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The Applicability of Commercial Glare Test Devices in the Aeromedical Certification of Pilot Applicants

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16. Abstract

In his FY-92/93 Annual Program Guidance and Current Policy Statement, the Federal Air Surgeon requested continued investigation of new testing modalities, such as glare vision testing, as to their relevance to medical certification. Glare sensitivity is a normal age-related physiological change depriving the human visual system of vital information. An instrument that can effectively detect and measure visual performance loss from glare in a clinical environment would be a valuable tool for an Aviation Medical Examiner evaluating pilot applicants. This study evaluated several commercially available glare tests using factors of measured visual performance loss and relevant clinical features. Sixteen subjects (32 eyes) with normal ocular health were tested with a Brightness Acuity Tester (BAT), Penlight Test, MCT 8000, and a Miller-Nadler Glare Tester to determine each instrument's ability to detect visual acuity changes under simulated glare conditions. In addition, individual glare testers were subjectively rated by examining personnel as to clinical features important for use in an aeromedical screening, such as cost, training and space requirements, ease of operation and scoring, etc. Our results suggest that the BAT by Mentor O&O, Inc., presented preferred test sensitivity and clinical features for use in screening glare disability. The other procedures either demonstrated an inability to detect visual acuity changes under simulated glare conditions or exhibited undesirable clinical features for use in aeromedical glare screening. These data may be used in evaluating future glare testers. Guidelines are provided for incorporating glare testing into the aeromedical certification process. Additional research is planned to identify specific glare problems in the aviation environment.

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The Applicability of Commercial Glare Test Devices in the Aeromedical Certification of Pilot Applicants

INTRODUCTION

Glare is a sensation produced by luminance (brightness) within the visual field that is significantly greater than the adapted state of the eyes (1). Direct glare results from a high luminance source in the field of vision. Reflected glare is an effect of a high luminance source image reflected from a shiny surface. Glare sources may be either point or veiling (diffuse light with no particular point of origin) (1,2).

The effect of glare may be classified into "discomfort" or "disability" glare. Discomfort glare is the subjective response of annoyance caused by a light source without any measurable effect on visual performance (3). This photophobic response may be observed in individuals with lightly pigmented eyes (4) or beginning contact lens wearers (5). Prolonged discomfort glare may result in visual fatigue and systemic and ocular symptoms. The use of sunglasses relieves most symptoms of discomfort glare. Disability glare reduces visual performance (1) by the apparent scattering of light within the eye (6).

Mild glare sensitivity due to intraocular light scattering is a normal age-related physiological change. Around the age of 40 years, a sudden acceleration in sensitivity to glare develops (7). Even in normal young eyes, approximately 10 to 20% of the light incident on the corneal stroma scatters, resulting in a reduction in the contrast of the retinal image of a target (8). This scattering is related to the wavelength of the incident light and the arrangement of the stromal fibrils that make up the corneal tissue (9). Near ultraviolet (UV) or blue light, which is of relatively short wavelength (approximately half the wavelength of red light), will scatter 16 times more than red light in the cornea (10). The macula lutea absorbs some of this scattered, short wavelength light energy, leaving the residual to contribute to retinal image degradation.

The major source of abnormal intraocular scattering is the opacified crystalline lens (cataract), resulting in ghost images (halos around lights) or being dazzled by intense light (car headlights, bright daylight). Besides cataracts, other ophthalmic conditions that can induce either discomfort or disability glare, include: corneal edema (swelling due to fluid in the intercellular tissue) from contact lens wear (5), lens capsule opacification after cataract surgery (11), radial keratotomy (a refractive surgical procedure in which incisions made in the corneal anterior surface flatten the cornea and reduce nearsightedness) (12), pterygium (a growth on the bulbar conjunctiva) (13), aphakia, and intraocular lens implants (14).

A visual image can be degraded as light rays carrying the image pass through light-scattering environmental media, including fog, dust, rain, and smog. Synthetic materials, such as scratched or hazed windscreens and ophthalmic corrective devices, also may scatter light. These extraocular light-scattering mechanisms, combined with intraocular light scattering, may result in temporary functional blindness, compromising an individual's ability to "see and avoid" a life-threatening situation.

Since an estimated 80% of the information required to pilot an aircraft is visually acquired, vision standards were established to ensure that applicants met minimum performance requirements. Recurrent testing is mandated (first-class or transport pilot every 6 months; second-class or commercial pilot every 12 months; and third-class or private pilot every 24 months) to ensure that these capabilities are maintained. In the United States, the current vision standards to obtain a civil airman medical certificate (15) and the recommended procedures (16) for evaluating airman applicants use static tests of visual function (visual acuity, accommodation, eye alignment), performed in controlled, clinical environments.

