FAA-AM-73-18

UTILITY OF SEVERAL CLINICAL TESTS OF COLOR DEFECTIVE VISION IN PREDICTING DAYTIME AND NIGHTTIME PERFORMANCE WITH THE AVIATION SIGNAL LIGHT GUN

Jo Ann Steen, B.A.
William E. Collins, Ph.D.
Mark F. Lewis, Ph.D.
FAA Civil Aeromedical Institute
P.O. Box 25082
Oklahoma City, Oklahoma 73125

December 1973

Availability is unlimited. Document may be released to the National Technical Information Service, Springfield, Virginia 22151, for sale to the public.

Prepared for
DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Office of Aviation Medicine
Washington, D.C. 20591

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FAA-AM-73-18	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle UTILITY OF SEVERAL CLINICAL TESTS OF COLOR DEFECTIVE VISION IN PREDICTING DAYTIME AND NIGHTTIME PERFORMANCE WITH THE AVIATION SIGNAL LIGHT GUN		5. Report Date December 1973 6. Performing Organization Code
7. Author(s) Jo Ann Steen, B.A., William E. Collins, Ph.D., and Mark F. Lewis, Ph.D.		8. Performing Organization Report No.
9. Performing Organization Name and Address FAA Civil Aeromedical Institute P. O. Box 25082 Oklahoma City, Oklahoma 73125		10. Work Unit No. 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Office of Aviation Medicine Federal Aviation Administration 800 Independence Avenue, S.W. Washington, D. C. 20591		13. Type of Report and Period Covered OAM Report 14. Sponsoring Agency Code

15. Supplementary Notes

This research was conducted under Tasks No. AM-A-73-PSY-45 and AM-D-74-PSY-45.

16. Abstract

Subjects of varying type and degree of color deficiency were tested on a battery of color tests, including the American Optical Company Plates (both 1940 and 1965 editions), the Dvorine Plates, the Farnsworth-Munsell 100-hue, the Farnsworth Lantern, the Farnsworth Panel D-15, the SAM Color Threshold Tester, the Titmus Vision Tester Color Plate, and an anomaloscope. Correlations with a daytime and nighttime practical test of the ability of subjects to discriminate aviation signal red, white, and green were obtained. The results indicate that color defective people can identify flashes from a signal light gun better at night than during the day. It was also found that the Farnsworth Lantern, the SAM Color Threshold Tester, the two sets of A O Plates, and the Dvorine Plates were among the best predictors of performance on the practical test; the Titmus Plate was the poorest predictor.

17. Key Words Color Vision Signal Lights Night Flight	18. Distribution Statement Availability is unlimited. Document may be released to the National Technical Information Service, Springfield, Virginia 22151 for sale to the public.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	16	$3.00

Form DOT F 1700.7 (8-69)

ACKNOWLEDGMENTS

The authors express their appreciation to Major General William J. Smith and to Colonel William Behrens for their assistance in the acquisition and testing of military personnel at Tinker Air Force Base, Oklahoma City, and also especially thank Colonel Carl Porter and Captain Richard Proctor for their generous assistance during the testing procedure.

UTILITY OF SEVERAL CLINICAL TESTS OF COLOR DEFECTIVE VISION IN PREDICTING DAYTIME AND NIGHTTIME PERFORMANCE WITH THE AVIATION SIGNAL LIGHT GUN

I. Introduction.

Medical certificates (Class II and III) issued by the Federal Aviation Administration require that candidates be able to discriminate aviation signal red, green, and white.[4] There are several clinical color vision tests which are approved and currently used by Aviation Medical Examiners to satisfy this color vision requirement. If the candidate fails one of these clinical tests, he can appeal to take a practical test using the signal light gun. If he fails the signal light gun test, which is given during the day, his certificate is marked invalid for "night flight or by color signal control." Due to a question as to how well the applicant might do on the signal gun test if it were given at night, a study[11] was conducted. the results of which indicated an improvement in performance under nighttime conditions. In the previous study,[11] similarities of the Farnsworth Lantern (a clinical test) and the signal gun were noted, i.e., both required identification of red, white, and green lights. As a result of that study, it was suggested from several sources that if the Farnsworth Lantern were administered in a darkened room instead of the daylight illumination recommended by the manufacturer, its ability to predict performance on the nighttime signal light gun test might be improved. In addition, requests were received from medical field personnel for an evaluation of the original 1940 edition of a pseudo-isochromatic plate test developed by American Optical Company and a revised 1965 edition of the same test. A third objective of the study was to improve over previous work[7,11] control of several experimental variables: thus a larger group of color defectives was used, a control group was added, and a possible practice effect was eliminated by randomizing the order of daytime and nighttime presentations of the signal light gun.

II. Method.

A. *Subjects.* Arrangements were made to screen approximately 4000 active-duty medical records at Tinker Air Force Base for evidence of color defect. Of those men identified as color defective, 137 were contacted and completed the entire test battery of both clinical and practical tests. A group of 128 normal control subjects, also active-duty males at Tinker AFB, were tested on the same battery.

