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Evaluation of Functional Color Vision Requirements and Current Color Vision Screening Tests for Air Traffic Control Specialists

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16. Abstract

An experiment was conducted to evaluate the relation of type and degree of color vision deficiency and aeromedical color vision screening test scores to performance of color-dependent tasks of Air Traffic Control Specialists. The subjects included 37 normal trichromats of which 6 had mild color abnormalities. Those subjects with color vision deficiency included 18 simple anomalous trichromats, 22 extreme anomalous trichromats, and 31 dichromats; both protan and deutan types were included. Simulations of ATC color tasks concerned color coding in flight progress strips used at en route centers, color weather radar systems used at flight service stations and en route centers, and the Aviation Signal Light indicator light and aircraft lights as pertinent to ATC tower operations. Errors were rare among normals and those with mild color abnormalities in simulated normal operating conditions. Error frequency in the simulated ATC tasks was significantly higher among simple anomalous trichromats, and those with more severe deficiencies. The aeromedical screening tests were generally acceptable in terms of selecting individuals that did not make errors on the ATC tasks. These findings support the requirement that air traffic control personnel be normal trichromats. Recommendations for improvement of job-related color vision screening are discussed.

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EVALUATION OF FUNCTIONAL COLOR VISION REQUIREMENTS AND CURRENT COLOR VISION SCREENING TESTS FOR AIR TRAFFIC CONTROL SPECIALISTS

INTRODUCTION

Applicants for Air Traffic Control Specialist (ATCS) jobs in en route center, terminal, and Flight Service Stations (FSS) of the Federal Aviation Administration are required to have normal color vision (Office of Personnel Management, U.S. Government) because a number of ATCS tasks involve critical color-coded information and, therefore, "involve the discrimination of color for safe performance" (Adams and Tague, 1985).

Previous research by Adams and Tague (1985) found that protanopes, a group with severe color vision deficiency, made errors on simulated ATCS color tasks, but normal trichromats made no errors. Kuyk, Veres, Lahey, and Clark (1986, 1987) showed similar deficits in performance of simulated ATCS color tasks by deutan and protan types with moderate and severe levels of deficiency. These studies were consistent in finding inaccurate ATCS color task performance by color deficients and, therefore, suggest the need for an ATCS color vision standard. Additional research is desirable, therefore, to clarify the level of color vision ability required for accurate color discrimination performance in ATCS tasks, and to evaluate the validity of current color vision tests used to screen ATCS personnel.

The following ATCS tasks involving color-coded information were identified and used in previous research (Adams and Tague, 1985; Pickrel and Convey, 1983), and job analysis (Lahey, Veres, Kuyk, Clark, and Smith, 1984a, 1984b):

(1) Reading of red and black printing and red and black (or blue) handwriting on flight progress strips used by ATCSs at en route facilities.

(2) Scanning of color weather radar displays at en route centers and FSS facilities. Red, yellow, and green colors indicate different weather levels.

(3) Identifying aircraft and their direction of flight at night from the ATC tower while they are in the air and on the ground, based on identification of red, green, and white navigation lights.

(4) Identifying the color of the Aviation Signal Light (ASL) indicator that gives the ATCS visual feedback concerning the signal color (red, green, or white) that is presented to direct an aircraft or ground vehicle when radio communication fails or is not available.

(5) Identifying aircraft in daytime ATC tower operations by color of aircraft or its markings.

(6) Reading of a variety of color-coded charts at all types of facilities.

(7) Selecting the appropriate colored indicator lights, keys, switches, and buttons at all types of facilities.

The flight strips, weather radar, aircraft navigation lights, and ASL indicator tasks involve color as a primary, non-redundant cue. Errors in color identification/discrimination in those tasks have the potential to place pilots, passengers, and their aircraft in danger. Tasks 5 through 7 typically involve color coding as a redundant cue of secondary importance, with primary cues such as symbol/object position, shape, alphanumerics, etc. conveying the same information. Impaired color discrimination would be most likely to affect efficiency of performance rather than accuracy in tasks 5 through 7. Decreased efficiency in time-limited situations, however, has the potential to lead to error.

This study was performed to determine the relation of errors in performance of simulated ATCS color tasks to type and degree of color vision deficiency in order to evaluate the level of color vision ability required in ATCS personnel. The simulations all involved the actual color materials from the ATCS tasks, or used materials with characteristics determined to be equivalent through spectroradiometric and colorimetric measurements. The relation of performance on color vision tests currently accepted by the FAA for aeromedical screening to performance of ATCS Tasks 1 through 4 was studied to evaluate the validity of the clinical tests in current use for ATCS screening. The performance on flight strips and radar tasks were studied under both average conditions, and difficult observation conditions that have been observed in the field, i.e., low illumination of flight strip materials and small weather radar targets as observed by Adams and Tague (1985) and Lahey, et al. (1984b). Time limitations, due to the large number of tests required for this study, prevented inclusion of all ATCS tasks. ATCS Tasks 1 through 4, as listed above, were selected for study because of their frequent and consistent involvement of color as a primary task cue in safety-critical air traffic control situations.

METHODS

Subjects.

Subjects for this study included 37 normal trichromats (23 males and 14 females) with a mean age of 31.4 yrs and a standard deviation of 7.4 yrs and 71 anomalous trichromats and dichromats (67 males and 4 females) with a mean age of 32.3 yrs and a standard deviation of 9.7 yrs. All subjects had at least 20/30 visual acuity in both near and distant vision with the OPTEC 2000 vision tester. Subjects with color vision deficiency were solicited through advertisements in newsletters at Tinker Air Force Base and local newspapers of the Oklahoma City metropolitan area. All subjects were paid an hourly wage.

Diagnostic Color Vision Tests.

The principle diagnostic instrument was the Nagel Type I anomaloscope (Schmidt-Haensch). The anomaloscope is generally recognized as the best instrument for differentiation of normal trichromats from individuals with "red-green" color vision deficiencies, for differentiation of protan and deutan types among the red-green deficients, and also recommended for diagnosis and differentiation of level of deficiency (i.e. simple anomalous, extreme anomalous, and dichromats, in order of severity) by the NRC-NAS Committee on Vision (1981). Other tests were given to corroborate diagnoses of red-green color vision deficiencies and to detect and diagnose the rare "blue-yellow" deficiencies that the Nagel anomaloscope does not detect.

The anomaloscope testing procedure described by Steen, Collins, and Lewis, (1974) was used to obtain matches for both "neutral" and "chromatic" adaptation conditions. The anomaloscope diagnostic classification procedure used was that described and recommended by the NRC-NAS Committee on Vision (1981). This procedure bases diagnoses primarily on measurements obtained under chromatic adaptation (i.e., matches obtained after the observing the anomaloscope stimulus for at least 20 s). The classifications obtained are listed in ascending order of severity:

Normal (n=31). These individuals comprise the majority of normal trichromats and have a high level of color discrimination ability.

