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16. Abstract

Subjects of varying type and degree of color deficiency were tested on a battery of color tests, including the American Optical H-R-R plates, the Dvorine plates, the Color Threshold Tester, the Farnsworth Lantern, the Farnsworth-Munsell 100-hue, the Farnsworth Panel D-15, the Titmus Vision Tester Color Plate, and an anomaloscope examination. Correlations with a practical test of the ability of subjects to discriminate aviation signal red, white, and green were obtained. The results generally indicated that the Farnsworth Lantern was a superior predictor of performance on the practical test.

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COLOR DEFECTIVE VISION AND THE RECOGNITION OF AVIATION COLOR SIGNAL LIGHT FLASHES

I. Problem.

Candidates for Federal Aviation Administration medical certificates (Classes II and III) must be able to discriminate among aviation signal red, white, and green.[1] To test for this requirement, a variety of commercial color vision tests have been approved for use by FAA-designated Aviaition Medical Examiners, although many of these tests have not been standardized against specific aviation requirements. Many investigators[2] have compared these tests for clinical effiicacy in classifying and quantifying color defective vision. The purpose of the current study was to compare several of these tests, together with some currently non-FAA-approved clinical tests for predictive value when used with an aviation criterion.

II. Method.

A. *Subjects.* Five thousand and sixteen visitors to the 1968 Oklahoma State Fair were screened using the American Optical H-R-R, the Dvorine plates and the Farnsworth Panel D-15 (these tests are described below) with 460 of these fair-goers showing some degree of color deficiency. These 460 people were invited to participate in this investigation. From this group, 49 men and five women were tested on the test battery. Additional subjects were obtained from Tinker Air Force Base. Arrangements were made to screen 4000 active duty medical records for evidence of color defect. Two hundred forty-seven Air Force personnel were so identified and, of these, 73 men completed the Group 1 test battery. These 127 subjects comprise the Group 1 test population.

One year later, the Air Force medical records were again screened and 369 additional defectives were identified. At this time, the Titmus Vision Tester Color Plate was added to the test battery and 71 men completed the battery and comprise the Group 2 test population.

B. *Tests and Procedure.* The complete test battery is described below. Because the Titmus Vision Tester was not used at the time they were run, Group 1 subjects did not receive that test.

1. The A. O. H-R-R plates (American Optical H-R-R Pseudoisochromatic plates, 2nd edition, American Optical Company, 1957), which are really pseudoachromatic plates, were designed[3][4] to discriminate color defective vision from normal color vision, to classify type of defect, and to indicate the degree of defectiveness. The testing procedure prescribed by the test authors was followed except that no repetition was given. Each subject was shown the four demonstration plates and asked to identify any symbols he saw. He was told there would be one, two, or no figures on each plate. He was then shown the test plates and asked to identify the figures. The first response was recorded and no corrections were allowed. For this study, a subject was scored as failing if any errors were made in plates 12–14 of the diagnostic series.

2. Of the Dvorine plates (Dvorine Pseudo-Isochromatic Plates, 2nd edition, Harcourt, Brace and World, Incorporated, 1953), the 15 numerical plates, including one demonstration plate, were used. The seven plates for illiterates and the nomenclature test were excluded from the study. Each subject was shown the plates and asked to identify the numbers. The criterion for failure was 12 or more errors on plates 1–15.

3. The Farnsworth Panel D-15 (Farnsworth Dichotomous Test for Color Blindness, Panel D-15, Psychological Corporation) was designed to distinguish the severely color defective from the color normal and the moderately color defective.[5] The test consists of 15 plastic color caps plus a rack containing a reference color cap mounted at one end. Each subject was instructed to place the color caps in order, so that each cap was placed next to the caps most like it in color. After completing the test the subject was asked

1

to review it and make any changes to correct the order. The failure criterion was at least two crossovers in approximately the same direction on the score sheet circle.