In flight, airmen are subjected to numerous glare sources. For instance, flying under different flight rules (e.g., Visual, Marginal Visual, or Instrument Flight Rules (17)) exposes the airman to various environmental light conditions that limit visibility and contrast between objects. Other examples of glare in aviation, include: airmen flying at high altitudes may be exposed to darkened skies above with brighter

light from the clouds beneath them (Note: The anatomical structure of the human facial contour serves to protect the eyes from bright light coming from above but not from below (18).); the sun's rays are more intense at altitude (At sea level, the aviator is exposed to approximately 10,000 foot-candles; at 10,000 feet, exposure is estimated at 11,800 foot-candles (19).); light may scatter off dirty or scratched windscreens; and the airman may be temporarily visually disabled when flying from behind the shadow of mountains or cloud cover into a brightly-lit environment.

The American Medical Association (20) and the National Academy of Science's Institute of Medicine (21) recommended including glare testing (GT) as part of the medical certification of pilot applicants. A device that can identify the early signs of glare sensitivity may be a valuable screening tool for the Aviation Medical Examiner (AME) providing a more comprehensive assessment of visual performance in "real world" situations.

Commercial devices are available to evaluate glare sensitivity in clinical ophthalmic practice, primarily to support medical decisions for surgical procedures. In clinical research studies, patients with normal visual function, as measured by traditional acuity tests, have shown severely degraded vision performance in glare-producing environments. GT devices may predict functional outdoor visual acuity (22,23) and may be considerably more reliable in their estimate of outdoor vision performance than traditional indoor Snellen acuity (24). However, such devices can vary in their predictions of functional outdoor vision (25).

To be of clinical value in screening for early signs of abnormal glare sensitivity, an instrument should be able to produce a measurable vision performance loss even in subjects with normal ocular health. Such an instrument would have the sensitivity to detect incipient glare problems of applicants with otherwise normal vision (approximately 20/20 Snellen acuity) during a medical examination. Other clinical factors of importance to the AME, include: cost, technical training requirements, space requirements, ease of operation and scoring, duration of test, and test flexibility.

The Civil Aeromedical Institute's Vision Research Section evaluated several commercially available instruments and methods for testing glare sensitivity to determine their appropriateness as screening devices in the medical certification of civil airman applicants. The results of these evaluations are reported in this manuscript.

METHODS

Obtained through a local contracting agent, 16 subjects (nine males, seven females), ranging in age from 20-30 years (average = 25.0 years), were required to meet the vision standards for a Federal Aviation Administration (FAA) third-class airman medical certificate. The vision standards, include:

1) Distant Vision: At least 20/50, without correction; or if vision is poorer than 20/50, must correct to 20/30 or better with corrective lenses (glasses or contact lenses).
2) Near Vision: At least 20/60 with each eye separately with or without correcting glasses.
3) No serious pathology of the eye.

Each subject was tested twice, approximately seven days apart, lasting approximately two hours per visit. During the first visit, each subject read a research protocol summary, signed a release form, and completed an initial eye examination.

The initial eye examination evaluated:
1) External ocular health,
2) Extraocular muscles,
3) Phoria (maddox rod),
4) Posterior ocular segment (direct and monocular indirect ophthalmoscopy, non-mydriatic photography),
5) Anterior ocular segment, including evaluation of crystalline lens (slit lamp),
6) Color Vision (Dvorine Pseudo-Isochromatic Plates),

7) Objective refraction (Nikon Auto Refractometer, NR-5000),

8) Subjective manifest refraction (distant and near),

9) Snellen visual acuity,

10) Pupil diameter,

11) Eye dominance,

12) Macular integrity (Amsler grid),

13) Pupillary distance,

14) Intraocular pressure (air-puff tonometry), and

15) Field of vision (Humphrey Field Analyzer, Model 630).

Subjects who passed the initial eye examination, which verified their normal ocular health status, were scheduled for glare testing with the following GT instruments or method:

1) Penlight Test,

2) Brightness Acuity Tester (BAT) distributed by Mentor O&O, Inc.,

3) Multivision Contrast Tester (MCT) 8000 distributed by Stereo Optical Co., Inc., and

4) Miller-Nadler Glare Tester (MNGT) distributed by Titmus Optical, Inc.

(Note: A review of the literature identified several other glare test procedures and instruments. These were not selected for testing for the following reasons: relatively high cost, complex methodology, non-availability, and lack of clinical data.)

All glare tests were performed by a single optometric technician with subjects wearing their best subjective refraction prescription in trial lenses, if required. The Bailey-Lovie (BL) acuity charts were used to evaluate visual performance with the Penlight and BAT tests (Note: Figure 1.). The other two instruments had acuity targets incorporated into their design. BL charts have demonstrated excellent correlation to Snellen acuity scores with good test-retest characteristics (26). Acuity scores may be obtained in visual acuity rating (VAR) units, which are easily manipulated for statistical analysis (VAR scores were later converted to Snellen acuity for presentation as summary data). Both high-contrast (90% contrast) and low-contrast (10% contrast) versions of the BL chart were used. Percent contrast of a target is defined as (27),

$$PERCENT\ \ CONTRAST = \left(\frac{LUMINANCE_{MAX} - LUMINANCE_{MIN}}{LUMINANCE_{MAX} + LUMINANCE_{MIN}}\right) \times 100.$$

Ambient luminosity at the subject's eyes was maintained at approximately 20 foot-candles (ft-cd), and the BL charts illuminated to approximately 85 ± 5 cd/m^2. Subjects identified all recognizable letters and were encouraged to guess when in doubt (multiple-alternative forced-choice criteria). Two versions of each contrast were alternated during the tests to minimize subject memorization.