Minor (Mild) color abnormality (n=6). This classification contains those normal trichromats called "deviant normal trichromats" and "weak normal trichromats." The anomaloscope color matching behavior of normal trichromats varies by a relatively small amount, but it does vary. These subgroups of normal trichromats may be thought of as representing the "tails" of either the distribution for the matching range size (the "weak" normal trichromats) or the distribution for matching range midpoint (the "deviant" normal trichromats). Some of these individuals may show a very slight reduction in color discrimination ability.

Simple anomalous trichromats. The simple anomalous trichromats are the "mildest" of inherited red-green color vision deficiencies. They were separated into simple protanomalous (n=5) and simple deuteranomalous (n=13). These individuals may have moderate impairment of color discrimination ability.

Extreme anomalous trichromats. These color deficients were separated into extreme protanomalous (n=5) and extreme deuteranomalous (n=17). These individuals have severe impairment. The extreme protanomalous are also distinguished by having reduced sensitivity to long wavelength (red) light.

Dichromats. Dichromats were similarly separated into protan and deutan groups called protanopes (n=11) and deuteranopes (n=20), respectively. All dichromats have severe color deficiencies and protanopes, like the extreme protanomalous, have reduced sensitivity to long wavelengths while deuteranopes do not.

Several other tests were used to obtain additional diagnostic information. The Farnsworth Dichotomous Test for Color Blindness Panel D-15 provided information to support differentiation between protan, deutan, and tritan types. The Farnsworth F2 Plate and AOC-HRR were other tests providing information to support identification of tritan diagnoses. Those tests have been described by others (NRC-NAS Committee on Vision, 1981: Pokorny, Smith, Verriest, and Pinckers, 1979).

ATCS Color Tasks.

Flight Progress Strip (FPS) Test. The FPS test was similar to tests used in previous research by Adams and Tague (1985). It required identification of colors in color-coded computer printing or hand-writing on FPSs as used at en route centers. Subjects responded by identifying color of computer printing (103 items) and hand writing (76 items) as red or black (blue). Since blue is permitted to be used instead of black, a small number of blue items were included. FPS materials were obtained from the Ft. Worth (Texas) en route center. There was no time limit for responding and performance was assessed in terms of number of errors and pass-fail; the failure criterion was any error. The incident illumination level was 59 lux, an average workstation illumination measured at the Ft. Worth en route center.

Flight Progress Strip Test-Low Illumination (FPS-L). This test utilized a subset of 38 of the hand-written items from the above test that were presented a second time under a lower, 14 lux incident illumination level. In subsequent discussion, data concerning testing at the normal 59 lux level with these items is referred to as the FPS-N test. The low illumination level was selected to be marginal for normals based on preliminary measurements, but was slightly higher than the lowest level (8.4 lux) found at an en route center that was reported by Adams and Tague (1985). There was no time limit for responding, and performance was assessed in terms of total errors and pass-fail; the failure criterion was any error.

Color Weather Radar Test - Large Targets (Radar-L). This test involved identification of seven colors including the six colors of the FAA weather radar color code that represent six different levels of precipitation, and "black," representing background or no precipitation detected. The weather radar color code involves two shades each of red, yellow, and green. The characteristics of display colors, 1931 CIE chromaticity coordinates x and y and luminance (L=candelas per square meter), were: (i) light green, x=.308, y=.574, L=48.3; (ii) dark green, x=.314, y.563, L=25.5; (iii) light yellow, x=.420, y=.495, L=65.3; (iv) dark yellow, x=.423, y=.488, L=34.3; (v) light red, x=.598, y=.357, L=18.6; (vi) dark red, x=.575, y=.361, L=11.0; and (vii) black, x=.385, y=.402, L=2.6. The display color measurements were made with the same ambient illumination that was used during testing. The display colors and that 118 lux ambient illumination level were similar to measurements obtained at the

McAlester (Oklahoma) FSS. The display was viewed by the subject at a distance of 71 cm. On every trial, a bar showing the colors of all six precipitation levels in order of magnitude was located 7 degrees above the center of the target. Each color segment in the bar subtended 0.5 degrees vertically and 1.3 degrees horizontally. The radar task required identifying of the color of a 0.5 degree square target that was located at the center of a 4 degree square background. All possible combinations of target/background colors were used to discourage guessing, but only the 12 combinations most commonly used in radar and which represent precipitation levels were used for test trials and scored. There was no time limit for responding. Following a response, there was a 5-s delay before presentation of the next stimulus. Any error caused failure of the test. Total errors were also counted.

Color Weather Radar Test-Small Targets (Radar-S). This task was identical to Radar-L, with the exception that targets were smaller, subtending approximately 0.1 degree. The 0.5 degree target size of Radar-L was chosen to be sufficiently large that color discrimination of individuals with normal color vision would not be adversely affected by target size. With the 0.1 deg size, somewhat decreased discrimination ability for colors on the red-green axis would be expected. Discussions with Flight Service Specialists and meteorologists working at FAA facilities indicated that identification of the color of very small weather radar targets can be important. The 0.1 degree target size was similar to the size of small targets seen on several weather radar displays at FSS and en route centers and is approximately 4 x 4 pixels in size on the Tektronix 4125 color graphics work station used to present the weather radar tasks. The monitor, 38.3 cm on the diagonal, had a resolution of 1280 x 1024 pixels. Lahey, et al. (1984a) also selected 0.1 deg as a small target size relevant to ATCS color tasks.

Aircraft Lights Test. Ten pairs of lights simulating aircraft navigation lights were projected onto a white screen in a nearly dark room. The ambient illumination of the screen was 1.07 lux, the recommended maximum level for interior incident illumination on tower cab windows (Illumination Engineering Society, 1972). Kodak Wratten Filters 26 and 58 were mounted over small holes in slides to simulate red and green aircraft navigation lights. White navigation lights were simulated by using no filter. Intensity of lights was varied with neutral density Wratten filters to ensure that color could not be associated with brightness. Colors of simulated aircraft lights had the following approximate chromaticity coordinates: red, x=.693, y=.307; green, x=.269, y=.683; and white, x=.460, y=.417. Although this task was similar to the aircraft lights test of Adams and Tague (1985) in terms of target colors, the angular subtense of simulated aircraft light was smaller, 1.4 min of arc, and the two lights of each pair were separated vertically by 21 min of arc. The target colors met current standards of the International Civil Aviation Organization (1988) for aircraft navigation light colors. The criterion for failure of this test was any error.