4. The Farnsworth 100-hue Test (the Farnsworth-Munsell 100-hue Test for the Examination of Color Discrimination, Munsell Color Company, Incorporated, 1957) was designed to measure color discrimination in the color normal and the zones of color confusion in the color defective.[5] The test consists of four hinged boxes, each containing two fixed color reference caps at either end of one part of the box and one-fourth of the 85 color test caps randomly arranged in the other part. The subjects were instructed to place the color caps in order so that each cap was placed between the two caps most like it in color. Subjects were told to work in any order from either reference cap. The scoring procedure was identical to that described by the test author.[6] An error score of 100 or more was considered failing.

All of the above tests were administered in a darkened room with test illuminaton supplied by a Macbeth easel lamp with daylight filter to approximate C.I.E. Source C.

5. The Color Threshold Tester (SAM CTT) (Macbeth Corporation), which was developed for an Air Force criterion,[7] consists of a test light in front of which are two discs, each containing eight filters. The upper disc contains neutral density filters for varying the luminance of the test light, while the lower disc contains color filters for varying the test color. The subject was seated ten feet from the instrument in a dark room. All eight colors, at the highest luminance, were shown to the subject and named for him by the examiner before testing. The subject was instructed to report the color of each test light, and to use only the color names shown to him before testing. The subject was told to guess when not sure. All colors were shown at the lowest luminance first in the order prescribed by the test author. The order was reversed at each successively higher luminance. The criterion for failure was a score of 49 or less.

6. The Farnsworth Lantern (Farnsworth Lantern for Testing Color Vision, Macbeth Corporation) was designed for the screening of Navy personnel.[8] The Lantern permits successive presentation of nine vertically arrayed pairs of lights representing all possible combinations of the two positions and of the three colors, red, green, and white. Subjects were seated eight feet from the Lantern in a lighted room. Each subject was instructed to identify the colors of the pairs of lights presented to him. All nine pairs of lights were presented in random order and if the subject made no errors in identifying the pairs in the series, he was passed. If there were any errors, two additional series were run. Failure criterion was an average of more than one error per series of nine color pairs for the last two series.

7. The Titmus Plate (Color Perception Plate of the Titmus Vision Tester, Aeromedical model, Titmus Optical Company) was added to the test battery when Group 2 subjects were run. The test was designed to detect color deficiency, but not to diagnose the type of defect. It consists of a transilluminated plate containing six reproduced Ishihara Pseudo-Isochromatic Plates. The plate is viewed binocularly through a stereoscope that presents an image of the plate at an optical distance of 20 feet. The test was administered in an illuminated room. The subject was instructed to identify the numbers in each circle on the plate. Failure criterion was any error.

8. Each subject was given an anomaloscope examination with a Nagel-type anomaloscope (Schmidt and Haensch). The instrument presents a monocular view of a $2°10'$ circular bipartite field. The subject is required to match the two halves of the field to produce the Rayleigh equation, a variable mixture of wavelengths of 670 nm and 546 nm in one half and 589.3 nm of variable luminance in the other. The examination procedure began by asking the subject to fixate the Trendelenburg adaptation light for two minutes after which the subject was asked to match the halves of the bipartite field using both control knobs. For succeeding matches, the examiner set the red-green mixture, while the subject attempted to make a match by varying the luminance of the yellow field. This procedure was continued until the examiner reached the limits of the subject's range. Between matches the subject was asked to regard the adaptation field for thirty seconds. After the subject's range was determined under conditions of "neutral" adaptation, the range was redetermined for conditions of chromatic adaptation by asking the subject to look through the eye-

piece continuously. The subject used his preferred eye.

Subjects who made matches outside the limits of 38–44 on the instrument's arbitrary scale of 0–73 were classified as defectives. Ranges less than 10 were classified arbitrarly as mild defects, ranges between 11 and 25 as moderate, and ranges greater than 25 as severe. The anomaly was classified as extreme for subjects whose range of matches made with chromatic adaptation was greater than the range obtained with "neutral" adaptation. The direction of deviation of the center of the range of matches from the normal limits determined the diagnosis of type of deficiency, i.e., subjects who required more green than normal in their matches were classified as deutan, while those using more red than normal were protans. Dichromats, subjects who matched the entire range of the instrument, were classified as protanopes if the yellow luminance setting was very low for matches with red and as deuteranopes if the yellow luminance was normal. For the purpose of comparison with other tests, subjects whose range of matches exceeded 10 units were considered failing.

