RESEARCH ARTICLE

Can Color Vision Defective Subjects Who Pass the Farnsworth Lantern Test Recognize Surface Color Codes?

Barry L. Cole, Ka-Yee Lian, and Carol Lakkis

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Introduction: The International Civil Aviation Organization requires that pilots be able to distinguish the colors used in air navigation and in particular be able to identify the colors of signal lights. Most national aviation authorities use a lantern test to assess the ability of applicants for a pilot's license who have abnormal color vision to recognize the colors of signal lights. However, color-coding is now widely used in aviation systems other than signal lights. Color is used in tarmac markings, maps, manuals, and electronic flight instrument displays. These color codes can use 10 or more colors, many more than the 3 to 5 used for signal lights. This study investigated whether people with defective color vision (DCV) who pass the Farnsworth lantern test can recognize the main colors used for surface color codes. ***Methods:*** There were 99 subjects with DCV who were tested using the Optec 900™ version of the Farnsworth lantern test and also named the colors of a set of 10 surface colors that varied in shape (dots and lines) and size (3 sizes; angular diameters 0.27, 1.0, and 2.4°; angular widths 0.14, 0.27, and 0.50°). A control group of 20 subjects with normal color vision also named the surface colors. ***Results:*** Of the DCV subjects, 19% passed the Farnsworth lantern test, of whom 74% made no errors with the surface colors. The other 26% made few errors (up to 5 errors in 120 presentations) and those errors were mostly to confuse red, orange, and brown. The subjects with normal color vision made no errors naming the surface colors. ***Conclusion:*** Those who pass the Farnsworth lantern test can recognize the colors of a 10-color surface color code with few or no errors. This is because the small (2.9-min arc) stimulus of the lantern test presents a more difficult task than the larger surface colors.

Keywords: aviation color vision standards, abnormal color vision, signal lights.

THE INTERNATIONAL Civil Aviation Organization requires that pilots be able to distinguish the colors used in air navigation and in particular be able to identify the colors of signal lights. Most national aviation authorities use lantern tests to assess the ability of applicants for a pilot's license who have abnormal color vision to recognize red, green, and white signal colors. The Farnsworth lantern test is used in the United States and Australia, while other lantern tests, such as the Holmes-Wright lantern, Spectrolux, and Beyne lanterns are used in European countries (2,19).

However, with the introduction of electronic flight instrument displays, extensive and elaborate color coding is now to be found on the flight deck. Surface color codes are also used on airport tarmacs and in maps and manuals. Color coding is an important tool at the human interface with complex information systems because it facilitates efficient information transfer. It is well known that color coding of complex visual displays enhances performance by reducing errors and increasing the speed at which information can be extracted (3,12,13,20). The color codes in electronic visual displays often use 10 or more colors, not just the 3 to 5 used for signal lights, and it might be expected that observers with abnormal color vision who have difficulty recognizing red, green, and white signal lights may have even more difficulty recognizing colors in a 10-color code.

It is known that observers with abnormal color vision make errors naming the colors of color-coded electronic displays (1,14,15,17) and that they are slower and make more errors extracting information, even when the color is used redundantly (6). Sometimes they cannot even do the task because of an inability to discriminate the color coding used (18). The question that arises is whether those who pass the Farnsworth lantern test and are judged able to recognize colored signal lights can also recognize the colors of a more complex surface code that may use 10 or more colors. Ramaswamy and Hovis (17) proposed a special test of color naming for color vision deficient rail employees who use a color-coded computer display for controlling rail traffic because clinical tests of color vision were not a satisfactory selection tool. However, they did not test whether a lantern test would predict the ability to recognize the computer display color code.

METHOD

A consecutively presenting series of patients with abnormal color vision attending the color vision clinic

From the Department of Optometry and Vision Sciences, University of Melbourne, Victoria, Australia (B. Cole, C. Lakkis); and Clinical Vision Research Australia (C. Lakkis, K-Y. Lian) and the Melbourne Optometry Clinic (K-Y. Lian), Victorian College of Optometry, Victoria, Australia.

