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Validation of an Inexpensive Illuminant for Aeromedical Color Vision Screening

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16. Abstract

An inexpensive illuminant for color vision screening suggested by the NRC-NAS Committee on Vision was evaluated as a substitute for the Macbeth Easel Lamp. The Macbeth Easel Lamp is the recommended illuminant for pseudoisochromatic plate tests used in aeromedical color vision screening, but is no longer in production. Subjects included both normal trichromats (p=145) and persons with varying degrees and types of color vision deficiencies (p=152) as diagnosed with the Nagel Type I anomaloscope. Subjects were given the Dvorine Pseudo-Isochromatic Plate Test illuminated by each of the two light sources. One Verilux True Color Light tube (F15T8VLX) was installed in an adjustable fluorescent desk lamp and position at a height of 24 in above the center of the Dvorine test book to give a 270 lux illumination to match the illumination produced by the Macbeth light source. The two presentations of the Dvorine were separated by several other color vision tests. Each subject was given a different random order of plates 2-15 for each light source. Pass/Fail performance with the Dvorine test was virtually the same with the two light sources when criterion for failure was 3 or more errors. The Verilux True Color Light obtained a Kappa value of .97, and very low false positive (.021) and false negative (.006) rates when compared to the Macbeth Easel Lamp. Performance and possible applications of the Verilux True Color Light in aeromedical color vision screening are discussed.

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VALIDATION OF AN INEXPENSIVE TEST ILLUMINANT FOR AEROMEDICAL COLOR VISION SCREENING

Many of us have experienced first hand the effect that lighting type has on how colors appear. Usually, these experiences involve an annoying trip back to the department store to exchange mismatched clothing. However, some illumination-color-appearance situations have more significant consequences. An improperly illuminated color vision test, administered during Aeromedical screening, could result in an erroneous conclusion with respect to color vision ability (Lange, Morey, & Richards, 1980; Schmidt,1952). This could lead to an unnecessary career derailment due to failing an improperly administered test. The possibility of a person erroneously passing also exists (Farnsworth & Reed, 1943; Lange, Morey, & Richards, 1980; Schmidt,1952). If that person is incapable of performing the color identifications necessary to safely execute aviation related tasks, a critical situation could result for all involved.

Color vision requirements for medical certification of pilots are established by Federal Aviation Regulations (FARs). First-class certification requires "normal color vision" [FAR 67.13(b)(3)], and Second- and Third-class require an "ability to distinguish aviation signal red, aviation signal green, and white" [FAR 67.15(b)(5) and FAR 67.17(b)(3), respectively]. Confirmation of that color discrimination ability may involve a number of approved color vision plate tests (Guide for Aviation Medical Examiners, 1992), some of which require supplemental illumination. Poor choices for illumination of color vision tests have been shown to hinder or otherwise alter performance on those tests or resulted in an interaction between type of color vision deficiency and type of lighting (Farnsworth & Reed, 1943, 1944; Hardy, Rand, & Rittler, 1946; Richards, Tack, & Thome', 1971). Fletcher and Voke (1985) cautioned that "care must be taken when illuminating PIC [pseudoisochromatic plate tests] and all colour [sic] vision tests lacking an inbuilt illuminant" (p. 282), and Kalmus (1965) considered illuminant errors to be one of the most important sources of error in the administration of color vision tests.

Test developers Shinobu Ishihara and Israel Dvorine originally recommended the use of indirect natural daylight as an inexpensive source of illumination for color vision testing. Initially, this is appealing; however, as a standard illumination for critical color vision testing, natural daylight is impractical because of its variability in both intensity and spectral composition. Therefore, a more consistent source is desirable. The Macbeth Easel Lamp has been the standard illuminant for color vision testing for at least 50 years because it is an accepted, stable approximation of Northern Hemisphere, afternoon, north sky, natural daylight [National Research Council-National Academy of Sciences (NRC-NAS) Committee on Vision, 1981]. The Macbeth Easel Lamp is also the preferred illuminant for pseudoisochromatic plate tests used in Aeromedical color vision screening (Guide for Aviation Medical Examiners, 1992), but is no longer commercially available.

Several sources are available that provide guidelines for selection of fluorescent lamps capable of satisfactory color rendering for critical clinical decisions, and each cautions against generalizations concerning "daylight" fluorescent light sources because not all commercially available fluorescent lamps have equivalent color rendering properties (Fletcher & Voke, 1985; NRC-NAS, 1981; Pokorny, Smith, Verriest, & Pinckers, 1979).