N.B. After many subjects in Group 1 had been examined, it was discovered that the linkage between the comparison (yellow) slit and the micrometer drum had become misaligned so that the luminances of/ the yellow field were sharply attenuated. This condition made it impossible to distinguish clearly severe protanomalies from protanopes. To facilitate comparisons the misalignment was maintained for all subjects. The spectral specifications were not affected by the misalignment.

9. Each subject received a practical test of his ability to recognize light flashes of aviation signal red, white, and green. This test, which was identical to the test administered by FAA General Aviation District Offices to airman candidates who desire Statements of Demonstrated Ability for the color vision requirement, was given outdoors during daylight hours. An FAA color signal light gun was stationed indoors at a window at an elevation of 38 feet. The subject was stationed at distances of 1000 and 1500 feet from the window and at each distance three five-second flashes were presented at two-minute in-

tervals, the flash colors being randomly selected but with the proviso that all three colors be presented at least once within each six-flash test. The subject was asked to identify the color of each flash before the flash terminated. One or more errors in identifying the colors of the six flashes is a failing score.

The pass-fail criteria for the A.O. H-R-R plates, the Dvorine plates, the Color Threshold Tester, the Farnsworth Lantern, and the Titmus Vision Tester Plate are criterion scores used by Aviation Medical Examiners for candidates for Class II and III medical certificates.[1] The pass-fail criterion for the Farnsworth Panel D–15 is the criterion suggested by Farnsworth[9] for industrial and military applications, although no specific aviation criterion was suggested. The pass-fail criterion for the Farnsworth-Munsell 100-hue test is taken from Farnsworth's suggestion that error scores exceeding 100 fall beyond the range of normal competence for color discrimination.[6] The pass-fail criterion for the anomaloscope was arbitrarily selected. No effort was made, in the current study, to determine if pass-fail criteria other than those employed in the current study might produce improved correlations between any of the tests studied and the color signal light gun test.

III. Results.

The ranges of anomaloscope matches made by all subjects in Groups 1 and 2 are shown in Figures 1 and 2. The ranges for normal, protanomalous, and protanopic subjects are shown in Figure 1, while ranges for deuteranomalous and deuteranopic subjects are shown in Figure 2.

The ranges obtained under chromatic adaptation from subjects labeled extreme anomalies are indicated by broken lines, while solid lines indicate the matches obtained under "neutral" adaptation.