The following is a description of the equipment and procedure used to conduct each glare test.

I. The Penlight Test (Note: Figure 2.) uses a battery-operated ophthalmic penlight to simulate a glare source.

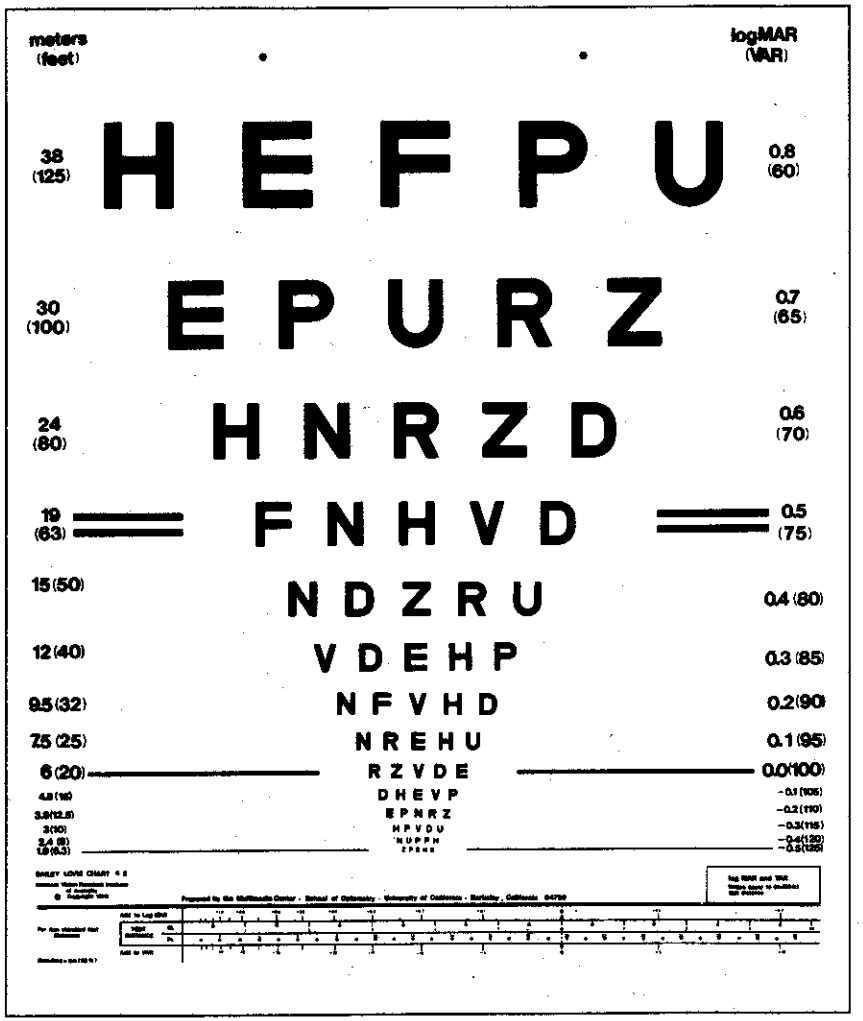
1. Monocular visual acuity was measured on the right eye with the high-contrast chart. The non-tested eye was patched.

2. An ophthalmic penlight was focused at the tested eye 15 to 30 degrees off the line of sight in the temporal direction, approximately 15 to 20 inches from the subject. A period of 30 seconds was given for the eye to adapt to the glare source. The subject was instructed not to look at the glare source. Visual acuity was measured with the alternate high-contrast BL chart (28).

3. Steps 1 and 2 were repeated for the left eye.

4. Steps 1, 2, and 3 were repeated, using the low-contrast chart.

II. The BAT (Note: Figure 3.) is a hand-held instrument that measures acuity under three luminance conditions: low (300 ft-cd, simulating bright overhead commercial lighting) or BAT-L; medium (2,500 ft-cd, simulating a partly cloudy day) or BAT-M; and high (10,000 ft-cd, simulating direct overhead sunlight) or BAT-H.