B. *Tests and Procedures.* Following is a description of the complete test battery given both groups of subjects.

1. The American Optical Pseudo-Isochromatic Plates for Testing Color Perception (1940 edition)[5] consist of 18 numerical test plates and one demonstration plate. Failure for this test was an incorrect response to five or more test plates.

2. The American Optical Pseudo-Isochromatic Plates for Testing Color Perception (1965 edition)[10] consist of 14 numerical test plates and one demonstration plate. It is a revised and shortened version of the 1940 edition. Incorrect response to five or more plates was failing.

3. The Dvorine Pseudo-Isochromatic Plates[1] consist of 15 numerical plates, including one demonstration plate. Failure for this test was any error on 12 or more plates.

4. The Farnsworth Panel D–15 was designed to differentiate the severe color defective from the moderate color defective and the color normal.[2] The test has 15 color plastic test caps and one reference cap. The subject was instructed to place each cap next to the one most like it in color and to begin with the reference cap. A failure was scored if there were at least two crossovers in approximately the same direction on the score sheet circle.

5. The Farnsworth-Munsell 100-hue Test was designed to measure color discrimination among

normals and areas of confusion in people with color defective vision.[2] The test consists of four hinged boxes. The lid of each box contains one-fourth of the 85 color test caps randomly arranged. The bottom has two fixed reference caps, one at either end. The subject was told to take the test caps from the lid and place them in the bottom half of the box in order according to color. The failure criterion was a calculated error score of 100 or more.

Each of the five previous tests was given in a darkened room under a Macbeth easel lamp equipped with a daylight filter. This lighting approximates the C.I.E. source C and is the manufacturers' recommended illumination for the above tests.

6. The Color Threshold Tester,[9] developed by the Air Force, consists of two vertically arranged discs, each containing eight filters, placed in front of a test light. The upper disc contains neutral density filters to vary luminance of the test light; the lower disc has color filters to vary color. The test, given in a darkened room, consisted of showing and naming the eight colors at the highest luminance and then having the subject name them first at the lowest luminance and then at each succeedingly higher luminance. The order of presentation of the colors was reversed from each previous lower luminance. Failure was considered to be a score of 49 or less.

7. The Farnsworth Lantern,[3] developed by the Navy, has a pair of vertically arrayed lights. They can be red, green, or white in any combination, and all nine possible pairs were shown to the subject in a random order. The subject passed if he completed the first series of the nine color pairs with no errors. If an error was made, two more series were shown and scored; a failure was an average of more than one error per series for the last two series. (The test was given in both a lighted room and a darkened room with the order of light or dark presentation random over the entire group of subjects.)

8. The Nagel-type anomaloscope (Schmidt-Haensch) displays a monocular, illuminated view of a bipartite circle. The top half is a variable red-green mixture, and the bottom is a yellow, the luminance of which can be varied. The subject was first told to stare at the Trendelenburg adaptation light for three minutes. Then he was asked to look into the anomaloscope at the circle and to vary both halves until they matched exactly in color and in brightness. He was then asked by the examiner to match a color set in the top half of the circle by varying the luminance of the bottom portion. Between each match, he was told to stare at the adaptation light for 30 seconds. The procedure continued until the outside limits for each subject's matches were established. After the series under "neutral" adaptation, a chromatic adaptation series was run. The subject was asked to continue staring into the anomaloscope at the circle between his matches and to adjust the luminance as the examiner adjusted the red-green mixture. Ranges for both series were noted. The Nagel anomaloscope uses a mixture of spectral red and spectral green to match a spectral yellow light. The largest portion of the subjects tested was classified as normal trichromats; i.e., they required a normal mixture of both red and green to match the yellow light. Dichromacy (protanopia or deuteranopia) was diagnosed when the proportion of red and green lights could be varied so that the subject matched yellow to both red and green alone. Protanopes were differentiated from deuteranopes by their need for the yellow light to be dimmed to match red, resulting from the protanopes' loss of luminosity at the red end of the spectrum. Anomalous trichromats were diagnosed by a large range of matches and classified as deuteranomalous or protanomalous according to whether their mean for red-green matches fell closer to spectral red or spectral green. The scale for the red-green mixture was 0 to 73. Specifically, for this study, a mean for matches made by the control group was found and the following arbitrary classifications were made. A normal was defined as having a range of 10 scale units or less with all matches falling within three standard deviations (SD) (36 to 49) of the mean. A borderline defective was defined as having a range of 10 scale units or less within four SD (34 to 52) of the mean; a mild defective as having a range of 15 or less within four SD (34 to 52) of the mean; a moderate defective as having a range of 25 or less and/or outside four SD (34 to 52) of the mean; a severe defective as having a range of 26 scale units or more. An "extreme" anomaly was diagnosed when the range under chromatic adaptation was greater than the range under "neutral" adaptation.[8] (*N.B.* It should be noted that a new anomaloscope was used in this study and no

direct comparison can be validly made with data from two previous studies.[7, 11])