Table 1 indicates the product-moment correlations (phi coefficients) between each clinical test and the color signal light gun test for Group 1 subjects. All correlations represent significant chi-squares at the 0.01 level. Examination of Table 1 indicates the highest correlations were obtained from the Color Threshold Tester and from the Farnsworth Lantern.
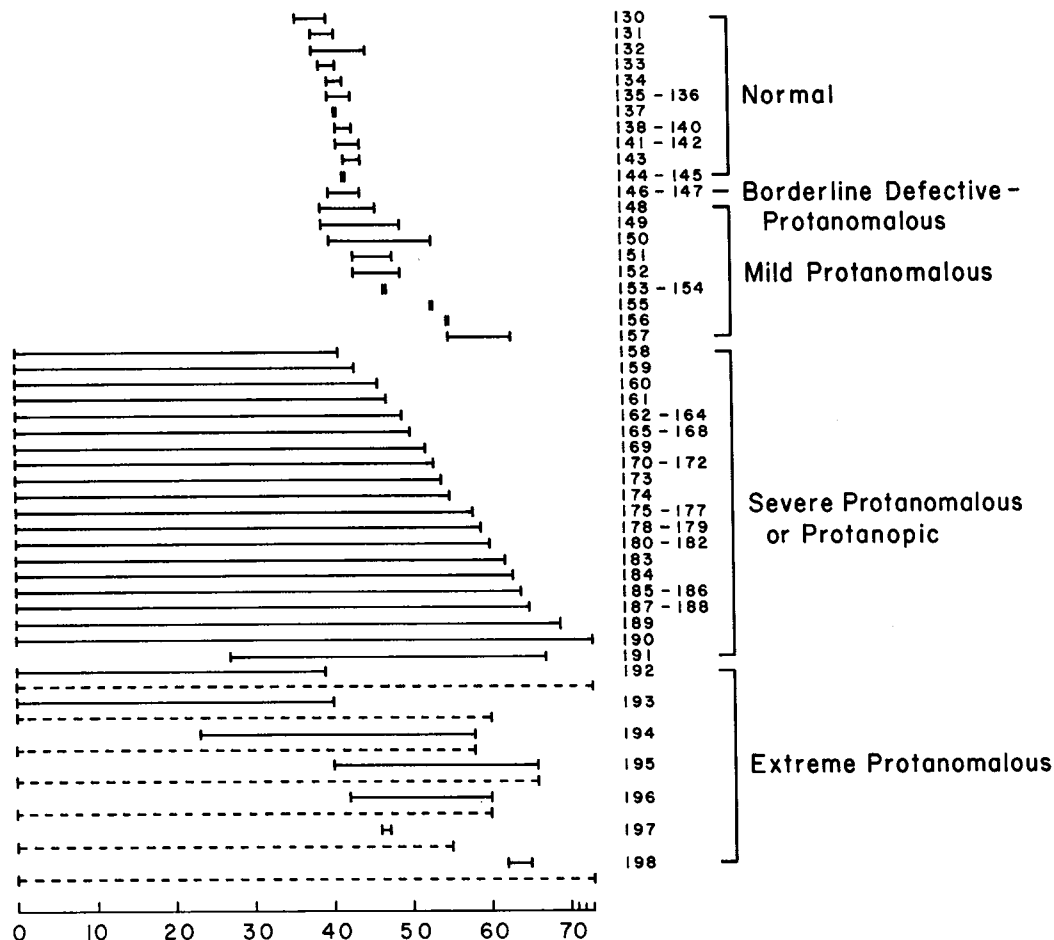
FIGURE 1. Range of anomaloscope matches made by normal, protanomalous, and protanopic subjects under conditions of "neutral" adaptation (solid lines) and, where different, chromatic adaptation (broken lines).

TABLE 1.—Correlations between clinical tests and the color signal light gun test.

Group 1

Test	Phi Coefficient*	Percent "Misses"
A. O. H–R–R	.52	14.2
Anomaloscope	.44	4.7
Color Threshold Tester	.58	10.2
Dvorine Plates	.52	7.9
Farnsworth Lantern	.58	3.1
Farnsworth 100-hue	.54	5.5
Farnsworth Panel D–15	.54	13.4

*All correlations are significant at the .01 level.

Also shown in Table 1 are the percent of "misses" for each test, i.e., the percent of subjects who passed the clinical test, but failed the color signal light gun test. The highest miss rates were obtained with the A.O. H–R–R, the Farnsworth Panel D–15, and the Color Threshold Tester. Wide variation in miss rate may be seen for tests with similar phi coefficients.

Table 2 indicates the product-moment correlation between each clinical test and the color signal light gun test and the per cent of "misses" for subjects in Group 2. Again, all correlations are significant at the 0.01 level.

This group was included so that the performance of the Titmus Vision Tester Plate could be evaluated relative to the other tests. Table 2 indicates that the Titmus Plate has the second lowest phi coefficient, but the lowest miss rate.

Table 3 indicates the correlations obtained when Groups 1 and 2 are combined. As before, the per cent of "misses" obtained with each test are also shown. Again, inspection of Table 3

4

reveals wide variation in miss rate with relatively little variation in phi coefficients.

IV. Discussion.

Examination of Tables 1, 2, and 3 suggests that the tests used in the current study may be divided into four groups. The first group consists of the A.O. H-R-R, the Color Theshold Tester, and the Farnsworth Panel D-15—all tests with very high miss rates. The number of "misses" is important, from the standpoint of safety, because these are the per cent of applicants who will receive medical certificates with-

TABLE 2.—Correlations between clinical tests and the color signal light gun test.