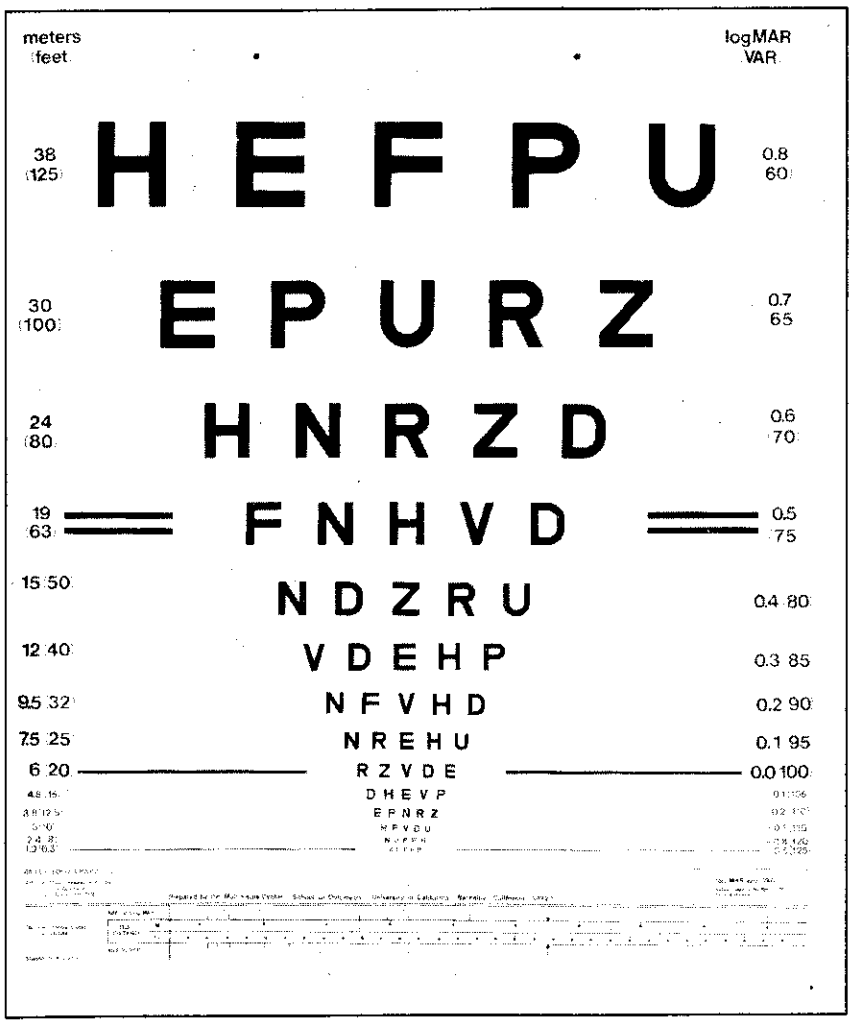


FIGURE 1: The Bailey-Lovie High- and Low-Contrast Acuity Chart.

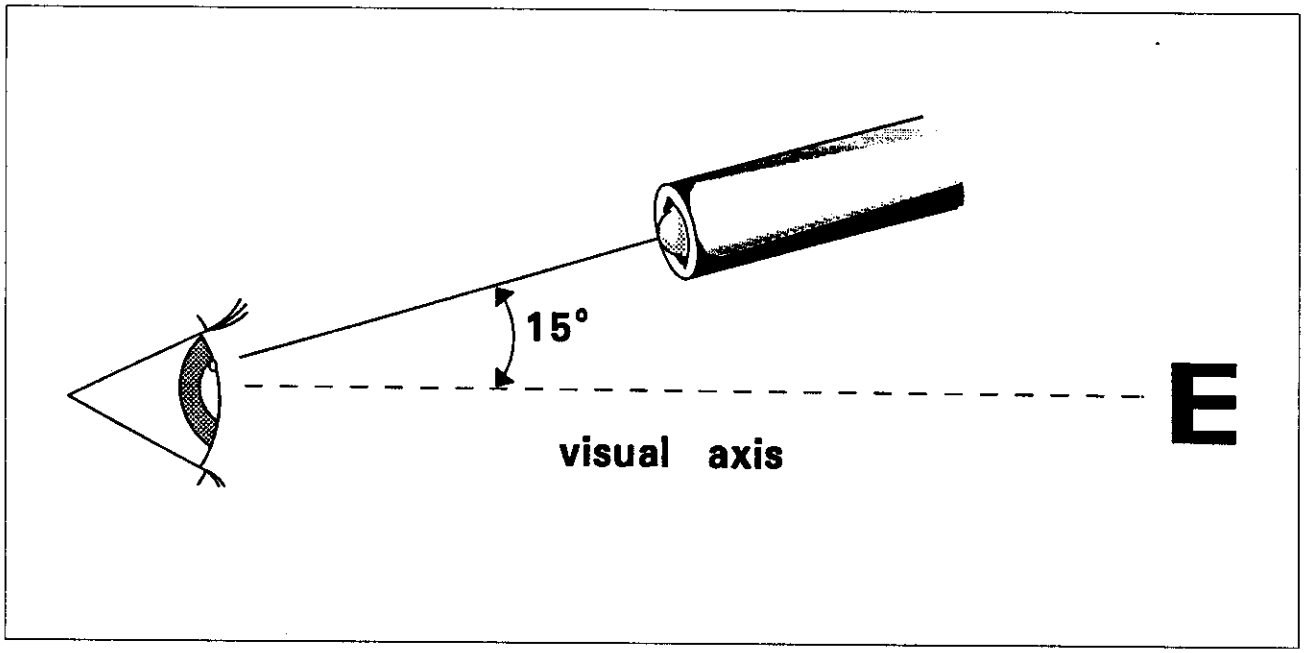


FIGURE 2: The Penlight Test.