Aviation Signal Light (ASL) Test. The subject identified signal colors as reflected in the indicator (bezel) on top of an ASL. Six signals were observed as the subject sighted the ASL out of a third floor, north window at the sky. The signals were regulated by an experimenter with controls shielded from the subject's view. Signals were of 5-s duration, and intervals between signals were 3 min. The ASL signal colors (red, green, and white) were presented randomly, with the restriction that each color be presented at least once during the six trials. This test was administered between the hours of 10:00 am and 3:00 pm with sky conditions varying from clear to heavily overcast. Any error constituted failure of the task.

Aeromedical Color Vision Screening Tests.

All aeromedical color vision screening tests currently known to be in use by Aviation Medical Examiners (AMEs) for the initial medical examinations of ATCSs and pilots were evaluated. These tests can be grouped into three categories; nine pseudoisochromatic plate tests, three lantern tests, and four vision tester measurements and are listed in Table 1 (Appendix A1) with their First Class disposition criteria (FAA Aviation Medical Examiner's Guide 1980). The Class I criteria are intended to select normal trichromats.

Pseudoisochromataic Plate Tests. The 14-, 16-, and 24-plate Ishihara tests all involve subsets of plates from the 38-plate Ishihara test. Only the 14-plate and 38-plate Ishihara tests were administered. Scores for the 16- and 24-plate tests were computed based on responses to appropriate subsets of plates of the 38-plate test. It is assumed that any differences between the plates of this simulation and the actual plates of those tests are minor and would be similar to different printings of the same plate. Macbeth lamps was used to illuminate all plate tests, with all other lighting extinguished during testing. All screening tests were administered according to manufacturer's directions.

Lantern Tests. The Farnsworth Lantern test was developed by the U. S. Navy and is currently used for aeromedical screening by both the Navy, and the U. S. Air Force. The Farnsworth Lantern test was given in a normally lighted room, according to directions. The U.S Air Force's School of Aviation Medicine Color Threshold Tester (SAM-CTT) was given, but those data are not included in this report since its use has recently been discontinued. The Edridge-Green Lantern test was not given because its use is rare and there are no known standard procedures for test administration.

Multifunction Vision Testers. Several multifunction vision instruments include color vision tests accepted by the FAA and all involve photographic reproductions, prints or positive transparencies, of pseudoisochromatic plates. The Titmus, Titmus II, and OPTEC 2000 vision testers all involve positive color transparencies that are reproductions of Ishihara test plates. Each of these tests was given in a different testing room at a different time and was given in a dimly-lit room. The Keystone test involves photographs of six plates that were developed specifically for that test. The Keystone test was illuminated using only that instrument's lamp; room lights were turned out.

Three-test Battery for ATCS Applicants That Fail Clinical Tests. The Three-test Battery is used by the FAA Office of Aviation Medicine to test ATCS applicants that fail the color vision test given during their initial aeromedical examination. The Three-test Battery is normally administered at offices of regional flight surgeons. The battery includes the Dvorine plate test, the Farnsworth D-15 test (both used with special disposition criteria given below) and the Air Traffic Controllers Functional Color Perception Test (FCPT) (Pickrel and Convey, 1983; Convey, 1985). If an applicant passes two of the three tests she/he is considered to pass the ATCS medical color vision standard that requires normal color vision. The Dvorine test is also one of the FAA-accepted tests used by AMEs, but is used in the battery with a different, less strict failure criterion: failure with 5 or more, rather than 3 or more errors. The D-15 test includes 15 numbered, colored chips that are arranged in order of color by the subject. It is scored by classifying errors in two categories: major errors and minor errors. Major errors of arrangement scored two points and involved placing two chips next to each other that are separated by three or more steps when placed in the correct order, while minor errors (of lesser magnitude) scored one point. A total error score of 7 or more is considered as failing on the D-15 test. The battery's scoring criteria for Dvorine and procedure for scoring the D-15 tests are based on recommendations of Lahey, et al. (1984a). The FCPT is in book form with subtests that depict aircraft navigation lights and exterior colors, color weather radar, and color-coded aviation charts. The FCPT was validated using the AOC (15-plate) test as the criterion (Pickrel and Convey, 1983). All three tests were illuminated with a Macbeth Easel Lamp in an otherwise dark room.

Procedure.

The simulated ATCS color tasks, diagnostic tests, and screening tests were administered at four testing stations, each supervised by a laboratory technician. All anomaloscope testing was performed by the author. The tests at each station took approximately 45 min to administer. The testing of each subject was performed in two, 2-hour sessions separated by a 1-hour lunch break or given on successive days. Within each session, the two 45-min testing periods were separated by a 15-min break. Since the OPTEC 2000, Titmus, and Titmus II involved reproductions of the same set of six Ishihara plates, each of those tests was placed at a different testing station to separate them in time and by administrations of several other tests.

RESULTS AND DISCUSSION

Relation of ATCS Color Task Performance to Color Vision Deficiency.

In air traffic control work, an error in one of the ATCS color tasks studied has the potential to place people and aircraft in jeopardy. The tasks were, therefore, scored on a pass/fail basis with failure contingent on the occurrence of any error. The number of subjects passing and failing, as a function of type and degree of color vision deficiency, is presented in Table 2 (Appendix A2), for the FPS task, the Radar-L task, the Aircraft Lights task, and the ASL task, all of which involve simulation of normal ATCS operating situations. The FPS task is the most important of those tasks due to the high frequency with which the discrimination of red and black must be performed in a working day in combination with the criticality of errors. Error was rare among normal trichromats (Normal or Mild diagnosis). One normal trichromat made one error on the Radar-L task, but normal trichromats made no errors on the FPS task with normal illumination, the Aircraft Lights task, or the ASL task. In contrast, many simple anomalous trichromats, extreme anomalous trichromats, and dichromats made errors in all tasks involving normal operating conditions. The deuteranomalous groups tended to pass more often than the protanomalous in the Radar-L task and the ASL task.

Table 2 (Appendix A2) also contains an overall pass/fail score. Any error on any of the four tasks caused failure of the overall score. Only one normal trichromat failed: the individual that made an error on the Radar task. In contrast, only one individual from the anomalous trichromat or dichromat groups failed to make any errors on any task.

Performance under normal and marginal conditions on either the flight strip or radar task is compared in Table 3 (Appendix A3). Under low (14 lux) illumination in the FPS-L task, 92% of normals made no errors, while 94% of anomalous trichromats and dichromats failed. In the Radar-S task, when target size was small, 73% of normal trichromats made no errors, while 99% of anomalous trichromats and dichromats did make errors. The probability of a color discrimination error is much higher among anomalous trichromats and dichromats than in normal trichromats under marginal/difficult viewing conditions as well as normal viewing conditions.