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Address reprint requests to: Barry L. Cole, Department of Optometry and Vision Sciences, University of Melbourne, Victoria 3010, Australia; bcole@optometry.unimelb.edu.au.

of the Melbourne Optometry Clinic at the Victorian College of Optometry were tested with a Farnsworth lantern and were also asked to name 10 surface colors, which were presented in 2 shapes (dots or lines) and 3 sizes. The data was collected as a part of a larger study of color naming reported elsewhere (4,5) and some of the data in this paper is also reported in those previous papers. The project was approved by the NVRI/DOVS/VCO Human Research Ethics Committee and subjects gave written informed consent to their participation in the study.

Subjects

We recruited 100 male subjects with abnormal color vision from consecutively presenting patients. One young subject (age 9) was excluded because he was not fully cooperative and a confident diagnosis of his color vision could not be made. The remaining 99 subjects were 8 to 52 yr of age (mean age 28.2 yr, ± 10.6; range 8–52). Their color vision was assessed using the Ishihara test (24-plate, 1993 edition), the Farnsworth D15 test (Richmond Products, Boca Raton, FL), the Medmont C100 test (Medmont Pty Ltd, Vermont, Australia) and the Nagel anomaloscope (Type 1 Schmidt and Haensch). The fail criterion for the Ishihara test was three or more errors and all subjects failed this test.

Subjects were grouped according to the von Kries classification of abnormal color vision (protanomaly, deuteranomaly, protanopia, and deuteranopia). This was done using the Nagel anomaloscope, which is accepted as the definitive diagnostic instrument for categorization of abnormal color vision. The anomaloscope measures loss of color discrimination and anomalous perception of color by requiring subjects to match a pure yellow light by varying a mixture of red and green light. Protanopes and deuteranopes have a severe loss of color discrimination and cannot distinguish red, yellow, and green when there is no brightness difference. At the anomaloscope they can match the yellow light of the anomaloscope to pure red, pure green, and any mixture of red and green simply by adjusting the brightness of the yellow light. Protanomals and deuteranomals have varying loss of color discrimination but less so than protanopes and deuteranopes. They perceive colors in an anomalous way, which is evident when they match the red-green mixture in the anomaloscope to the yellow light. This anomalous perception of colors may lead to misidentification of colors.

Anomalous trichromats were further classified as mild or moderate depending on whether they passed or failed the Farnsworth D15 test. The fail criterion for the Farnsworth D15 test was an arrangement in which there were two or more diametrical crossings. The anomaloscope was not used for four subjects because of equipment malfunction, but these subjects are presumed to be anomalous trichromats because three passed the Farnsworth D15 test and the other was classed as mild by the HRR test. They were confidently classified as protan or deutan by the Medmont C100. All the subjects had a visual acuity (with glasses if necessary) of better than 20/25 in the better eye and had no signs or history of ocular disease. **Table I** shows the number in each class of color vision deficiency in the sample and the number expected in a random sample.

TABLE I. NUMBER OF SUBJECTS CLASSIFIED BY TYPE AND SEVERITY OF THEIR COLOR VISION DEFICIENCY WHERE ANOMALOUS TRICHROMATS ARE CLASSIFIED AS MILD OR MODERATE USING THE FARNSWORTH D15 TEST.

	Number	Expected*
Protanomaly. Mild. Pass D15 test	15	8
Protanomaly. Moderate. Fail D15 test	5	4
Protanopia	8	12
Total protan	28	24
Deuteranomaly. Mild. Pass D15 test	44	42
Deuteranomaly. Moderate. Fail D15 test	16	21
Deuteranopia	11	12
Total deutan	71	75

*The expected numbers are based on the known prevalences in Caucasian societies in which protanopia, deuteranopia, and protanomaly each have a prevalence of 1% among males, and deuteranomaly has a prevalence of 5%. About one-third of anomalous trichromats and all dichromats fail the Farnsworth D15 test.