9. The Titmus Plate (Color Perception Plate of the Titmus Vision Tester)[12] 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

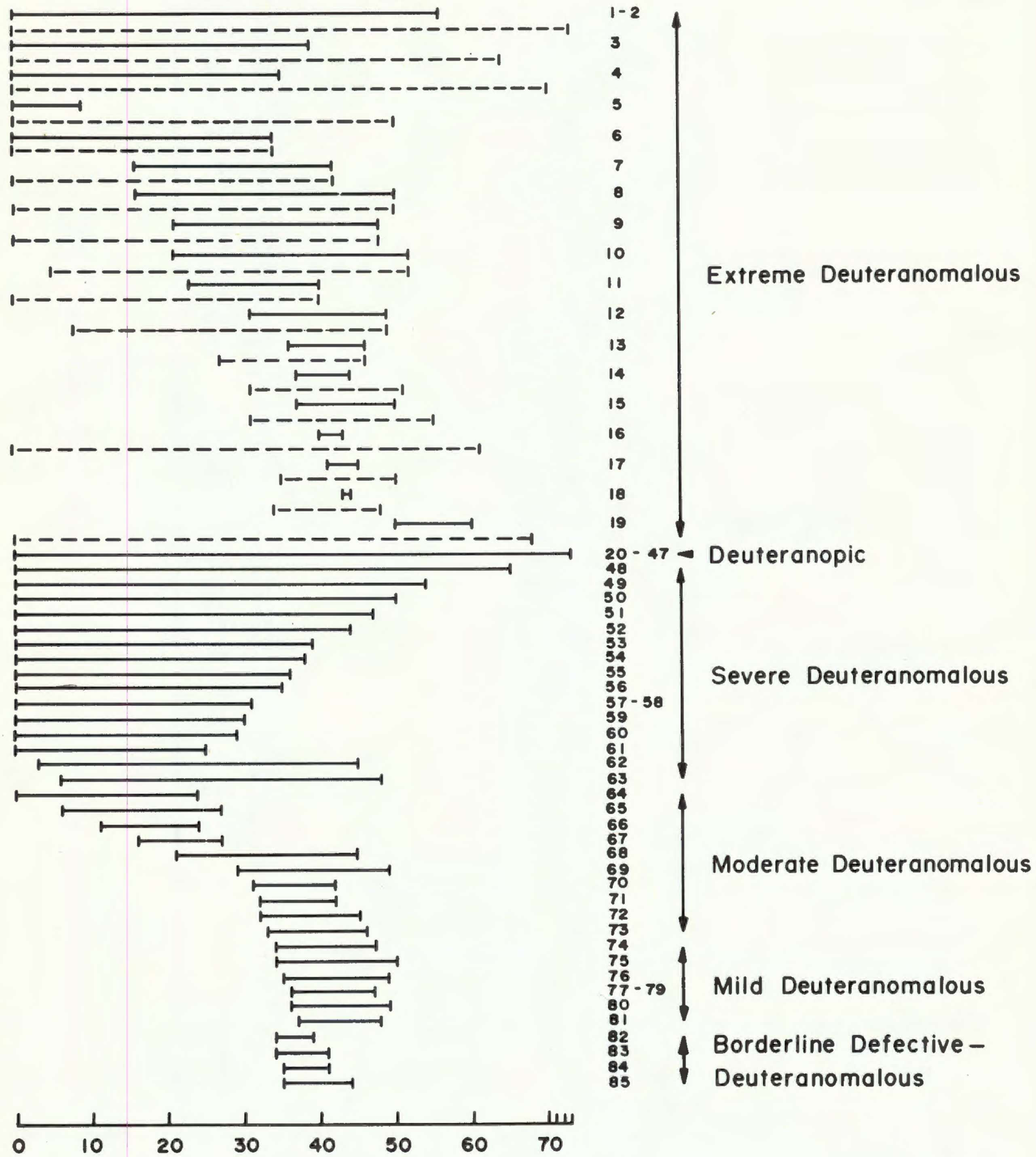

FIGURE 1. Range of anomaloscope matches made by deuteranomalous and deuteranopic subjects under conditions of "neutral" adaptation (solid lines) and, where different, chromatic adaptation (broken lines).