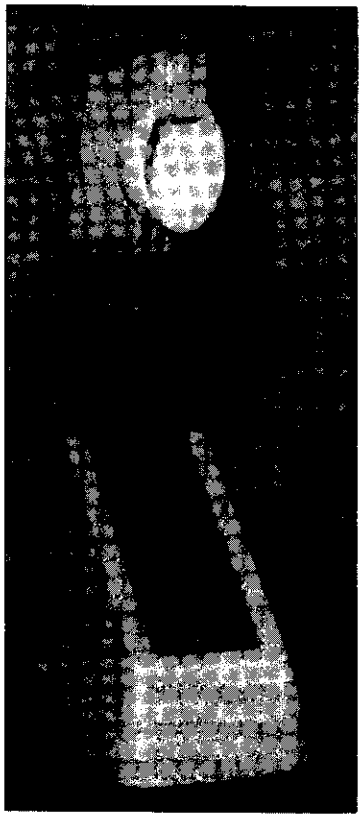


FIGURE 3: The Brightness Acuity Tester (BAT)

1) Monocular visual acuity of the right eye was measured with the high-contrast chart viewed through the instrument's 12mm aperture. The non-tested eye was patched.

2) Monocular glare acuity was then measured with the BAT-L, BAT-M, and BAT-H luminance settings, allowing 30 seconds for the eye to adapt at each setting. Acuity measurements were alternated between the two versions of the high-contrast chart.

3) Steps 1 and 2 were then performed on the left eye.

4) Steps 1, 2, and 3 were repeated, using the low-contrast charts (Note: Sufficient time was given between step 2 and step 4 to allow the subject to recover from the bleaching induced by the BAT-H luminance.)

III. The MCT 8000 (Note: Figure 4.) incorporates a variety of test targets and lighting conditions. Normally, this instrument uses sine-wave gratings to measure visual performance changes for its glare tests. However, the gratings were not used since most AMEs are unfamiliar with these targets, and they require mathematical conversion to obtain equivalent Snellen acuity. Instead, two versions of a standard high-contrast Snellen acuity chart, provided with the instrument, were used to measure vision performance.