The NRC-NAS Committee on Vision (1981) report lists illuminants that are suitable for color vision screening. The Macbeth Easel Lamp, and many others on that list, are no longer being manufactured. Of those listed, only one was found to be still available commercially. That lamp, the Verilux True Color Light [1] tube (F15T8VLX), is a relatively inexpensive "daylight" fluorescent with a manufacturer's reported

[1] The Verilux True Color Light is available from Verilux, Incorporated, Post Office Box 1512, Greenwich, CT 06836. The manufacturer's reported price for a single F15T8VLX fluorescent tube was $9.75 at the time of this printing.

color rendering index (CRI) of 93 when compared to "natural outdoor daylight." CRI is used to describe how closely a test source can reproduce color in comparison with a standard source. The closer the index is to 100, the closer the light source is considered to be to the reference standard.

The present experiment was designed to validate the Verilux True Color Light as an alternative to the Macbeth Easel Lamp for color vision screening tests. Performance on the Dvorine Pseudo-Isochromatic [sic] Plate Test illuminated by the Macbeth Easel Lamp was used as the criterion for assessing the Verilux True Color Light. Two separate criteria for failure of the Dvorine described in the Guide for Aviation Medical Examiners (1992) were examined: 1) the Aeromedical Certification requirement for a First-class medical certificate (failure with three or more errors), and 2) a less stringent criterion (failure with seven or more errors) required for a Second- or Third-class medical certificate.

METHOD

Subjects

Subjects included both normal trichromats (n=145) and persons with varying degrees and types of color vision deficiencies (n=152) as diagnosed with the Nagel Type I anomaloscope. Subjects ranged between 18 and 60 years of age. The normal trichromat group was composed of 102 men, with a mean age of 28.3 years and a standard deviation of 8.9 years, and 43 women whose mean age was 34.9 years and had a standard deviation of 12.2 years. The color deficient group consisted of 151 men (mean age 34.9 years and a standard deviation of 11.7 years) and 1 woman, 26 years of age. All subjects had at least 20/30 visual acuity in both near and distant vision, as measured by the Bausch and Lomb Orthorater vision tester. Participants for this study were recruited through advertisements in local newspapers and at area colleges and universities throughout the Oklahoma City (OK) metropolitan area and were paid an hourly wage.

The subjects performed several color vision tests in conjunction with several other studies, (Mertens & Milburn, 1992a, 1992b) which evaluated the color vision requirements and clinical color vision tests for selection of Air Traffic Control Specialists (ATCSs), and unpublished research concerning the development of practical color vision tests for ATCS selection.

Diagnostic Color Vision Tests

The procedure used for classification of deficiencies involved the Nagel Type I anomaloscope (Schmidt-Haensch) to classify individuals with red-green color vision deficiency, and other tests to detect and diagnose the rare blue-yellow deficiencies that the Nagel Type I anomaloscope does not detect. None of the latter were found.

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 is similar to that described and recommended by the NRC-NAS Committee on Vision (1981). The procedure described by that committee bases diagnosis primarily on measurements obtained under chromatic adaptation (i.e., matches obtained after looking at the anomaloscope stimulus for at least 20 sec). The anomaloscope classifications and the total number of subjects in each category are listed in Table 1. All anomaloscope measurements were administered by the second author to maintain consistency in procedure and diagnosis. A complete description of anomaloscope classifications and criteria for each is available in Mertens and Milburn (1992a).

Table 1

Number of Subjects by Anomaloscope Diagnosis

Color Vision Classification	No. of Subjects
Normal Trichromats	145
Simple Anomalous Trichromats	
Simple Protanomalous	19
Simple Deuteranomalous	35
Extreme Anomalous Trichromats	
Extreme Protanomalous	25
Extreme Deuteranomalous	39
Dichromats	
Protanopes	14
Deuteranopes	20
Total	297

Validation Criteria Materials

The Dvorine Pseudo-Isochromatic Plates

Two copies of the Second Edition (1953) of the Dvorine Pseudo-Isochromatic [*sic*] Plates by Israel Dvorine, produced by The Psychological Corporation, were used during this light source validation study. The Dvorine is a well respected and widely-used color vision screening test which achieved a high validity when compared to the Nagel Type I anomaloscope diagnosis of "normal trichromat" (Mertens & Milburn, 1993). The NRC-NAS Committee on Vision (1981) cited several reports (Belcher, Greenshields, & Wright, 1958; Frey, 1962; Sloan & Habel, 1956) that noted the high screening validity of the Dvorine.

For each plate of the Dvorine, the task of the observer is to identify a multi-colored Arabic numeral or numerals composed of three sizes of dots embedded in a multi-colored background of dots. The disguised number or numbers differ only in color from the background dots; size and intensity remain constant. The disguised number(s) are "hidden" only from the color deficient observers, and not from the color normal observers. The instruction to the observer is simply to "read the numbers on each plate." Plate 1 of the Dvorine is a demonstration plate, always given first, and one that all observers should be able to read. Only the literate plates (1-15) were used for this experiment. The alternate testing plates, (the path tracing plates), for illiterates were not used.