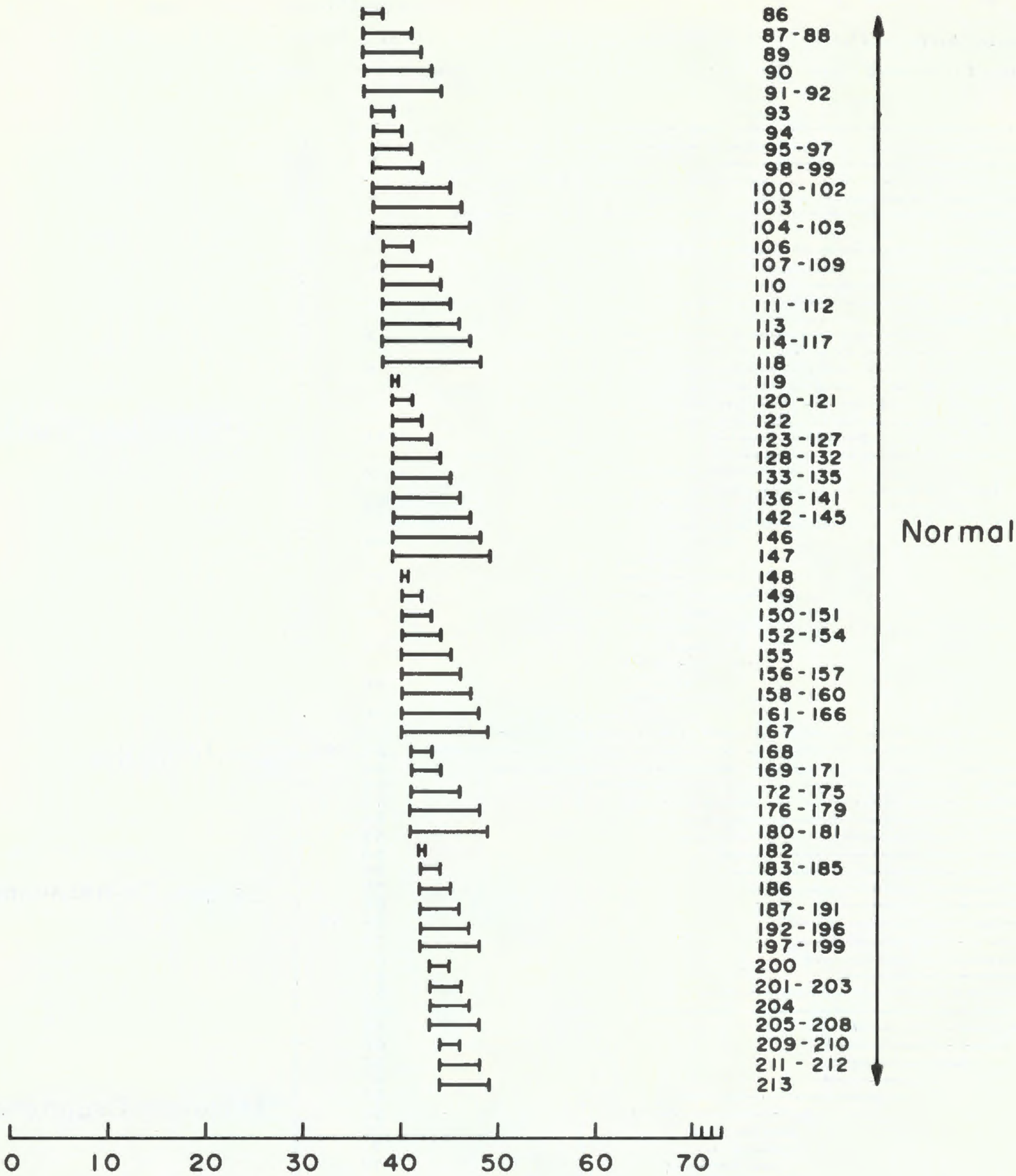

FIGURE 2. Range of anomaloscope matches made by normal subjects under conditions of "neutral" adaptation (solid lines) and, where different, chromatic adaptation (broken lines).

distance of 20 feet. The subject was instructed to identify the numbers in each circle on the plate. Failure criterion was any error.

10. The signal light gun is designed for projecting a high-intensity beam of light for clear (white), red, or green signals to airport traffic both in the air and on the ground. The optical system consists of a principal reflector, auxiliary reflector, lamp, color filters, cover glass, a color indicator, and a sight. The lamp is a 50 candle power, 6–8 V., RP–11 bulb, single contact prefocus base. The candle power of the clear beam in all directions making an angle less than 0.15° with the axis is not less than 150,000 candles, and in all directions making an angle greater than 1.0° with the axis is not more than 10,000 candles. The unit is focused for infinity. A single pistol grip contains all signal controls: an

index-finger trigger for selecting red or green filters for red or green signals, and a thumb-operated lever for selecting a clear, or white, signal. The color filters are specified as aviation red and aviation green and the definitions of the color are expressed in terms of the "standard observer" and coordinate system adopted by the International Commission on Illumination at Cambridge, England, in 1931.[6] The chromaticity coordinates are: aviation red, Y is not greater than 0.335 and Z is not greater than 0.002; aviation green, X is not greater than 0.440–0.320Y or greater than Y–0.170, and Y is not less than 0.390–0.170X; and aviation white, X is not less than 0.350 or greater than 0.540, and $Y-Y_o$ is not numerically greater than 0.01.

The signal light gun test was given to each subject both during the day and at night. The order of whether the test was given first at day or at night was randomized over the entire group of subjects to avoid a practice effect. The gun was stationed indoors at a clear window at an elevation of 38 feet. The subject was tested outdoors at distances of 1000 and 1500 feet from the window and asked to identify a five-second flash of aviation signal red, green, or white. Three flashes were presented two minutes apart at each distance. The order of presentation was selected randomly but each color was presented at least once in each six-flash series. The subject was asked to identify the color before the termination of the flash. The failure criterion was any error for each set of six flashes.