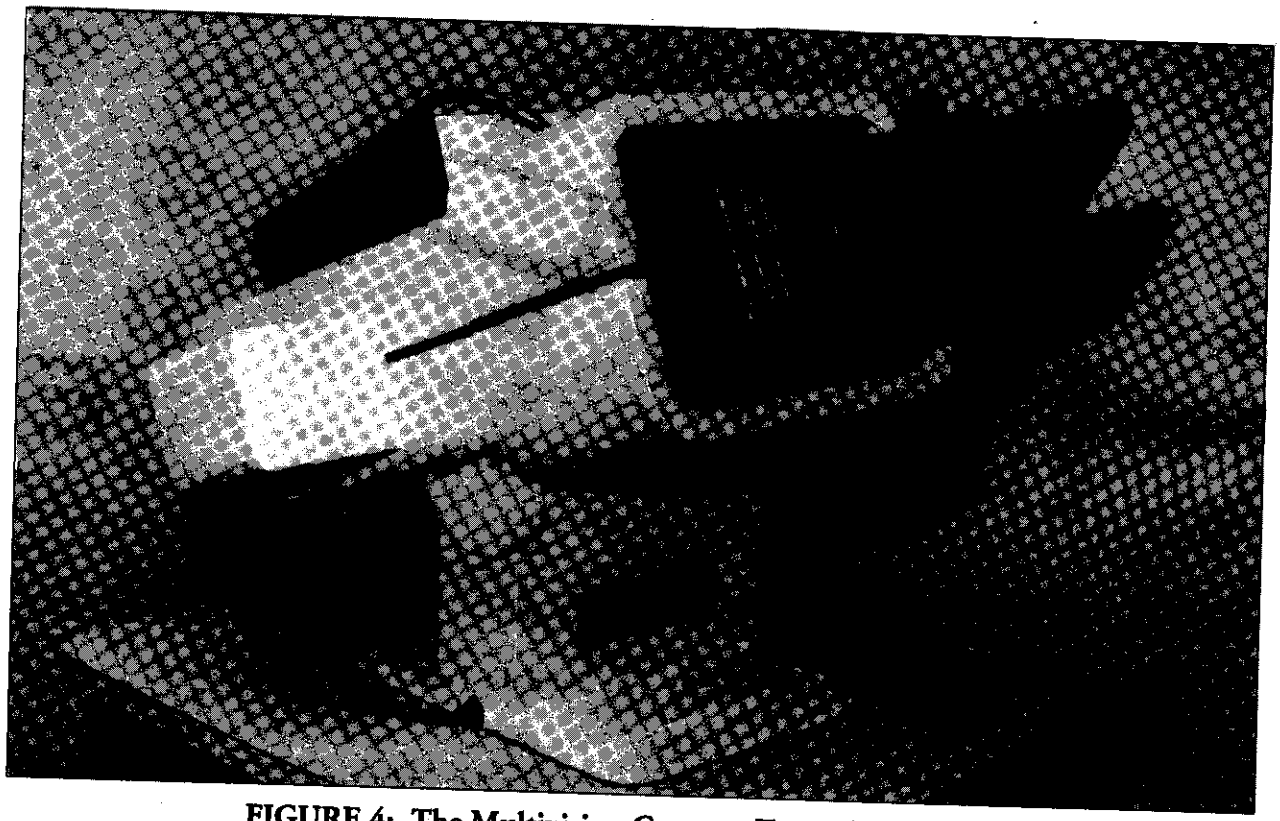


FIGURE 4: The Multivision Contrast Tester (MCT) 8000

Unfortunately, low-contrast letter charts were not available and comparison test data could not be evaluated.

1) Monocular visual acuity of the right eye was measured as the subject looked through the instrument eyepiece.

2) Monocular glare acuity was then measured for the same eye using the second acuity chart with the peripheral glare source engaged. A period of 30 seconds was given for the eye to adapt to the glare source.

3) Steps 1 and 2 were repeated on the left eye.

4) Individual acuity scores were interpolated to approximate decimal equivalence of the Snellen denominators and converted to VAR values with the following formula (Note: This method of interpolation assumes a linear relationship within a row of optotypes and provides each subject partial credit for a row in which less than three optotypes in succession were incorrectly identified. When three optotypes were missed, only optotypes in that row prior to the missed letters were given partial credit.):

$$VAR = 165 - 50 \times \log(d),$$

where, d = Snellen denominator (i.e., 20/d).

IV. The MNGT (Note: Figure 5.) incorporates a modified carousel slide projector with a built-in viewing screen mounted on an adjustable support frame. The frame includes a patient positioning device, consisting of a chin and forehead rest and an eye occluder. The instrument uses a series of 19 slides that are rear projected onto the viewing screen. Each slide has a centrally located black optotype (20/400 Landolt ring) surrounded by a circular background. The test optotype changes orientation to one of four positions (up, down, left, right) as the slides advance. The background varies with each subsequent slide, reducing the contrast between the optotype and the background from a maximum of 80% to a minimum of 2.5% contrast. Surrounding the optotype and the background is a rectangular, constant luminance, diffuse glare light source.

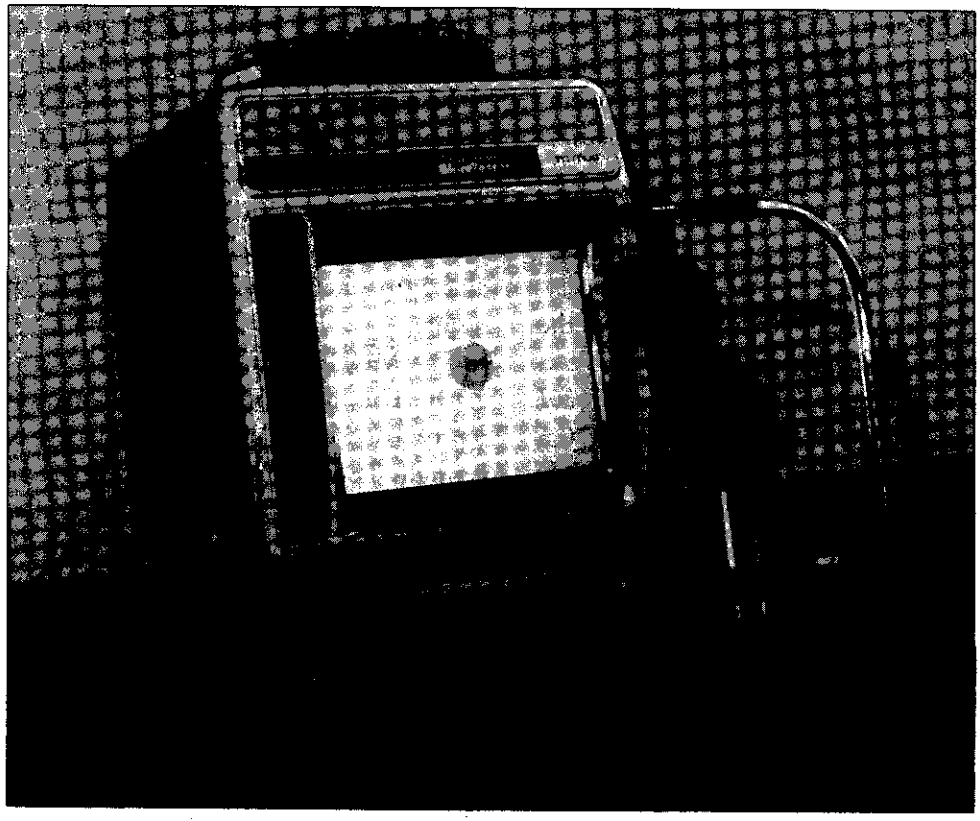


FIGURE 5: The Miller-Nadler Glare Tester (MNGT)

1. The right eye was tested with the slide series. The non-tested eye was patched. Scores were recorded as pass or fail for each slide.
2. The test was repeated for the left eye.
3. Scores were initially recorded in "percentage of glare disability" values, as defined by the manufacturer. With the aid of the "Effective Outdoor Snellen Acuity vs. Percentage of Glare Disability Chart," provided by the manufacturer, these scores were converted to Snellen fractions. Snellen acuity scores were then transformed into VAR values using the formula in section III (4).