We also recruited a control group of 20 male subjects with normal color vision (average age 34.6 ± 14.7 yr; range 12–57 yr) from among routine patients and colleagues. They all passed the Ishihara test, had no signs or history of ocular disease and had a visual acuity (with glasses if necessary) of better than 20/25 in the better eye.

The Lantern Test

The lantern test was given only to those subjects with abnormal color vision since, with very rare exception, it is known that those with normal color vision make no errors with this test (9). The lantern test was the new version of the Farnsworth lantern produced by the Stereo Optical Company and marketed as the Optec 900™. It is equivalent to the original Farnsworth lantern in its performance (4).

It was given in accordance with standard procedures under normal room lighting (illuminance in the horizontal plane at eye level 320 lux). The test distance was 2.4 m (8 ft), at which distance the diameter of the stimulus lights subtends a 2.9-min arc at the subject's eyes. The lantern test presents a series of nine vertically oriented pairs of colored lights, which may be red, green, or white, and each combination of red, green, and white is presented. Subjects were required to name the red, green, and white stimuli using only those three names. Each pair was shown for 2 s and three runs of the nine pairs were given rather than ending the test when no errors were made on the first run, as is usual when giving the test for the purpose of testing applicants for a pilot's license.

Subjects were deemed to have passed the test if they made no errors in the first run, or if they made errors in the first run, made no more than two errors in the second and third runs. This is the usual criterion for passing this test. One error is defined as making an error naming one or both of the colors in any pair of lights.

TABLE II. CHROMATICITY COORDINATES (x, y) AND REFLECTANCE FACTORS (Y%) OF THE 10 SURFACE COLORS MEASURED WITH RESPECT TO ILLUMINANT C (CIE 1931 COLOR SPACE).

	x	y	Y%		x	y	Y%
Red	0.523	0.313	14.3	Blue	0.172	0.183	11.3
Orange	0.502	0.389	25.1	Purple	0.278	0.217	10.7
Brown	0.443	0.392	12.3	White	0.299	0.299	72.0
Yellow	0.415	0.466	65.0	Grey	0.303	0.305	22.2
Green	0.287	0.475	20.2	Black	0.347	0.371	2.7
Background gray	0.303	0.305	53.1				

Color Naming Task

Both the color vision normal and the color vision deficient subjects were asked to name 10 surface colors which were red, orange, brown, yellow, green, blue, purple, white, gray, and black. The colors were chosen so that, in the judgment of the experimenters, each color fell unequivocally within 1 of the 10 color categories. The colors were printed on A4 size cards as dots or lines in three different sizes with a mid-gray background. The dots had diameters of 17.0 mm, 7.0 mm, and 1.9 mm. The lines were 20 mm long and 3.5 mm, 1.9 mm, and 1.0 mm wide. At the test distance of 400 mm, the dots subtended 2.4, 1.0, and 0.27° at the eye, and the width of the lines subtended 0.50, 0.27, and 0.14°. The length of the lines subtended 2.9°.

The 10 colors were in two horizontal rows of 5 colors on each sheet. The vertical distance between the centers of the rows and the horizontal distance between centers of adjoining dots or lines was 37 mm (5.3°). There were six sheets, each with one size of dot or one size of line. The order of the colors was different on each of the six sheets. The spectral reflectances of the colored samples were measured by spectroradiometry and their chromaticities and luminous reflectance calculated with respect to Illuminant C and are given in **Table II**.

The six cards were placed one at a time on an angled stand so that they were perpendicular to the line of sight of the subject and were viewed binocularly from a distance of 400 mm, which was set by a fixed forehead rest. The cards were illuminated at 1280 lux by two GE Polylux 860 18 W tri-phosphor fluorescent lamps (Manufacturer's specification: color temperature 6300 K, color rendering index 85).