III. Results and Discussion.

The ranges of anomaloscope matches are shown in Figures 1, 2, and 3. Figure 1 shows the ranges

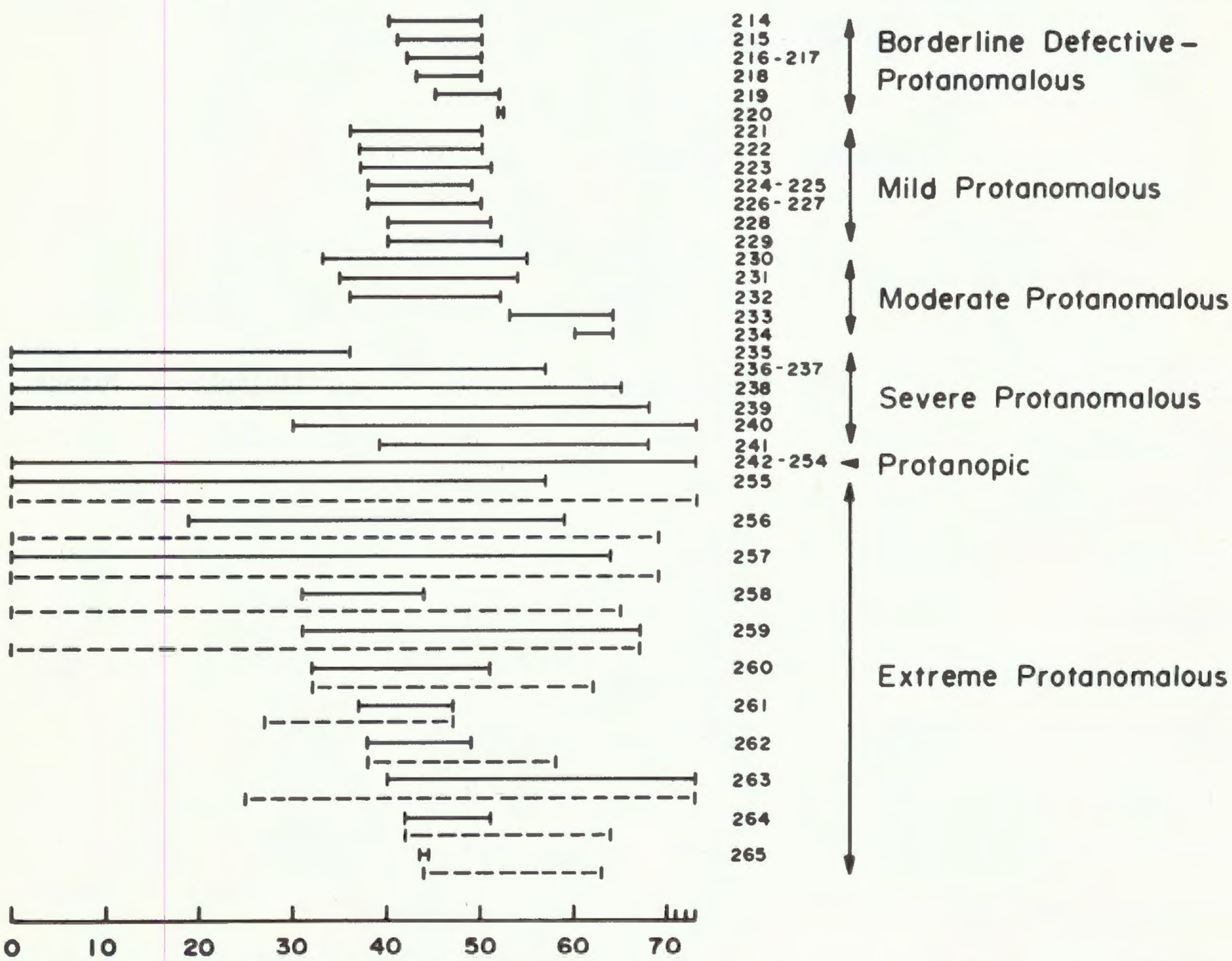

FIGURE 3. Range of anomaloscope matches made by protanomalous and protanopic subjects under conditions of "neutral" adaptation (solid lines) and, where different, chromatic adaptation (broken lines).

for deuteranomalous and deuteranopic subjects; Figure 2 shows ranges for normals; and Figure 3 shows ranges for protanomalous and protanopic subjects. The ranges under chromatic adaptation from subjects labeled as extreme anomalies are indicated by broken lines, while solid lines indicate the matches obtained under "neutral" adaptation. These figures show the distribution of the various types and also the severity of defect of color vision in the test population.