After each GT, subjects rated the luminance intensity of the glare source for each test device using the de Boer Glare Rating Scale (Note: Table 1.).

Table 1: The de Boer Glare Rating Scale

1)	Unbearable
2)	
3)	Disturbing
4)	
5)	Just Acceptable
6)	
7)	Satisfactory
8)	
9)	Just Noticeable

Individual glare tests were subjectively rated by the examining personnel as to clinical factors considered important for use by an AME. These factors included cost, training required, space required, ease of operation, ease of score interpretation, test duration, luminous flexibility, and acuity target flexibility.

RESULTS

Individual and average Snellen acuity scores for the different glare tests evaluated are presented in Table 2.

The average acuity change between the high- (20/[16.29 ± 2.48]) and low-contrast charts (20/[19.70 ± 4.52]), a reduction of target contrast of approximately 88.9%, decreased about one line of optotypes. There was a substantial increase in the standard deviation (SD) associated with low-contrast acuity scores.

The Penlight Test with the high-contrast chart resulted in an average acuity loss of less than one optotype between non-glare (20/[16.29 ± 2.48]) and glare (20/[16.43 ± 2.86]) conditions. There was a small increase in the SD with glare. With the low-contrast chart there was a decrease in visual performance between non-glare (20/[19.70 ± 4.52]) and glare (20/[20.10 ± 3.66]). Although low-contrast targets were more sensitive to the effects of glare, several individual acuity scores improved, which resulted in a decrease in the SD.

The BAT-L with the high-contrast chart resulted in an improved average acuity score from non-glare (20/[15.99 ± 2.08]) to glare (20/[15.89 ± 2.38]). The BAT-M average acuity score decreased from non-glare to glare (20/[16.36 ± 2.64]). There was also a decrease in the BAT-H average acuity score from non-glare to glare (20/[16.81 ± 2.95]). A gradual increase in the SDs was observed with increasing glare intensities.

The BAT-L with the low-contrast chart resulted in an improved average acuity score from non-glare (20/[21.38 ± 4.37]) to glare (20/[20.33 ± 2.98]). This acuity change is considerably larger than that observed for high-contrast targets. There was an improvement in the average acuity score of the BAT-M from non-glare to glare (20/[20.65 ± 3.26]). The largest change in visual performance was in the BAT-H from non-glare to glare (20/[25.89 ± 10.92]), an approximate decrement of one line of optotype. SD values increased with brighter glare intensities for low-contrast targets at a proportionally greater rate when compared to those of the high-contrast targets.

The MCT 8000 glare test resulted in improved average acuity scores from non-glare (20/[16.69 ± 3.05]) to glare (20/[16.45 ± 2.53]). There was a decrease in the SD value with glare, which is contradictory to the high-contrast Penlight and BAT test results.

The MNGT average glare score was 20/(33.81 ± 0.73). The instrument does not measure non-glare acuity. If we compared this glare score to that of the Penlight Test, using the high-contrast chart without glare (20/[16.29 ± 2.48]), one would suspect there had been a substantial loss in vision with glare. It is important to note that the best acuity the MNGT is capable of measuring is equivalent to 20/33 Snellen acuity, which is substantially poorer than acuities found in our sample population.

The de Boer Glare Rating values for each glare test are presented in Table 3. The BAT-H produced the highest glare response, followed by the BAT-M, MCT-8000, Penlight Test, BAT-L and the MNGT.

The clinical factors listed in Table 4 were subjectively evaluated by the Vision Research staff for each instrument. Since the selected device may be used by an AME, who is generally not an ophthalmic specialist, the evaluation criterion employed included those factors which would be of concern to general health care providers and their staff. Comparison of the particular clinical factor under consideration, other than cost, was made relative to that of the other instruments in this study. For example, if the majority of the staff felt the clinical attribute was positive with respect to the other instruments, a plus (+) rating was assigned to the device for that clinical factor. In a similar manner, a minus (-) rating was assigned for a negative factor relative to the other instruments.