Two separate criteria for failure were examined: 1) three or more errors, which corresponds to the requirements for a Class I Medical Certification and 2) seven or more errors, which corresponds to the medical certification disposition for Class II and Class III (Guide for Aviation Medical Examiners, 1992).

The Macbeth Easel Lamp

The Macbeth Easel Lamp used for this experiment was equipped with a 100 watt incandescent light bulb (General Electric part number 100A21IF) and a blue (Corning, Daylite 590) filter, which together produced a correlated color temperature of 6936 degrees Kelvin. The illumination was 270 lux as measured at the center of the page of the Dvorine test. The CIE (Commission Internationale d 'Eclairage) 1931 color coordinates for the Macbeth's illumination were x=.305 and y=.323. All measurements of illuminance, color temperature, and color coordinates in this study were obtained with the Photo Research Spectrascan PR-703AM spectroradiometer and the Photo Research RS-1 reflectance standard. The design of the lamp standardizes the height of the illuminant and the angle of the plate test, to control the spatial relationship between these and the observer.

The Verilux True Color Light

One Verilux True Color Light tube (F15T8VLX) was installed in an adjustable fluorescent desk lamp and positioned at a height of 24 inches above and 4 inches in front of the center point of the plate test to give a 270 lux illumination. The test materials were placed on a bookstand at an angle of 45 degrees to replicate the approximate position and angle inherent to the Macbeth Easel Lamp design. The Verilux daylight fluorescent tube used had a correlated color temperature of 5895 degrees Kelvin. The color rendering index of 93 is reported by the manufacturer of the Verilux tube. The 1931 CIE chromaticity coordinates of the F15T8VLX tube were x=.324 and y=.336.

Procedure

Each subject was given plate 1 (the demonstration plate) of the Dvorine first, then each person received a different random order of plates 2-15 for each of the two light sources described. The Dvorine test was placed on a book easel directly under the light source, and all other illumination was extinguished during testing. The two presentations of the Dvorine were separated by several other color vision tests that were part of other studies. All testing was completed within 4 hours, and subjects were given short breaks between each of the 4 testing stations.

Two separate copies of the Dvorine were alternated between the Macbeth and Verilux testing stations. The order of presentation of light source was randomized.

RESULTS AND DISCUSSION

The acceptability of the Verilux True Color Light (F15T8VLX) for illumination of color vision plate tests was evaluated regarding prediction of pass/fail performance on the Dvorine illuminated by the criterion light source, the Macbeth Easel Lamp. Cohen's kappa (Cohen, 1960), an index of agreement, was used to assess the validity of the Verilux True Color Light. The index can be interpreted as the percentage agreement between the independent variable and the criterion variable, with correction for chance (NRC-NAS,1981).

Table 2 reflects a very high agreement (K=.97) between responses obtained with the Macbeth and the Verilux light sources, with a failure criterion of three or more errors and a comparable kappa of .98 when the more liberal criterion was used. In addition to the validity (kappa), Table 2 lists the miss and false alarm rates for each failure criterion. Miss rate is the probability of passing the Dvorine illuminated by the Verilux, given failure on the Dvorine illuminated by the Macbeth (the criterion condition). The false alarm rate is the probability of failing the Dvorine when illuminated by the Verilux, given passing with the Macbeth. Miss and false alarm rates are sometimes referred to as false negative rate and false positive rate, respectively. The very low miss and false alarm rates for both pass criteria indicate negligible differences in performance on the Dvorine between the two light source conditions.

Table 2

Relationship of Dvorine Test Performance under the Macbeth and Verilux Illuminants for Two Failure Criteria

Fail with 3 or more errors
Kappa= .97
Miss Rate= .021 False Alarm= .006

Verilux	Macbeth Pass	Macbeth Fail
Pass	153	3
Fail	1	140

Fail with 7 or more errors
Kappa = .98
Miss Rate= .007 False Alarm = .012

Verilux	Macbeth Pass	Macbeth Fail
Pass	160	1
Fail	2	134

Tables 3 and 4 present pass/fail disposition for each light source within each of the previously designated anomaloscope color vision diagnosis classifications. One simple protanomalous subject and one normal trichromat subject passed with the Macbeth light and failed with the Verilux light source when the criterion for failure was established at 3 or more errors (Table 3). One deutranope subject passed with 6 errors on the Dvorine when it was illuminated by the Macbeth, and failed with 7 errors on the same test when illuminated by the Verilux (Table 4). Two simple anomalous trichromats (1 protan and 1 deutan) failed the Dvorine illuminated by the Macbeth, but passed with the same criterion of fewer than 7 errors when the test was illuminated by the Verilux.