Procedure

Subjects were given the diagnostic tests followed by the Farnsworth lantern test. They were then asked to name the colors of the surface colors using only the color names on a printed list. The six color cards were shown twice in order of decreasing size with the dot or line cards given first to alternate subjects. The order of presentation was reversed when the cards were shown the second time. Subjects were given up to 2 s (as judged by the experimenter) to name each color. This length of time was rarely needed and naming of all 120 stimuli was usually completed within 4 min.

RESULTS

None of the subjects with normal color vision made errors naming the surface colors. Of the subjects with abnormal color vision, 19% passed the Farnsworth lantern test. Most of these subjects (74%) made no errors naming the surface colors and those who made errors made very few. The maximum number of errors was 5 (4.2%). Those errors were mostly to confuse red with orange or brown and vice versa. One subject named green as red on one occasion. All the subjects who made errors passed the Farnsworth D15 test: three were mild deuteranomals and two were mild protanomals.

The mean percent errors naming the surface colors made by the subjects who failed the Farnsworth lantern was 4.4%. While 29% made no errors, some 15% made more than 10% errors. **Fig. 1** shows the distribution of errors for those who passed or failed the Farnsworth lantern test.

The size of the colored stimuli had an important effect on the probability of error. **Fig. 2** shows probability of error as a function of angular diameter for the various classes of abnormal color vision. The curves in Fig. 2 are fitted to the data points for surface colors using a model based on reciprocal of area, which is the best fit to the data, that takes into account the interaction between types of abnormal color vision and stimulus area (5). The Farnsworth lantern data points were not included when fitting the curves because the Farnsworth lantern presents only 3 colors while there were 10 surface colors. The Farnsworth lantern test presents stimuli that are very much smaller (2.9-min arc) than

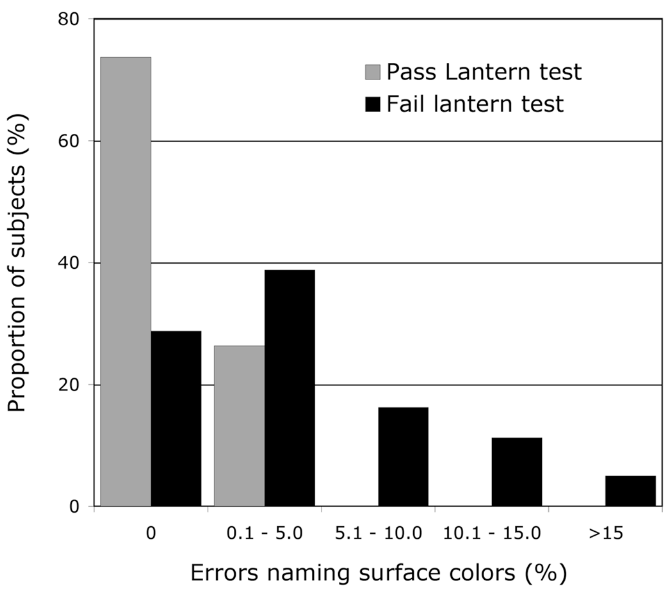

Fig. 1. Distribution of errors naming surface colors for subjects with abnormal color vision who passed or failed the Farnsworth lantern test.