The mean number of errors and 95% confidence intervals for the mean are shown for each of the four tasks in normal conditions in Table 4 (Appendix A4), as a function of degree of color vision deficiency. Confidence intervals are presented for comparison of means for deficients and normal trichromats. The low, often zero variance among normal trichromats makes analysis of variance inappropriate for comparison of these sample means (Box, 1954). The confidence intervals for means of simple tritanomalous, extreme tritanomalous and dichromat groups do not include the means for normal trichromat groups in any task. These data again indicate that the probability of error is higher among anomalous trichromats and dichromats than among normal trichromats on all four simulated ATCS tasks.

Comparison of the relative frequency of failing among protanomalous and deuteranomalous subjects shown in Tables 2 and 3 revealed a higher proportion failing among the protanomalous in the Radar-L task and the ASL task. In the case of the Radar-S task, the probability of failing was high in both protans and deutans. The performance of protans and deutans was also compared in terms of mean errors on all tasks. Analysis of variance was used to evaluate differences in error scores as a function of degree of color vision deficiency among protans and deutans; normal trichromats were excluded from the analysis. Deutans made significantly fewer errors on the average than protans in the FPS and Radar tasks, but not in Aircraft Lights or ASL tasks. The data are shown for the FPS tasks in Figure 1 (Appendix B1) and the Radar tasks in Figure 2 (Appendix B2). For the FPS data, the main effects of type of deficiency, protan vs. deutan ($F=21.87$; $df=1,107$; $p<.001$), degree of deficiency ($F=20.70$; $df=2,107$; $p<.001$), and illumination level ($F=27.13$; $df=1,107$; $p<.001$) were statistically significant. The interaction of illumination level with type and degree was also significant ($F=5.03$; $df= 2,107$; $p<.01$), indicating that the significant difference between deutans and protans occurred only among the extreme anomalous and dichromats, not among the simple anomalous. In the case of the radar tasks, the main effects of type ($F=5.15$; $df=1,107$; $p<.05$), degree ($F=10.07$; $df=2,107$; $p<.001$), and target size ($F=96.13$; $df= 1,107$; $p<.001$) were again statistically significant, but no significant interactions were observed.

<u>Validity of Aeromedical Color Vision Screening Tests.</u>

The validities of color vision tests currently in use for aeromedical screening of ATCS personnel were evaluated regarding prediction of pass/fail performance on the ATCS color tasks. The validity of screening tests was also compared with the validity of an anomaloscope as a predictor of performance. Cohen's Kappa (Cohen, 1960), an index of agreement, was used to assess the validity of the color vision screening tests as recommended by the NAS-NRC Committee on Vision (1981). The index can be interpreted as the percentage agreement between test and criterion variable, with correction for chance. The four ATCS co. r tasks involving normal and difficult color task situations were used as the criteria for assessing the screening tests. That is, the four ATCS color tasks were used as samples of critical ATCS work behaviors against which the color vision tests were validated as personnel selection criteria. These data on validity are given in Tables 6, 7, 8, 9, and 10 (Appendix A). Validities given in Table 5 involve the overall pass/fail performance index discussed above. Failure of any test among the FPS, Radar-L, Aircraft Lights, and ASL tests, the tests performed under normal conditions, caused failure in the overall performance index. In addition to those simulations that represent common conditions in ATCS tasks, validities are also given for prediction of performance in the FPS task under low illumination (FPS-L) and in the Radar task with smaller target sizes (Radar-S), less common conditions, but still within the range of conditions that could occur in those ATCS tasks. In addition to validities, each table lists the miss and *false alarm* rates for each test. Miss rate is the probability of passing the test, given failure on the criterion ATCS color task. The false alarm rate is the probability of failing the screening test, given passing on the criterion task. Miss and false alarm rates are sometimes alternatively referred to as false negative rate and false positive rate, respectively.

A diagnosis of normal trichromat (Normal or Mild classification) was required for "passing" the anomaloscope test in the present analysis. Passing the anomaloscope was highly related to performance on the FPS and Aircraft Lights tasks; validities (Cohen's Kappa) of 0.90 or above were obtained. Several color vision plate tests had comparable high validities for predicting color discrimination/identification in the FPS and Aircraft Lights tasks. Plate tests with relatively high validity were those known to have high validity for screening normal trichromats. The validities of the anomaloscope test were lower for prediction of performance on the Radar-L task and the ASL task, primarily due to more simple and extreme anomalous trichromats passing the two ATCS color tasks. The highest validities were obtained in those cases with the Farnsworth D-15 and Lantern tests. Both tests are known to pass some individuals diagnosed as simple anomalous by the anomaloscope (Steen, et al., 1974). In Table 3 (Appendix A3), the data for Radar-S task show that with small targets, only one subject among the simple and anomalous trichromats passed. Although many color deficients can discriminate colors in radar displays when targets subtend 0.5 deg, almost no individual with color vision deficiency can do so when targets subtend 0.1 deg. The highest validity for prediction of ability to identify color of small radar targets was again found among those screening tests that are recommended by the Committee on Vision (1981) for selecting normal trichromats.

The very high predictive validities for the FPS and Aircraft Lights test indicate the requirement for a high level of color vision ability in normal task performance. Almost all FAA-accepted color vision tests for the Class I standard have low miss rates, but false alarm rates vary widely. The Farnsworth Lantern has the highest miss rate, and is known to pass some anomalous trichromats (Steen, et al., 1974). It is recommended that one of the plate tests with high validity be used for color vision screening of ATCS personnel instead of the Farnsworth Lantern. The Titmus Tester, Titmus II Tester, and OPTEC 2000 failed a very high percentage of individuals that could accurately identify red and black in flight strips, including many normal trichromats. Reliance on those tests will lead to rejection of many individuals that can perform ATCS color tasks; many rejected will be normal trichromats.

The Three-Test Battery generally had validity that was only slightly lower than the best plate tests. It should be noted that the validity of the battery, however, was usually less than the validity for the Dvorine test alone, when the latter is used with the failure criterion of 5 or more errors. Administration of the Farnsworth D-15 and the FCPT does not appear to add to the value of the battery as a screening tool.

An anomaloscope diagnosis of normal trichromat or a passing score on any one of several FAA-accepted color vision plate tests that are designed to select normal trichromats were the best predictors of error-free performance on simulated ATCS color tasks that involved either actual ATCS task materials, or accurate simulations of the color characteristics of the actual materials. The validities of those screening tests in the vicinity of 0.90 or above for prediction of performance on the Flight Strips and Aircraft Lights tasks, and overall performance are very high. Those validity levels are comparable to the validity of the same tests in differentiating between normal trichromats and color vision deficients. The high validities of the better plate tests not only confirm the importance of normal trichromatic color vision for performance of those ATCS tasks, but also suggest that there would be little to gain even if it were possible to use simulations of ATCS tasks as screening tests. Simulations would be more complex to administer and more prone to error if administered outside a laboratory situation, and it is unlikely that their reliability would be higher than the validity of the plate tests. The gain in face validity with use of simulations for screening tests would not be likely to increase predictive validity, and but would lengthen the color vision testing process, and because of added complexity, make the screening testing process more susceptible to error.

