all the colors correctly or made mistakes. The sensitivity and specificity of the color vision tests (CMT and Panel D-15) against true abnormal (false color recognition of objects used in daily life) were obtained for the Pass and Fail test results with the CMT and Panel D-15.

Sensitivity was the "test positive"/"true abnormal" ratio; in other words, the percentage of individuals with false color recognition who were classed as Fail with the CMT or Panel D-15 test. If this is 100%, it means that all subjects who could not name colors correctly were color abnormal in the tests.

Specificity was the "test negative"/"test normal" ratio; in other words, the percentage of individuals who named the colors correctly that were classed as Pass on the CMT or Panel D-15 test. If this is 100%, it means that all subjects who were able to name the colors correctly were also "normal" on the tests.

As mentioned in the methods, there were some missing values. Of the 47 subjects, 39 performed the colored pencil test (missing results for 8 people) and 46 people performed the electrical wire color code test (missing results for 1 person).

The results are shown in Table 6. The sensitivity of the CMT against the colored pencil test (were all 12 colors correct, or were there mistakes?) was 100%, and the specificity was 43%. The sensitivity of the Panel D-15 test was 100% and the specificity was 27%.

The sensitivity of the CMT against the electrical wire color code test (were all 12 colors correct, or were there mistakes?) was 75%, and the specificity was 42%. The sensitivity of the Panel D-15 test was 88% and the specificity was 21%.

As mentioned above, Cole and Orenstein (2003) in their study on the relationship between the color naming test with fabric and paint samples of 10 colors each, found that the sensitivity of the Panel D-15 test was 80% and the specificity 69% in identifying people with false color recognition. People with false color recognition were those with poorer results than the worst results of the subjects with normal color vision. Considering color discrimination of fabric and paint samples from the number of colors and size of the object (visual angle), their results are fairly similar to the color discrimination of colored pencils in Study II in the present study. The Panel D-15 results in Study II had sensitivity of 100% and specificity of 43%.

In comparison, the sensitivity of the CMT against false color recognition of colored pencils in Study II was 100%, and the sensitivity was 43%. The specificity was quite high.

Even though the specificity of the CMT was better than that of the Panel D-15, specificity of 43% means that 57% of the people who had no false color recognition were classed as Fail on the CMT test and people who had no false color recognition of colored pencils used in daily life were judged to have a problem in color discrimination on the CMT.

Let us consider the limitations of meaning of Table 6. In this study the subjects included only males who were diagnosed as having abnormal color vision with the Ishihara test and anomaloscope. There have been almost no studies on color naming and various color vision tests in which the subjects also included people with normal color vision. It should be noted that the results of the present test are for people who made mistakes on the Ishihara test, in whom sensitivity and specificity would differ from those in the general population.

The results of Table 6 indicate that, of the existing color vision tests, selection with the Ishihara test is the least appropriate method of estimating the possibility that a person will have false color recognition in daily life. The results of the Panel D-15 should also be used cautiously. Therefore, when attempting to evaluate whether a person will have false color recognition in daily life, testing with actual colored objects, such as by showing subjects colored pencils, electrical wires, or a selection of bell peppers, and having them respond with the correct color is probably the most appropriate way to test them.

5. Historical Environment for the CMT and Study Conclusions and Conclusion

The Ophthalmologic School Doctors Association in Nagoya city where the author's (Y.T.) study took place was established in 1972. Since that time the difficulty of diagnosing color vision in school health checkups has been recognized, and a central examination system has been adopted by the city's board of education based on the determination that diagnosis should be done by a specialist. At that time, about 800 students suspected of having abnormal color vision were selected each year from the approximately 30,000 students in the fourth grade of elementary school and the first year of junior high school, respectively, for close examination. Through investigation of the examination results it came to be recognized that ophthalmological diagnosis and the level of disability in daily living differed. The Ophthalmologic School Doctors Association and the authors approached the relevant authorities and called for a reconsideration of people with abnormal color vision and easing or abolition of restrictions.