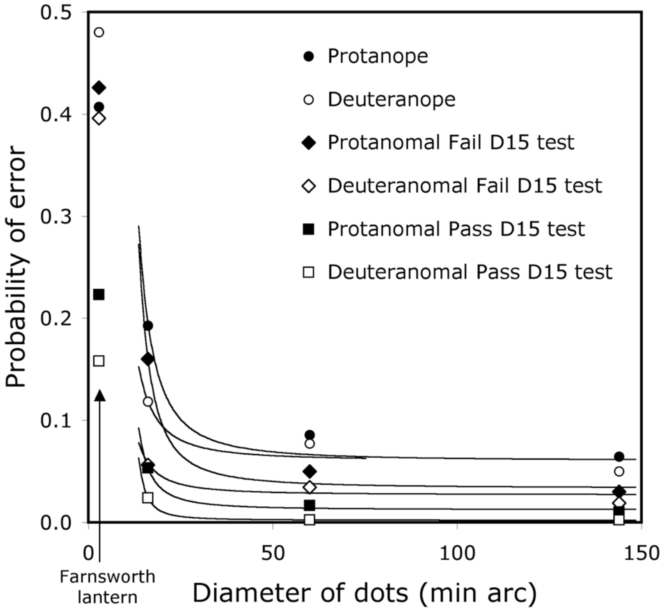

Fig. 2. Probability of error naming colors as a function of the angular diameter of the colored stimuli for various classes of abnormal color vision. The data points at the 2.9-min arc are for probability of error naming the colors of Farnsworth lantern stimuli; the other data points are for dot surface color stimuli.

the surface color stimuli, the smallest of which are the 1-mm wide lines, which subtend an angle of an 8.4-min arc, but have an angular length of 2.9°, and the 1.9-mm diameter dots, which subtend a 16-min arc. The higher probability of error for the Farnsworth lantern compared with the surface color stimuli can be attributed in large part to the small size of its stimulus.

It is also evident in the scatter plot of errors made by the 99 DCV subjects (**Fig. 3**) that the Farnsworth lantern presents a more difficult task than the surface colors. The probability of error is higher for the Farnsworth lantern than for naming surface colors despite the Farnsworth presenting only 3 colors compared with 10 colors for the surface colors. It is perhaps worth noting that there were only five DCV subjects who made no errors on both tasks.

DISCUSSION

Three-quarters of the subjects who passed the Farnsworth lantern were able to name the 10 main colors used in surface color codes without error and the one-quarter who did make errors made very few. The maximum error rate was 4%. The errors they made were to confuse red, orange, and brown occasionally. This suggests that those who pass at the Farnsworth lantern will be able to discriminate surface color codes such as those used in aviation maps and flight instrument displays without too much difficulty, and that the Farnsworth lantern test is a sufficient test of this ability.

The Farnsworth D15 test was devised to identify from among those with abnormal color vision those who could discriminate the main colors used to code electrical wires (11). Clinicians use the Farnsworth D15 test to categorize those with abnormal color vision into those with a mild deficiency and those with a moderate to severe deficiency. It is often presumed that those who pass the Farnsworth D15 test and are classed as mild are able to identify surface color codes, even though it is known that some of those who pass the test do make color naming errors both with signal lights (7,10) and surface colors (5,8,17).

However, it is clear from the data of this study that the Farnsworth D15 test sets a lesser level of difficulty than does the Farnsworth lantern test: all the subjects in this study who passed the Farnsworth lantern also passed the Farnsworth D15 test, as has been reported before (7,10). If the Farnsworth lantern is used for selection of those able to recognize signal lights there is no point to subsequently testing with the Farnsworth D15 test. Of course the Farnsworth D15 test can usefully be given as a screening test prior to administering the