Group 2

Test	Phi Coefficient*	Percent "Misses"
A. O. H-R-R	.43	14.1
Anomaloscope	.35	7.0
Color Threshold Tester	.38	8.5
Dvorine Plates	.47	4.2
Farnsworth Lantern	.45	4.2
Farnsworth 100-hue	.33	8.5
Farnsworth Panel D-15	.54	11.3
Titmus Plate	.34	1.4

*All correlations are significant at the .01 level.

out color vision restrictions, but who should receive certificates with restrictions, since they are unable to discriminate among aviation signal colors. For this reason, the tests in this group appear to be unsatisfactory for screening airman applicants.

The second group of tests consists of the anomaloscope, the Dvorine plates, and the Farnsworth-Munsell 100-hue test—all tests with average correlations and moderate miss rates. None of these tests is an outstanding measure of color vision requirements for aviation, but all have some predictive value without the high miss rate associated with the first group of tests.

TABLE 3.—Correlations between clinical tests and the color signal light gun test.

Groups 1 and 2

Test	Phi Coefiicient*	Percent "Misses"
A. O. H-R-R	.50	14.1
Anomaloscope	.41	5.6
Color Threshold Tester	.50	9.6
Dvorine Plates	.50	6.6
Farnsworth Lantern	.53	3.5
Farnsworth 100-hue	.47	6.6
Farnsworth Panel D-15	.55	12.6

*All correlations are significant at the .01 level.

The remaining two tests stand alone. Based on the data in Table 2, the Titmus Vision Tester Plate appears to have a low predictive value. This seemingly inferior performance is accompanied by the lowest per cent of "misses" encountered in the current study. That both the Titmus phi coefficient and miss rate are low is due to the high per cent of false positives (39.4%) obtained with this test. The false positives are those subjects who failed the Titmus Plate, but passed the color signal light gun test. Thus a relatively high number of applicants will fail this test, when they should be passed. Airman applicants who fail the color perception plate of the Titmus Vision Tester should be given an opportunity to take another test for the color vision requirement.

The Farnsworth Lantern consistently yielded one of the highest correlations with the color signal light gun test and, at the same time, consistently yielded low miss rates. These data together with the Farnsworth Lantern's high face validity suggest that the Farnsworth Lantern may be the preferred test for screening airman applicants.

Examination of Figures 1 and 2 reveals that a high proportion of the subject population were dichromats or severe anomalies. Had a test population with a higher number of mild and moderate anomalies been used, the correlations observed in this study would certainly have been different.
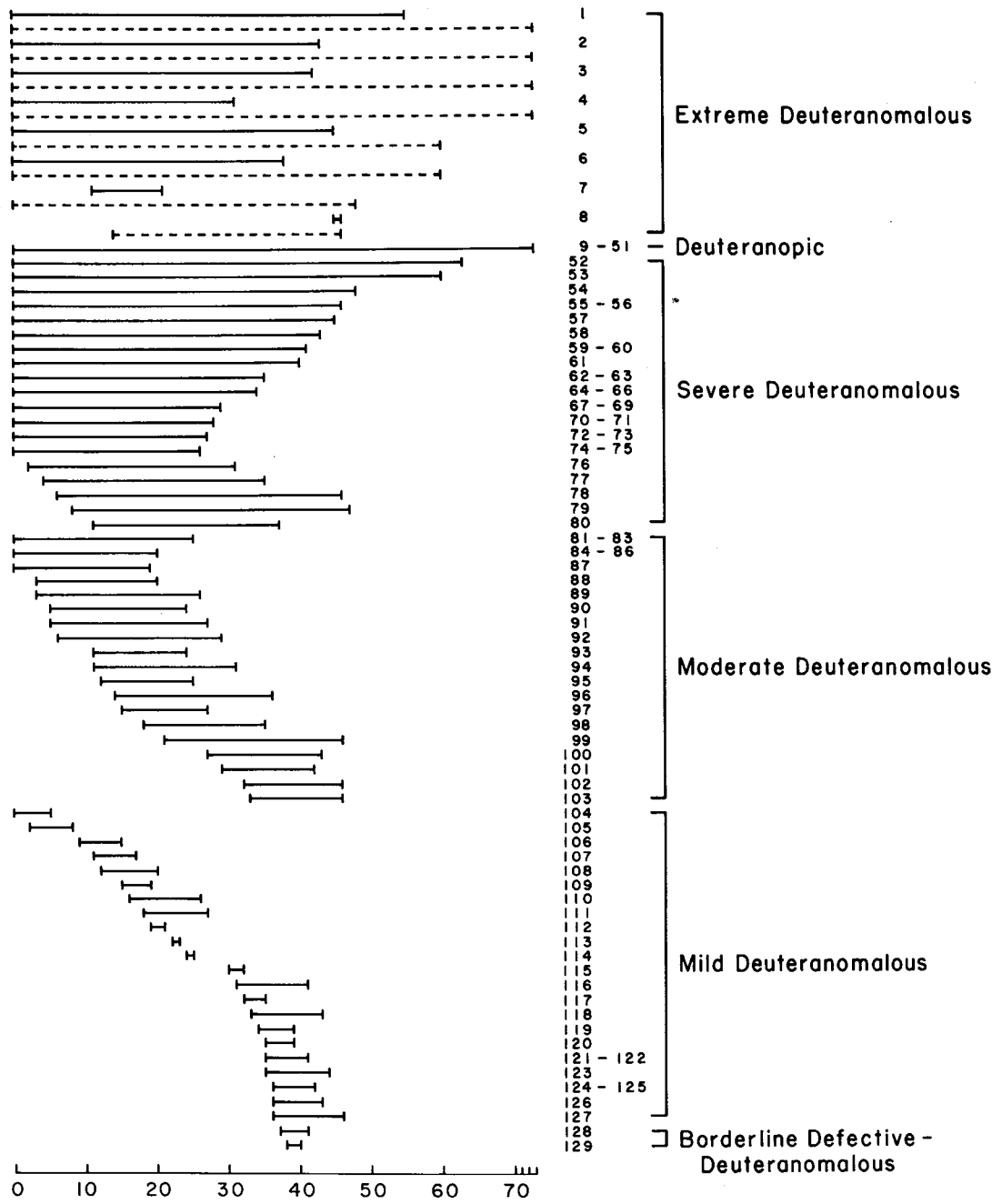
FIGURE 2. Range of anomaloscope matches made by deuteranomalous and deuteranopic subjects under conditions of "neutral" adaptation (solid lines) and, where different, chromatic adaptation (broken lines).