Tables 5 and 6 show that the light source had no effect on responses of different types of color vision deficients (protan or deutan). In several earlier studies, (Farnsworth & Reed, 1943, 1944; Hardy, Rand, & Rittler, 1946) an interaction between the type of light source and type of deficiency was reported. In this experiment, neither protan nor deutan types showed a difference in performance between the two illuminants tested.

Table 3

Number of Subjects within each Anomaloscope Diagnosis by Pass/Fail Disposition for each Light Source (Failure Criteria for the Dvorine 3+ errors)

			SIMPLE		EXTREME		DICHROMAT	
		NORMAL	PROT	DEUT	PROT	DEUT	PROT	DEUT
MACBETH	PASS	144	5	7	0	0	0	0
	FAIL	1	14	28	25	39	14	20
VERILUX	PASS	143	4	7	0	0	0	0
	FAIL	2	15	28	25	39	14	20

Table 4

Number of Subjects within each Anomaloscope Diagnosis by Pass/Fail Disposition for each Light Source (Failure Criteria for the Dvorine 7+ errors)

			SIMPLE		EXTREME		DICHROMAT	
		NORMAL	PROT	DEUT	PROT	DEUT	PROT	DEUT
MACBETH	PASS	145	6	9	0	0	0	1
	FAIL	0	13	26	25	39	14	19
VERILUX	PASS	145	7	10	0	0	0	0
	FAIL	0	12	25	25	39	14	20

Table 5

Crosstabulation of Pass/Fail Disposition by Type for each Illuminant (3+ Errors failure Criteria)

		NORMAL	PROTAN	DEUTAN
MACBETH	PASS	144	5	7
	FAIL	1	53	87
VERILUX	PASS	143	4	7
	FAIL	2	54	87

Table 6

Crosstabulation of Pass/Fail Disposition by Type for each Illuminant (7+ Errors failure Criteria)

		NORMAL	PROTAN	DEUTAN
MACBETH	PASS	145	6	10
	FAIL	0	52	84
VERILUX	PASS	145	7	10
	FAIL	0	51	84

Table 7

Crosstabulation of Pass/Fail Disposition by Degree for each Illuminant (3+ Errors failure Criteria)

		NORMAL	SIMPLE	EXTREME	DICHROMAT
MACBETH	PASS	144	12	0	0
	FAIL	1	42	64	34
VERILUX	PASS	143	11	0	0
	FAIL	2	43	64	34

Table 7 presents pass/fail performance data for both illuminants broken down by degree of color vision deficiency. No interaction between type of illumination and degree of deficiency was found.

CONCLUSIONS

Pass/Fail performance with the Dvorine test was virtually the same (K>.97) with the two light sources when the two established criteria for failure (3 or more errors and 7 or more errors) were examined. Similar results were reported by Johnson, (1992) using the Ishihara Pseudoisochromatic 24-Plate Test and the same F15T8VLX single tube installed in a new product called the True Daylight Illuminator, a fixture produced by Richmond Products, that incorporates a lamp mounted above a book easel in a one-piece unit. The design offers a more convenient, standardized, and stable assembly than the adjustable desk lamp and book easel used in this experiment. The True Daylight Illuminator yielded a higher level of illumination (945 lux) than the arrangement of the F15T8VLX (270 lux) used during the present experiment. However, Pokorny (1979) cites several sources (Frey, 1964; Hardy, 1946; Schmidt, 1952; Sloan, 1943) that indicate that screening test results are unaffected by changes in illumination level ranging from 100 lux to 1076 lux.

No interaction between type of deficiency with type of lighting was found in this study, although earlier studies (Farnsworth & Reed, 1943, 1944; Hardy, Rand, & Rittler, 1946) reported such an interaction. That interaction might be attributed to the very different spectral characteristics of the light produced by those sources being compared in the earlier studies, when compared to the Macbeth Easel Lamp.

The results of our study support Johnson's findings that performance for both color deficients and normal trichromats, on the respective plate tests used, is essentially unchanged when the test is illuminated by the Verilux True Color Light as compared to the Macbeth Easel Lamp. The inexpensive "daylight" fluorescent tube (F15T8VLX), configured in a similar arrangement as previously described, is an adequate substitute for the unavailable Macbeth Easel Lamp for Aeromedical color vision screening using the Dvorine. Ideally, validation of the F15T8VLX as an illuminant for other color vision screening tests should be accomplished before generalizations are made concerning its acceptability for use with those tests. Also, generalizations of these findings to other commercially available "daylight" fluorescent lamps should be avoided, since many color vision researchers tend to agree that not all "daylight" lamps have equivalent color rendering properties (Fletcher & Voke, 1985; NRC-NAS, 1981; Pokorny, Smith, Verriest, & Pinckers, 1979).

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