CONCLUSIONS

Normal color vision is required for performance of certain tasks by ATCS personnel. The present data show that error in simulated ATCS color tasks was rare among normal trichromats in normal operating conditions. Only one normal trichromat made an error on one of the tasks in normal conditions. Many individuals with color vision deficiency made errors on the ATCS color tasks when normal conditions were simulated. Color vision deficients were also more adversely affected than normal trichromats by marginal illumination conditions in the Flight Strips task and with small targets in the radar task. Therefore, under adverse conditions, including unexpected situations such as lamp failure, etc., the probability of error in color identification or discrimination will still be much lower for normal trichromats than for individuals with color vision deficiency.

The occurrence of some errors in normal trichromats observed in the present study under adverse observation conditions in the flight strips and radar tasks is also of concern. Extremely low illumination levels for flight strips should also be avoided and dependence on nonredundant color coding for identification of small targets on the order of 0.1 deg in size on radar displays should be avoided. Measures to prevent such marginal conditions should be considered. Three types of color weather radar displays examined by the author all have a "zoom" function that can be used to enlarge target size. It should be noted that the FAA currently requires "Flight Watch" positions (controllers who brief aircraft in flight) at flight service stations to use a Remote Radar Weather Display System (RRWDS); other types of briefing positions often do not have that equipment. The RRWDS system has level blink and level delete special functions, in addition to the zoom function, that can provide redundant cues in parallel with the color code for weather level. The present findings support the desirability of having and using such special functions in all color weather radar display systems.

Several color vision screening tests had very high validities for predicting performance on ATCS color tasks, particularly in the Flight Strips and Aircraft Lights tasks (0.90 and above). When a passing score was contingent upon passing all four ATCS color tasks, the predictive validities were even higher, 0.96 for one test. That finding is important, since ATCS personnel do frequently move from one type of facility to another, due to the requirements of the ATC system and the needs of individual ATCSs, including the desire for promotion, etc. Miss rates and false alarm rates for the screening tests with highest validity were frequently in the vicinity of 5% or less in the overall performance index. While most of the tests accepted for aeromedical screening have reasonably low miss rates, some had very high false alarm rates that would cause many individuals, very capable of performing ATCS color tasks, to fail color vision screening. The latter tests should not be used for ATCS screening.

These results suggest that use of the Three-test Battery should be discontinued in favor of one of the more valid plate tests. When the Three-test Battery was applied to prediction of simulated ATCS color task performance using the criterion of passing two out of three tests, the validity of the battery was acceptable, but was actually lower than the validities of the Dvorine test and of several other individual pseudoisochromatic plate tests. Use of the D-15 and FCPT in addition to the Dvorine does not appear to benefit the ATCS color vision screening process and actually decreases predictive validity. In addition, it is recommended that the FCPT should not be used for color vision screening because it is not a "pure" color vision test. For example, because the test is timed and some instructions and questions must be read during the timed periods, reading speed and comprehension would affect performance.

Color vision deficients with red-green deficiencies comprise more than 99.9% of all inherited color vision deficiencies, and the findings of this study apply only to the screening of those individuals, since blue-yellow (tritan) deficients were not a part of this study. The question should be raised whether ATCS color vision screening should include testing for tritan deficiencies. It is felt that because critical ATCS color tasks of the present ATCS environment involve the colors red, yellow, green, and white, that impact of tritan deficiencies would be negligible. However, as increasing use of color-CRT workstations is planned for future ATCS air traffic control and weather information systems, that may not remain the case. Additional studies are planned to evaluate color displays being developed for future ATCS use in that regard.

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Table 1

Color Vision Tests Accepted by the FAA for Airmen Certification

ACCEPTED TESTS	FULL TEST NAME	ATCS FAILURE CRITERIA (Class I Certification)
Pseudoisochromatic Plate Tests		
1. AOC (18-Plate)	American Optical Company Pseudoisochromatic Plates - 1940 Edition.	4 or more errors, plates 1-18
2. AOC (15-Plate)	American Optical Company Pseudoisochromatic Plates - 1965 Edition	5 or more errors, plates 1-15
3. Richmond	Richmond Pseudo-Isochromatic [sic] Plates for Testing Color Perception	5 or more errors, plates 1-15
4. AOC-HRR	American Optical - Hardy, Rand, Rittler Pseudoisochromatic Plates - Second Edition	any error on plates 1-6
5. Dvorine (2nd Ed.)	Dvorine Pseudo-Isochromatic [sic] Plates - Second Edition	3 or more errors, plates 1-15
Ishihara's Tests for Color-Blindness		
6. Ishihara (14-Plate)	Concise Edition	2 or more errors, plates 1-11
7. Ishihara (16-Plate)	16 Plates Edition	2 or more errors, plates 1-8
8. Ishihara (24-Plate)	24 Plates Edition	3 or more errors, plates 1-15
9. Ishihara (38-Plate)	38 Plates Edition	4 or more errors, plates 1-21
Lantern Tests		
10. Edridge-Green Lantern	Edridge-Green Colour *Perception Lantern*	not studied, rarely used
11. Farnsworth Lantern	Farnsworth Lantern	avg. of more than 1 error per series
12. SAMCTT	School of Aviation Medicine Color Threshold Tester	not studied, no longer used by USAF
Multifunction Vision Testers		
13. Keystone Orthoscope/ Telebinocular	Keystone Telebinocular Test Unit, Aeromedical Model	any error
14. OPTEC 2000	OPTEC 2000 Vision Tester, Aeromedical Model	any error
15. Titmus	Titmus Vision Tester	any error
16. Titmus II	Titmus II Vision Tester	any error

Table 2

Number of Subjects Passing or Failing Four Simulated ATCS Color Tasks as a Function of Color Vision Deficiency

		COLOR VISION CLASSIFICATION							
		Normal Trichromats		Anomalous Trichromats				Dichromats	
TASK		Normal	Mild	Simple		Extreme			
				Prot	Deut	Prot	Deut	Prot	Deut
Flight Progress Strips (59 lux Illumination)	Pass	31	6	1	2	0	1	0	1
	Fail	0	0	4	11	5	16	11	19
Color Weather Radar (0.5 Deg Targets)	Pass	30	6	0	9	0	5	0	3
	Fail	1	0	5	4	5	12	11	17
Aircraft Lights	Pass	31	6	0	2	1	0	0	1
	Fail	0	0	5	11	4	17	11	19
ASL Indicator	Pass	30*	6	3	9	0	6	1	3
	Fail	0	0	2	4	5	11	10	17
ALL TESTS (Fail with any error, any test)	Pass	30	6	0	1	0	0	0	0
	Fail	1	0	5	12	5	17	11	20

* ASL data were lost for one Normal due to technical error.