When the School Health Law was partially amended in 1995, congenital color vision abnormalities were tested for as an impairment for the purpose of the school health check. The purpose was not to make a diagnosis but to be able to take appropriate follow-up measures for children who would experience troubles in school. The CMT was developed for this purpose in 1995. Since that time the city board of education has used the expression “color special” to refer to students who have problems with color vision, and the CMT has been used as a secondary test to identify the kinds of consideration that are needed for these children in learning.

In 2002 the Ministry of Education, Culture, Sports, Science and Technology reviewed their approach to color vision, and adopted measures to ease restrictions against people with color vision abnormalities. At that time the color vision test was removed from the regular health checks at school.

The authors (Takayanagi *et al.*, 2010) compared the CMT with the Ishihara test and Panel D-15, which have been used until recently, and also compared the ability to discriminate the colors of objects used in daily life. No such studies have been seen in Japan, which has a long history of harsh restrictions on people with color vision abnormalities. Internationally, examples of such studies are the valuable earlier study of Cole and Orenstein (2003) and a study on how color is seen on color computer displays (Ramaswamy and Hovis, 2004). These studies have all concluded that color discrimination ability in daily life and the workplace cannot be predicted with conventional color vision tests.

The CMT was developed as a color vision test for school use. It is used when parents notice color difficulties in their young children and consult the school, or a child’s teacher feels that the child has problems using color in daily life and consults the school nurse or school doctor. At these times, they can observe the color combinations that confuse the child and how the child responds to color. It is a test that can be used to provide assistance in educational settings.

The authors compared the CMT with the Panel D-15 and Ishihara tests, and analyzed their relation to false color recognition in daily life. The subjects for the study were a total of 1,017 second-year junior high school students (915 boys, 102 girls) in one city who made mistakes on the Ishihara test during the regular health check, and later took a secondary test for color vision conducted by the city’s board of education. The students were divided into Pass and Fail groups based on the results of a Panel D-15 test. The students in the Fail group were then further classified as proton (P group) and deutan (D group). The mean number of errors on the CMT was 0.57 in the Panel D-15 test Pass group, 1.85 in the P group, and 1.75 in the D group. The difference was statistically significant ($p < 0.001$).

Next, two kinds of color naming test (colored pencils and electrical wire codes) that are problems of color discrimination in daily life were conducted. The subjects were 47 males who underwent a close color vision examination at one ophthalmology clinic. The respective sensitivity and specificity of the CMT and Panel D-15 were then obtained with all correct or some mistaken answers as the dividing criterion. In the relation between CMT test results and false color recognition, colored pencils had sensitivity of 100% and specificity of 43%, while electrical wiring code had sensitivity of 75% and specificity of 42%. When the Panel D-15 results were analyzed similarly, it was found that for colored pencils the sensitivity was 100% and specificity 27%, and for electric wire color codes the sensitivity was 88% and the specificity 21%.

The CMT is meant for school use, and the response of students to the CMT directly shows their color vision characteristics. The CMT is intuitive and easy to understand, and the tester can share the experience with the student. In the relation with evaluation of color discrimination ability in daily life, while the CMT may have the best sensitivity and specificity, its specificity for false color recognition in daily life is low. Therefore, even the CMT cannot predict which colors will be falsely recognized by the Fail group in daily life. The Panel D-15 has even lower specificity than the CMT. The specificity of the Ishihara test is even lower still (overdiagnosis), and therefore it is inappropriate for use in screening for color discrimination ability in daily life.

The Ministry of Health, Labour and Welfare (2001), in a pamphlet entitled “Revisions of Health Check Items for Hiring,” wrote that “these revisions do not prohibit color vision tests. When color vision tests are conducted, their relation with the content of the work should be fully explained to the worker, and the test must be conducted appropriately based on the consent of the worker. Sufficient care is needed to make sure that the color vision test reflects the ability to perform the work at the work site. Even when tests are to be conducted, it is sufficient that they check whether or not a person can judge the colors used at respective work sites.” The results of the present study also indicate that when it is necessary to evaluate color discrimination ability in daily life, evaluations using colored objects are the most appropriate.

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