6

REFERENCES

1. Federal Aviation Administration: Guide for Aviation Medical Examiners. Department of Transportation, Federal Aviation Administration, Office of Aviation Medicine, June 1970.

2. Lewis, M. F., and F. K. Ashby: Diagnostic Tests of Color Defective Vision. Annotated Bibliography, 1956–66. FAA Office of Aviation Medicine Report No. AM 67–8, May 1967.

3. Hardy, L. H., G. Rand, and M. C. Rittler: The H-R-R Polychromatic Plates. I. A Test for the Detection, Classification, and Estimation of the Degree of Defective Color Vision, A.M.A. ARCH. OPHTHAL., 51:216–228, 1954.

4. Hardy, L. H., G. Rand, and M. C. Rittler: The H-R-R Polychromatic Plates. II. Comparison of Qualitative Quantitative Classifications by H-R-R Plates and Other Tests, A.M.A. ARCH. OPHTHAL., 52:353–368, 1954.

5. Farnsworth, D.: The Farnsworth-Munsell 100-Hue and Dichotomous Tests for Color Vision, J. OPT. SOC. AMER., 33:568–578, 1943.

6. Farnsworth, D.: *The Farnsworth-Munsell 100-Hue Test for the Examination of Color Discrimination. Manual*, Baltimore, Munsell Color Company, 1957.

7. Rowland, L. S.: Selection and Validation of Tests for Color Vision—Relationship between Degree of Color Deficiency and Ability to Identify Signals from a "Biscuit Gun." School of Aviation Medicine Project Report No. 137–7, November 1943.

8. Farnsworth, D., and P. Foreman: Development and Trial of the New London Navy Lantern as a Selection Test for Serviceable Color Vision. BuMed Project X-457 (AV-241-K), Color Vision Report No. 12, U.S. Submarine Base, New London, Connecticut, 6 May 1946.

9. Farnsworth, D.: *The Farnsworth Dichotomous Test for Color Blindness. Manual*, New York, Psychological Corporation, 1947.