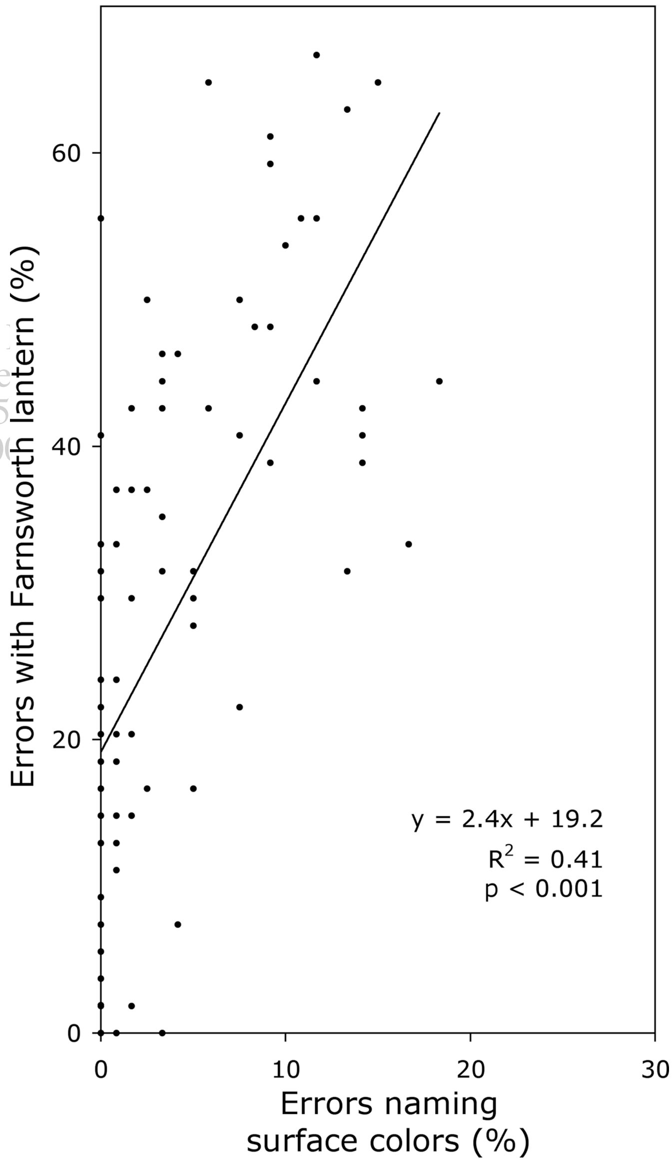

Fig. 3. Scatter plot of percent errors made by subjects with abnormal color vision naming the colors of the Farnsworth lantern test and the surface colors. Percent errors with the Farnsworth lantern counts errors made on all three runs. The plot excludes an outlier protanope who made 42% errors with the surface colors and 48% errors with the Farnsworth lantern.

Farnsworth lantern, since all those who fail the D15 test will, with rare exceptions, fail the lantern test (7,10).

It is not entirely surprising that those who pass the Farnsworth lantern test can name surface colors with no or few errors. The Farnsworth lantern is a more demanding test than the task of naming surface colors because of the small size of its stimulus. The ability of observers with abnormal color vision to discriminate surface color codes is dependent on the angular size of the colored stimuli (5). The angular size of the stimuli in the Farnsworth lantern is a 2.9-min arc, which is much smaller than the angular size of the surface colors used in this study and of the colored chips used in the Farnsworth D15 test. The colors in the Farnsworth D15 test subtend a 100-min arc.

It is concluded from this study that testing with the Farnsworth lantern will ensure that those who pass have a reasonable ability to recognize both the colors of signal lights and color-coding used in electronic flight instrument displays. This is not to say that passing the Farnsworth lantern is a sufficient test of the ability to recognize aviation color codes. Questions were raised about the adequacy of the tests of color vision used in aviation following the crash of Federal Express flight 1478 on July 26, 2002 (16). One of the causes of this accident was the pilot's inability to interpret the colors of the PAPI glidepath signals because of his defective color vision, despite having been shown to have a mild color deficiency by passing the Farnsworth lantern test.

This is not surprising. The Farnsworth lantern simulates recognition of red, green, and white signal lights, but it does not simulate demanding conditions. The angular size of the Farnsworth lantern stimulus is equivalent to viewing an aviation signal from about 300 m when aviation signals are viewed in practice from several nautical miles. The illuminances generated by the Farnsworth lantern are 70 to 200 μlux, but aviation signals are sometimes viewed from long distances or in poor visibility conditions so that illuminances can be one-hundredth of these values. Moreover, the criterion for passing the Farnsworth lantern allows up to two errors in the second and third runs, which is a surprisingly tolerant error rate of 5.5%. This means that some of those who pass the Farnsworth lantern test will make occasional errors with the colors of signal lights. Likewise, our study shows that while the majority of those who pass the Farnsworth lantern test can recognize surface color codes, some will make occasional errors.

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