Table 3

Number of Subjects Passing or Failing Simulated ATCS Color Tasks as a Function of Color Vision Deficiency and Adverse Viewing Conditions

		COLOR VISION CLASSIFICATION								
		Normal Trichromats		Anomalous Trichromats				Dichromats	
TASK		Normal	Mild	Simple		Extreme			
				Prot	Deut	Prot	Deut	Prot	Deut
Flight Progress Strips									
FPS-N (59 lux Illum.)	Pass	31	6	2	2	0	5	0	1
	Fail	0	0	3	11	5	12	11	19
FPS-L (14 lux Illum.)	Pass	29	5	1	0	0	2	0	1
	Fail	2	1	4	13	5	15	11	19
Color Weather Radar									
Radar-L	Pass	30	6	0	9	0	5	0	3
(0.5 deg Targets)	Fail	1	0	5	4	5	12	11	17
Radar-S	Pass	24	3	0	1	0	0	0	0
(0.1 deg Targets)	Fail	7	3	5	12	5	17	11	20

Table 4

Errors on Simulated ATCS Color Tasks as a Function of Color Vision Deficiency

TEST	DIAGNOSIS	MEAN	STANDARD DEVIATION	95% CONF. INTERVAL
Flight Progress Strips (59 lux illum.)	Normal	0.00	0.00	0.00 TO 0.00
	Mild	0.00	0.00	0.00 TO 0.00
	Simple	5.22	5.54	2.47 TO 7.98
	Extreme	18.05	19.54	9.38 TO 26.71
	Dichromat	27.42	20.09	20.05 TO 34.78
Color Weather Radar (0.5 deg Targets)	Normal	0.03	0.18	-0.03 to 0.10
	Mild	0.00	0.00	0.00 to 0.00
	Simple	0.89	1.13	0.33 to 1.45
	Extreme	2.18	1.94	1.32 to 3.04
	Dichromat	3.06	1.90	2.37 to 3.76
Aircraft Lights	Normal	0.00	0.00	0.00 to 0.00
	Mild	0.00	0.00	0.00 to 0.00
	Simple	3.06	2.84	1.64 to 4.47
	Extreme	5.73	3.28	4.27 to 7.18
	Dichromat	7.90	3.94	6.46 to 9.35
Aviation Signal Light	Normal	0.00	0.00	0.00 to 0.00
	Mild	0.00	0.00	0.00 to 0.00
	Simple	0.39	0.61	0.09 to 0.69
	Extreme	1.14	0.83	0.77 to 1.51
	Dichromat	1.55	0.96	1.20 to 1.90

Table 5

Validity of Color Vision Selection Tests for Prediction of Overall Performance (Fail on Any Task Under Normal Conditions)

TEST	ERROR RATE (%) Miss	False Alarm	Validity (Kappa)
Anomaloscope (Pass Normal or Mild)	1.4	2.7	.96
FAA-Accepted Tests (Class I)			
AOC (15-Plate)	1.4	10.8	.90
Richmond	1.4	16.2	.85
AOC (18-Plate)	4.2	8.1	.88
AOC-HRR	1.4	10.8	.90
Ishihara (14-Plate)	1.4	2.7	.96
Ishihara (16-Plate)	1.4	13.5	.87
Ishihara (24-Plate)	1.4	5.4	.94
Ishihara (38-Plate)	1.4	5.4	.94
Dvorine (Fail 3 errors)	1.4	8.1	.92
Titmus Tester	0.0	73.0	.33
Titmus II Tester	0.0	54.1	.53
OPTEC 2000	1.4	43.2	.61
Keystone	1.4	10.8	.90
Farnsworth Lantern	11.3	2.7	.82
Three-test Battery	5.6	2.7	.90
Dvorine (Fail 5 errors)	1.4	2.7	.96
Farnsworth Panel D-15	32.4	0.0	.59
Funct. Color Percept. Test	4.2	73.0	.27

Table 6

Validity of Aeromedical Color Vision Screening Tests for Prediction of Performance on the FPS Test (59 lux Illumination)

TEST	ERROR RATE (%) Miss	False Alarm	Validity (Kappa)
Anomaloscope (Pass Normal or Mild)	0.0	11.9	.90
FAA-Accepted Tests (Class I)			
AOC (15-Plate)	0.0	19.0	.84
Richmond	0.0	23.8	.80
AOC (18-Plate)	3.0	16.7	.82
AOC-HRR	0.0	19.0	.84
Ishihara (14-Plate)	0.0	11.9	.90
Ishihara (16-Plate)	0.0	21.4	.82
Ishihara (24-Plate)	0.0	14.3	.88
Ishihara (38-Plate)	0.0	14.3	.88
Dvorine (Fail 3 errors)	0.0	16.7	.86
Titmus Tester	0.0	76.2	.28
Titmus II Tester	0.0	59.5	.45
OPTEC 2000	0.0	47.6	.57
Keystone	0.0	19.0	.84
Farnsworth Lantern	10.6	11.9	.77
Three-test Battery	4.5	11.9	.84
Dvorine (Fail 5 errors)	0.0	11.9	.90
Farnsworth Panel D-15	27.3	0.0	.67
Funct. Color Percept. Test	4.5	76.2	.22

Table 7

Validity of Color Vision Selection Tests for Prediction of Performance on the Flight Progress Strips Subtest Given Under Both Normal (FPS-N) and Low (FPS-L) Illumination