Table 1 gives the product-moment correlations (phi coefficients) between each of the clinical tests in the battery and the signal light gun test under both day and night conditions. The phi coefficient shows how well each clinical test fared as a predictor of performance on the practical test. All correlations are significant at the $p<.01$ level. As can be seen from Table 1, all phi coefficients declined for nighttime conditions as compared to the daytime conditions. The efficacy with which the clinical tests will predict performance on the night practical test was much less than with daytime testing. The same lower predictability of clinical color vision tests was found in a previous study.[11]

The phi coefficients for the Farnsworth Lantern were essentially the same when the test was given under both dark and light conditions. In agreement with a previous study,[11] this test ranked as one of the best predictors of performance on the signal light gun test, whether given during the day or the night. The phi coefficients

Table 1

Correlations (phi coefficients) between clinical tests and the color signal light gun test and the per cent misses (i.e., the percentage of subjects who passed the clinical test but failed the practical test). All correlations are significant at the .01 level.

	Signal Light Gun Test			
	Day		Night	
Clinical Tests	Phi Coefficients	Per Cent Misses	Phi Coefficients	Per Cent Misses
American Optical Co. - 1940	.79	.0	.46	.0
American Optical Co. - 1965	.77	.0	.44	.0
Anomaloscope	.56	.0	.32	.0
Dvorine Plates	.74	3.8	.48	.8
Farnsworth-Munsell 100-hue	.58	3.0	.39	.4
Farnsworth Lantern in Dark	.79	2.6	.51	.4
Farnsworth Lantern in Light	.79	1.9	.52	.0
Farnsworth Panel D-15	.64	6.4	.42	1.9
SAM Color Threshold Tester	.77	1.9	.50	.0
Titmus Plate	.36	.0	.20	.0
Signal Light Gun Test at Night	.51	14.3	---	---

for the two American Optical tests were comparable to the Dvorine Plates, and all three of these plate tests can be considered to have given satisfactory results. The other plate test, the Titmus Plate, correlated much lower with the light gun than did any of the other tests in the test battery (this test was also the poorest of several types tested previously[11]). The other clinical tests had phi coefficients ranging in between the above tests.

The "miss" rates for the nighttime signal gun were the same as or lower than those for daytime testing. The "miss" rate is that percentage of subjects who pass the clinical test but fail the practical test. This is an important statistic since this percentage represents those airmen receiving an unrestricted certificate who should be receiving one with color vision restrictions. In all the clinical tests, however, this rate was exceedingly low.

The high miss rate for the nighttime signal gun test represents that population who passed the nighttime test but failed the daytime test. Of the 61 subjects who failed one of the signal light gun tests, only two passed the daytime test and failed the nighttime test. Both of these men were protanopic and required the highest amounts of brightness recorded from this group of subjects to match pure green on the anomaloscope. They both identified red correctly but confused the white and green flashes. (In previous work,[11] of 35 subjects who failed a practical test, only four passed in the daytime and failed during the nighttime.) Of the 21 subjects in the present study who failed both night and day signal gun tests, six missed the same number of flashes under both conditions, 10 missed more during the day, and five missed more flashes at night. Of all 61 subjects who failed at least one of the practical tests, 38 of these passed the nighttime but failed

Table 2

Classification of subjects by their results on the signal light gun test and the anomaloscope.

ANOMALOSCOPE DIAGNOSIS		N	PASS NONE	PASS DAY ONLY	PASS NIGHT ONLY	PASS DAY & NIGHT
Normal		128				128
Borderline Defective	Protanomalous	7				7
	Deuteranomalous	4				4
Mild	Protanomalous	9				9
	Deuteranomalous	7				7
Moderate	Protanomalous	5			1	4
	Deuteranomalous	11	1		1	9
Severe	Protanomalous	7	2		1	4
	Deuteranomalous	16	1		5	10
	Protanopic	13	5	2	5	1
	Deuteranopic	28	6		14	8
Extreme	Protanomalous	11	3		4	4
	Deuteranomalous	19	3		7	9
	TOTAL	265	21	2	38	204

the daytime testing. In percentages of the subjects who failed only one practical test, 95 per cent passed the night only while 5 per cent passed the day only. This corresponds with similar results in a previous study[11]: that is, the majority of those subjects passing only one of the two practical tests passed the nighttime signal light gun test. The actual numbers of subjects for the present study who passed and/or failed the practical tests, and their deficiencies as diagnosed by the anomaloscope are found in Table 2.

Table 3 gives the false alarm rates for the clinical tests. The false alarm rate is that percentage of subjects who failed the clinical test but passed the practical test. As was previously demonstrated, all false alarm rates rose under nighttime conditions. This shows that many of those who fail a clinical test can pass the signal light gun test when given at night. The Farnsworth Lantern, when given in a darkened room, had the lowest false alarm rate; it was, however, not significantly better than several other tests in this respect.

Several conclusions can be reached as a result of this study. It is clear from both these data and those of a previous study[11] that color defective people can better identify colored flashes from the signal light gun at night than when it is administered during the day, as it is currently. Because failure on this practical test prohibits the pilot from flying at night, it may be reasonable that the applicant who fails a daytime test be given a chance to demonstrate his ability to identify color signals at night. It should be emphasized, however, that passing the signal light gun of itself does not indicate normal color vision; it simply indicates adequate performance on this particular color task. Seventy-six of our

Table 3

False alarm rates: the percentage of subjects who failed each clinical test but passed the color signal light gun test.