	NORMAL ILLUM. (59 lux)			LOW ILLUM. (14 Lux)		
	Error Rate (%)			Error Rate (%)		
TEST	Miss	False Alarm	Validity (Kappa)	Miss	False Alarm	Validity (Kappa)
Anomaloscope (Pass Normal or Mild)	0.0	21.3	.81	4.3	10.5	.86
FAA-Accepted Tests (Class I)						
AOC (15-Plate)	0.0	27.7	.75	2.9	15.8	.84
Richmond	0.0	31.9	.71	1.4	18.4	.84
AOC (18-Plate)	3.3	25.5	.73	5.7	13.2	.82
AOC-HRR	0.0	27.7	.75	2.9	15.8	.84
Ishihara (14-Plate)	0.0	21.3	.81	4.3	10.5	.86
Ishihara (16-Plate)	0.0	29.8	.73	2.9	18.4	.81
Ishihara (24-Plate)	0.0	23.4	.79	4.3	13.2	.84
Ishihara (38-Plate)	0.0	23.4	.79	4.3	13.2	.84
Dvorine (Fail 3 errors)	0.0	25.5	.77	4.3	15.8	.81
Titmus Tester	0.0	78.7	.23	0.0	73.7	.32
Titmus II Tester	0.0	63.8	.39	0.0	55.3	.51
OPTEC 2000	0.0	53.2	.50	0.0	42.1	.64
Keystone	0.0	27.7	.75	2.9	15.8	.83
Farnsworth Lantern	9.8	19.1	.72	12.9	7.9	.76
Three-test Battery	3.3	19.1	.79	7.1	7.9	.84
Dvorine (Fail 5 errors)	0.0	21.3	.81	4.3	10.5	.86
Farnsworth Panel D-15	24.6	4.3	.69	31.4	0.0	.61
Funct. Color Percept. Test	3.3	76.6	.22	4.3	73.7	.26

Table 8

Validity of Color Vision Selection Tests for Prediction of Performance on Tests Radar-L and Radar-S

	LARGE TARGETS			SMALL TARGETS		
	Error Rate (%)			Error Rate (%)		
TEST	Miss	False Alarm	Validity (Kappa)	Miss	False Alarm	Validity (Kappa)
Anomaloscope (Pass Normal or Mild)	1.8	32.1	.66	12.5	3.6	.76
FAA-Accepted Tests (Class I)						
AOC (15-Plate)	1.8	37.7	.61	11.3	10.7	.73
Richmond	1.8	41.5	.57	8.8	10.7	.77
AOC (18-Plate)	1.8	32.1	.70	13.8	7.1	.72
AOC-HRR	1.8	37.7	.61	10.0	7.1	.77
Ishihara (14-Plate)	1.8	32.1	.66	12.5	3.6	.76
Ishihara (16-Plate)	1.8	39.6	.59	11.3	14.3	.70
Ishihara (24-Plate)	1.8	34.0	.65	12.5	7.1	.74
Ishihara (38-Plate)	1.8	34.0	.65	12.5	7.1	.74
Dvorine (Fail 3+ errors)	1.8	35.8	.65	11.3	7.1	.75
Titmus Tester	0.0	81.1	.19	2.5	71.4	.33
Titmus II Tester	0.0	67.9	.32	6.3	57.1	.42
OPTEC 2000	1.8	60.4	.38	8.8	46.4	.48
Keystone	1.8	37.7	.61	10.0	7.1	.77
Farnsworth Lantern	5.5	22.6	.72	21.3	3.6	.63
Three-test Battery	1.8	26.4	.72	16.3	3.6	.70
Dvorine (Fail 5+ errors)	1.8	32.1	.66	12.5	3.6	.76
Farnsworth Panel D-15	16.4	3.8	.80	40.0	0.0	.44
Funct. Color Percept. Test	0.0	75.5	.25	7.5	75.0	.21

Table 9

Validity of Color Vision Selection Tests for Prediction of Performance on the Aircraft Lights Test

TEST	ERROR RATE (%) Miss	False Alarm	Validity (Kappa)
Anomaloscope (Pass Normal or Mild)	0.0	9.8	.92
FAA-Accepted Tests (Class I)			
AOC (15-Plate)	0.0	17.1	.86
Richmond	0.0	22.0	.82
AOC (18-Plate)	3.0	14.6	.84
AOC-HRR	0.0	17.1	.86
Ishihara (14-Plate)	0.0	9.8	.92
Ishihara (16-Plate)	0.0	19.5	.84
Ishihara (24-Plate)	0.0	12.2	.90
Ishihara (38-Plate)	0.0	12.2	.90
Dvorine (Fail 3+ errors)	0.0	14.6	.88
Titmus Tester	0.0	75.6	.29
Titmus II Tester	0.0	58.5	.47
OPTEC 2000	0.0	46.3	.59
Keystone	0.0	17.1	.86
Farnsworth Lantern	9.0	7.3	.83
Three-test Battery	4.5	9.8	.86
Dvorine (Fail 5+ errors)	0.0	9.8	.92
Farnsworth Panel D-15	28.4	0.0	.66
Funct. Color Percept. Test	4.5	75.6	.23

Table 10

Validity of Color Vision Selection Tests for Prediction of Performance on the Aviation Signal Light Indicator Test

TEST	ERROR RATE (%) Miss	False Alarm	Validity (Kappa)
Anomaloscope (Pass Normal or Mild)	0.0	37.9	.60
FAA-Accepted Tests (Class I)			
AOC (15-Plate)	0.0	43.1	.55
Richmond	0.0	46.6	.51
AOC (18-Plate)	2.0	39.7	.56
AOC-HRR	0.0	43.1	.55
Ishihara (14-Plate)	0.0	37.9	.60
Ishihara (16-Plate)	0.0	44.8	.53
Ishihara (24-Plate)	0.0	39.7	.58
Ishihara (38-Plate)	0.0	39.7	.58
Dvorine (Fail 3+ errors)	0.0	39.7	.58
Titmus Tester	0.0	82.8	.16
Titmus II Tester	0.0	70.7	.28
OPTEC 2000	0.0	62.1	.36
Keystone	0.0	43.1	.55
Farnsworth Lantern	2.0	27.6	.69
Three-test Battery	0.0	32.8	.65
Dvorine (Fail 5+ errors)	0.0	37.9	.60
Farnsworth Panel D-15	14.3	10.3	.75
Funct. Color Percept. Test	0.0	77.6	.21

Figure 1

Flight Progress Strips Errors As A Function of Color Vision Deficiency

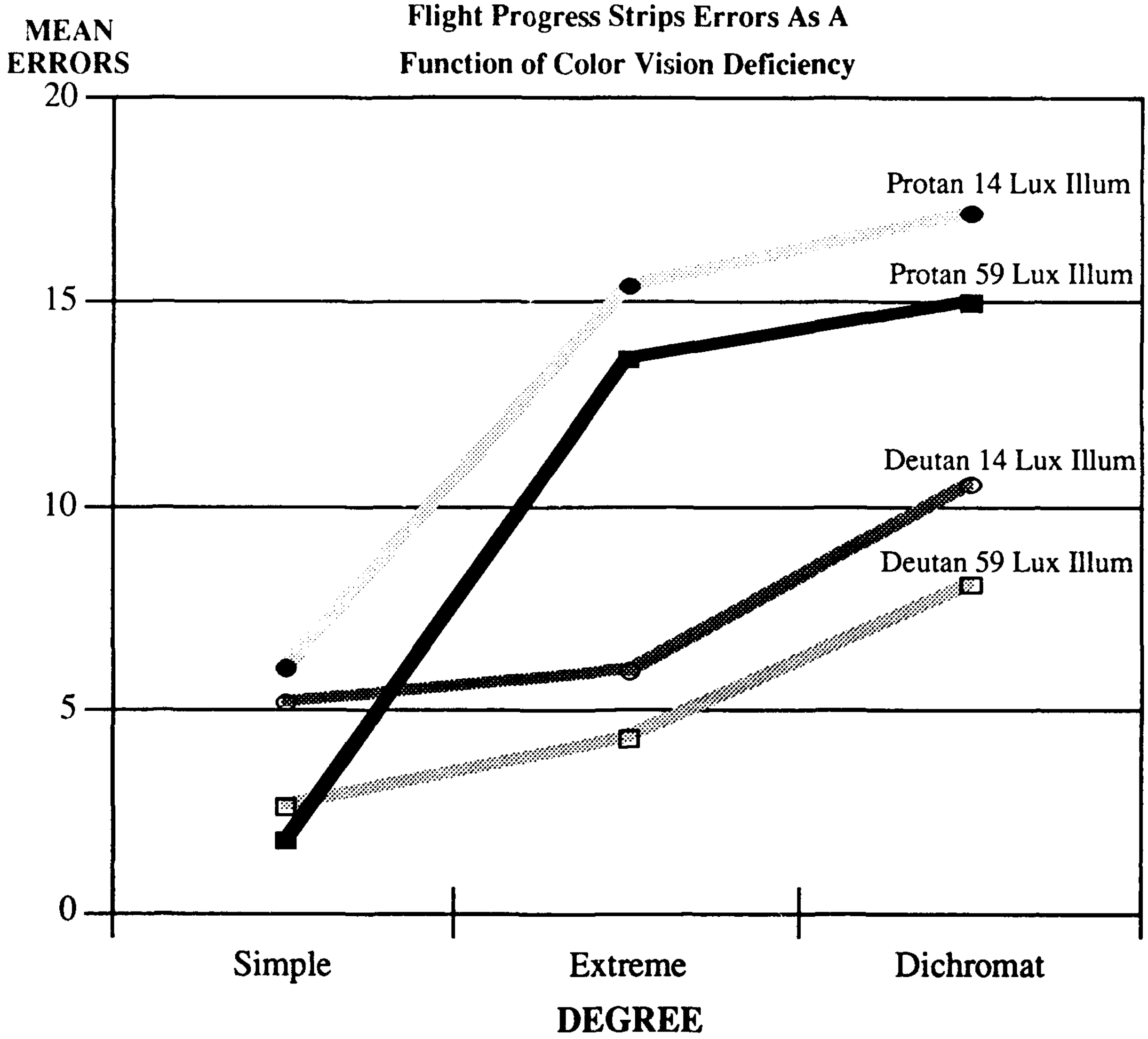
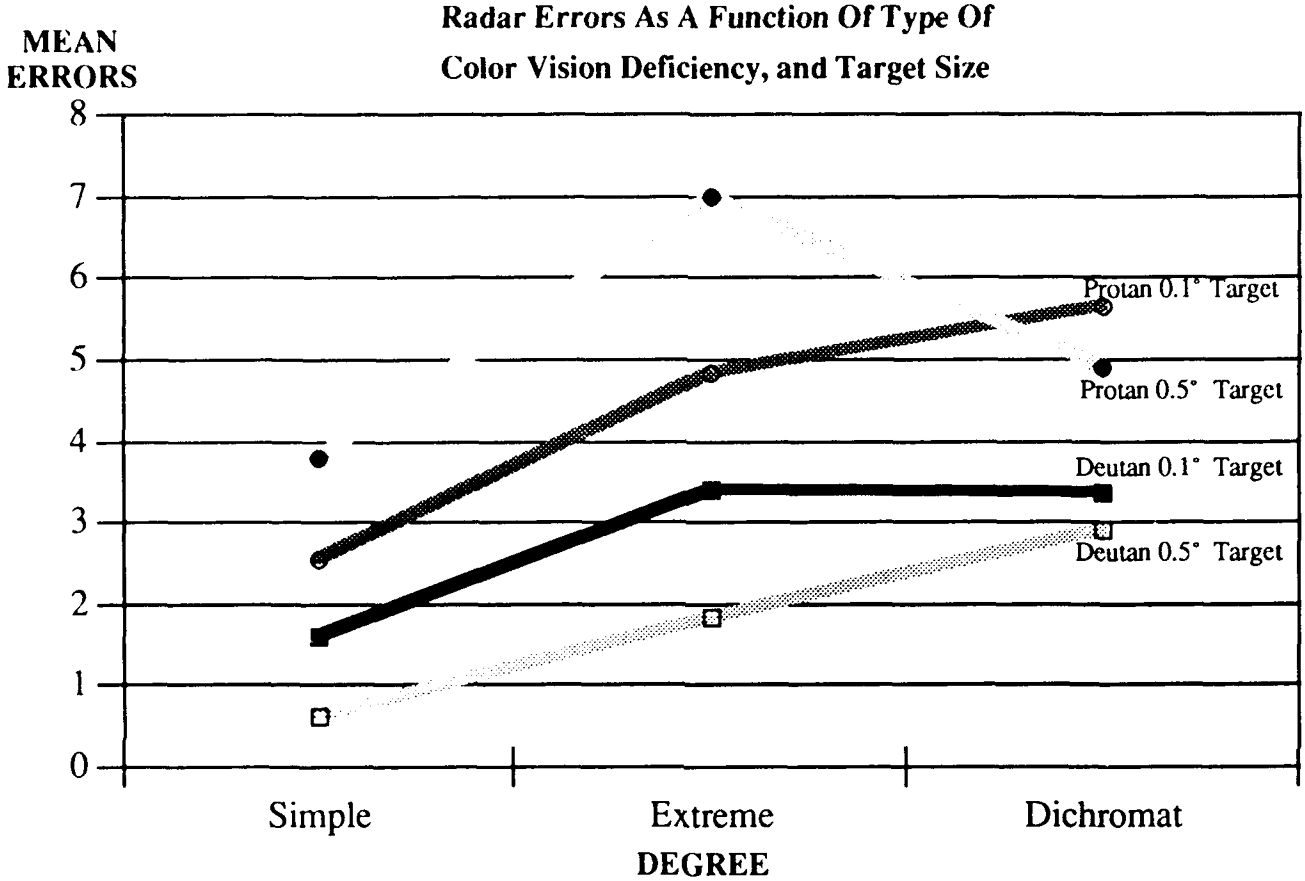


Figure 2

Radar Errors As A Function Of Type Of Color Vision Deficiency, and Target Size



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