Clinical Test	Signal Light Gun Test Day	Signal Light Gun Test Night
American Optical Co. - 1940	9.1	22.6
American Optical Co. - 1965	10.2	23.8
Anomaloscope	25.3	38.9
Dvorine Plates	5.7	16.2
Farnsworth-Munsell 100-hue	15.8	26.8
Farnsworth Lantern in Dark	4.9	16.2
Farnsworth Lantern in Light	6.0	17.7
Farnsworth Panel D-15	6.0	15.1
SAM Color Threshold Tester	7.2	18.9
Titmus Plate	47.2	60.8
Signal Light Gun Test at Night	0.8	----

137 subjects identified by the anomaloscope as color defective were able to pass the signal light gun test under both daytime and nighttime conditions (see Table 2).

Secondly, the difference in illumination (i.e., darkness or daylight conditions) in administration of the Farnsworth Lantern did not significantly affect its ability to predict performance on signal light gun tests. In general, the tests which require the recognition of colored lights (i.e., the Farnsworth Lantern and the SAM Color Threshold Tester) are good predictors of performance on the signal light gun. Also, the revised version (1965) of the American Optical test was found to be very similar to the 1940 A O edition and to the Dvorine Plates in predicting performance on the practical tests. These three plate tests are reasonably satisfactory tests of ability to pass the signal light gun requirements, *provided that the tests are given under the recommended illuminant and according to the instructions accompanying each set of plates.*

Finally, the data of this study support earlier findings[11]; variations in some aspects of experimental design did not appreciably change any of the qualitative results. However, the addition to the test population of a substantial number of color normals produced generally higher phi coefficients, lower miss rates, and lower false alarm rates than previously reported[11] for most of these clinical tests.

REFERENCES

1. Crawford, A.: The Dvorine Pseudo-Isochromatic Plates, BRITISH JOURNAL OF PSYCHOLOGY, 46:139–143, 1955.
2. Farnsworth, D.: The Farnsworth-Munsell 100-hue and Dichotomous Tests for Color Vision, JOURNAL OF THE OPTICAL SOCIETY OF AMERICA, 33:568–578, 1943.
3. 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, May 1946.
4. Federal Aviation Administration: Guide for Aviation Medical Examiners, Department of Transportation, Federal Aviation Administration, Office of Aviation Medicine, June 1970.
5. Hardy, L. H., G. Rand, and M. C. Rittler: A Screening Test for Defective Red-Green Vision, JOURNAL OF THE OPTICAL SOCIETY OF AMERICA, 36:610–614, 1946.
6. Judd, D. B.: The 1931 I.C.I. Standard Observer and Coordinate System for Colorimetry, JOURNAL OF THE OPTICAL SOCIETY OF AMERICA, 23:359–374, 1933.
7. Lewis, M. F., and J. A. Steen: Colour Defective Vision and the Recognition of Aviation Colour Signal Light Flashes. Proceedings of the International Symposium on the Perception and Application of Flashing Lights, London, 1971.
8. Linksz, A.: *An Essay on Color Vision and Clinical Color-Vision Tests*, New York, Greene and Stratton, 1964.
9. 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.
10. Seefelt, E. R.: An Evaluation of the Validity and Reliability of the AOC 15-Plate Pseudo-Isochromatic Test in Routine Testing, AMERICAN JOURNAL OF OPTOMETRY AND ARCHIVES OF AMERICAN ACADEMY OF OPTOMETRY, 41:371–381, 1964.
11. Steen, J. A., and M. F. Lewis: Color Defective Vision and Day and Night Recognition of Aviation Color Signal Light Flashes, AEROSPACE MEDICINE, 43:34–36, 1972.
12. Titmus Optical Co., Inc.: Titmus Vision Tester, Aeromedical Model, Reference Manual, 1969.

Appendix

Contingency tables showing the percentages of subjects who passed (P) and failed (F) the various combinations of clinical and practical tests. Phi coefficients (Ø) for day and night conditions are also shown.

DAY

Signal Gun Test

A. O. Co. - 1940	P	F	
F	.091	.223	.314
P	.687	.000	.687
	.778	.223	

Ø = .79*

NIGHT

Signal Gun Test

A. O. Co. - 1940	P	F	
F	.226	.087	.313
P	.687	.000	.687
	.913	.087	

Ø = .46*

N = 265

* Correlations are significant at the .01 level.

FIGURE 1. Contingency tables and phi coefficients for the signal light gun test and the A.O.Co. plates (1940 edition).

DAY

A. O. Co. - 1965 \ Signal Gun Test	P	F	
F	.102	.223	.325
P	.675	.000	.675
	.777	.223	

Ø = .77*

NIGHT

A. O. Co. - 1965 \ Signal Gun Test	P	F	
F	.238	.087	.325
P	.675	.000	.675
	.913	.087	

Ø = .44*

N = 265

* Correlations are significant at the .01 level.

FIGURE 2. Contingency tables and phi coefficients for the signal light gun test and the A.O.Co. plates (1965 edition).

DAY

ANOMALOSCOPE \ Signal Gun Test	P	F	
F	.253	.223	.476
P	.525	.000	.525
	.778	.223	

Ø = .56*

NIGHT

ANOMALOSCOPE \ Signal Gun Test	P	F	
F	.389	.087	.476
P	.525	.000	.525
	.914	.087	

Ø = .32*

N = 265

* Correlations are significant at the .01 level.

FIGURE 3. Contingency tables and phi coefficients for the signal light gun test and the anomaloscope.

DAY

DVORINE	Signal Gun Test P	Signal Gun Test F	
F	.057	.185	.242
P	.721	.038	.759
	.778	.223	

Ø = .74*

NIGHT

DVORINE	Signal Gun Test P	Signal Gun Test F	
F	.162	.079	.241
P	.751	.008	.759
	.913	.087	

Ø = .48*

N = 265

* Correlations are significant at the .01 level.

FIGURE 4. Contingency tables and phi coefficients for the signal light gun test and the Dvorine plates.

DAY

100-HUE	Signal Gun Test P	Signal Gun Test F	
F	.158	.192	.350
P	.619	.030	.649
	.777	.222	

Ø = .58*

NIGHT

100-HUE	Signal Gun Test P	Signal Gun Test F	
F	.268	.083	.351
P	.645	.004	.649
	.913	.087	

Ø = .39*

N = 265

* Correlations are significant at the .01 level.

FIGURE 5. Contingency tables and phi coefficients for the signal light gun test and the Farnsworth 100-hue test.

DAY

Farnsworth Lantern-Light × Signal Gun Test

Farnsworth Lantern-Light	Signal Gun Test P	Signal Gun Test F	Total
F	.060	.204	.264
P	.717	.019	.736
Total	.777	.223	

$\phi = .79$*

NIGHT

Farnsworth Lantern-Light × Signal Gun Test

Farnsworth Lantern-Light	Signal Gun Test P	Signal Gun Test F	Total
F	.177	.087	.264
P	.736	.000	.736
Total	.913	.087	

$\phi = .52$*

N = 265

* Correlations are significant at the .01 level.

FIGURE 6. Contingency tables and phi coefficients for the signal light gun test and the Farnsworth Lantern test administered in the light.

DAY

Farnsworth Lantern-Dark × Signal Gun Test

Farnsworth Lantern-Dark	Signal Gun Test P	Signal Gun Test F	Total
F	.049	.196	.245
P	.728	.026	.754
Total	.777	.222	

$\phi = .79$*

NIGHT

Farnsworth Lantern-Dark × Signal Gun Test

Farnsworth Lantern-Dark	Signal Gun Test P	Signal Gun Test F	Total
F	.162	.083	.245
P	.751	.004	.755
Total	.913	.087	

$\phi = .51$*

N = 265

* Correlations are significant at the .01 level.

FIGURE 7. Contingency tables and phi coefficients for the signal light gun test and the Farsnworth Lantern test administered in the dark.

DAY

Signal Gun Test

D-15	P	F	
F	.060	.158	.218
P	.717	.064	.781
	.777	.222	

Ø = .64*

NIGHT

Signal Gun Test

D-15	P	F	
F	.151	.068	.219
P	.762	.019	.781
	.913	.087	

Ø = .42*

N = 265

* Correlations are significant at the .01 level.

FIGURE 8. Contingency tables and phi coefficients for the signal light gun test and the Farnsworth Panel D-15 test.

DAY

Signal Gun Test

SAMCTT	P	F	
F	.072	.204	.276
P	.706	.019	.725
	.778	.223	

Ø = .77*

NIGHT

Signal Gun Test

SAMCTT	P	F	
F	.189	.087	.276
P	.725	.000	.725
	.914	.087	

Ø = .50*

N = 265

* Correlations are significant at the .01 level.

FIGURE 9. Contingency tables and phi coefficients for the signal light gun test and the Color Threshold Tester.

DAY

Signal Gun Test

TITMUS		P	F	
	F	.472	.223	.695
	P	.306	.000	.306
		.778	.223	

Ø = .36*

NIGHT

Signal Gun Test

TITMUS		P	F	
	F	.608	.087	.695
	P	.306	.000	.306
		.914	.087	

Ø = .20*

N = 265

* Correlations are significant at the .01 level.

FIGURE 10. Contingency tables and phi coefficients for the signal light gun test and the Titmus Plate.

DAY

Signal Gun Test

NIGHT Signal Gun Test		P	F	
	F	.008	.079	.087
	P	.770	.143	.913
		.778	.222	

Ø = .51 *

N = 265

* Correlations are significant at the .01 level.

FIGURE 11. Contingency table and phi coefficient for the signal light gun test administered under day and night conditions.

32563