DISCUSSION

Several glare tests produced improvements in acuity scores. This result is probably due to an optical phenomenon, known as the "pinhole effect." A pinhole lens is used by eye doctors to aid in clinical

TABLE 2: SNELLEN ACUITY SCORES FOR THE DIFFERENT GLARE TEST EVALUATED

SUB #	EYE	BASE TEST HC	BASE TEST LC	PENLIGHT HIGH-CONTRAST		PENLIGHT LOW-CONTRAST		BAT HIGH-CONTRAST				BAT LOW-CONTRAST				MCT 8000		MNGT	
		NG	NG	NG	G	NG	G	NG	LOW	MED	HI	NG	LOW	MED	HI	NG	G	NG	G
1	OD	14.45	21.88	13.18	13.18	18.20	19.05	15.85	15.14	15.14	15.14	18.20	19.95	19.05	21.88	23.70	22.16	14.45	33.59
	OS	15.14	19.05	13.18	13.18	17.38	18.20	13.80	14.45	14.45	14.45	14.45	18.20	17.38	17.38	16.47	17.93	15.14	33.59
2	OD	19.05	30.20	16.60	17.38	26.30	26.30	16.60	18.20	17.38	17.38	27.54	22.91	25.12	22.91	25.72	20.71	19.05	33.59
	OS	17.38	22.91	17.38	17.38	19.95	20.89	16.60	16.60	17.38	16.60	21.88	19.05	21.88	20.89	20.71	18.13	17.38	33.59
3	OD	19.05	28.84	18.20	19.05	25.12	25.12	19.05	16.60	18.20	17.38	26.30	26.30	20.89	27.54	19.95	19.95	19.05	33.59
	OS	19.05	23.99	17.38	17.38	22.91	22.91	19.05	16.60	17.38	18.20	20.89	21.88	20.89	23.99	14.97	16.47	19.05	33.59
4	OD	19.05	33.11	19.95	20.89	20.89	19.95	19.95	19.05	20.89	26.30	30.20	26.30	26.30	52.48	16.47	15.70	19.05	36.06
	OS	20.89	38.02	26.30	27.54	36.31	30.20	20.89	19.95	20.89	18.20	34.67	26.30	26.30	33.11	17.28	17.28	20.89	36.06
5	OD	18.20	20.89	15.85	16.60	23.99	20.89	15.85	17.38	17.38	19.95	25.12	20.89	26.30	22.91	24.95	24.95	18.20	33.59
	OS	20.89	28.84	19.95	17.38	27.54	30.20	16.60	19.95	19.95	18.20	27.54	27.54	25.12	34.67	18.13	18.13	20.89	33.59
6	OD	14.45	19.05	15.14	15.85	17.38	18.20	14.45	17.38	15.85	19.95	17.38	17.38	25.12	43.65	14.97	14.97	14.45	33.59
	OS	15.14	25.12	15.85	17.38	17.38	17.38	17.38	15.85	17.38	20.89	20.89	22.91	22.91	69.18	19.92	14.97	15.14	33.59
7	OD	16.60	18.20	13.18	13.18	16.60	16.60	13.18	13.18	13.18	19.95	20.89	17.38	20.89	22.91	15.70	14.97	16.60	33.59
	OS	16.60	22.91	16.60	13.80	16.60	20.89	14.45	13.80	16.60	19.05	19.95	19.05	17.38	38.02	14.97	14.97	16.60	33.59
8	OD	13.80	18.20	16.60	14.45	19.05	15.85	13.18	13.18	13.18	16.60	19.05	17.38	17.38	21.88	15.70	14.97	13.80	33.59
	OS	13.80	16.60	14.45	14.45	18.20	19.95	13.18	13.80	13.80	17.38	18.20	16.60	18.20	26.30	14.97	14.97	13.80	33.59
9	OD	18.20	20.89	16.60	18.20	21.88	23.99	18.20	15.85	18.20	17.38	20.89	18.20	21.88	20.89	14.97	14.97	18.20	33.59
	OS	17.38	23.99	18.20	15.14	21.88	18.20	17.38	16.60	18.20	17.38	21.88	19.05	21.88	27.54	14.97	14.97	17.38	33.59
10	OD	18.20	21.88	15.85	16.60	19.95	19.05	18.20	16.60	18.20	18.20	21.88	22.91	20.89	26.30	17.28	17.28	18.20	33.59
	OS	15.14	19.05	15.14	15.85	16.60	16.60	17.38	17.38	16.60	18.20	22.91	20.89	22.91	26.30	14.97	14.97	15.14	33.59
11	OD	16.60	26.30	17.38	17.38	21.88	22.91	18.20	16.60	17.38	17.38	23.99	22.91	21.88	31.62	15.70	16.47	16.60	33.59
	OS	16.60	23.99	17.38	15.14	22.91	20.89	15.85	16.60	16.60	19.95	28.84	20.89	23.99	22.91	14.97	14.97	16.60	33.59
12	OD	16.60	18.20	13.80	13.80	19.05	18.20	13.18	13.80	13.18	13.80	18.20	18.20	17.38	20.89	14.97	14.97	16.60	33.59
	OS	13.18	15.14	14.45	13.80	18.20	17.38	13.80	14.45	13.18	13.80	17.38	18.20	15.14	18.20	14.97	14.97	13.18	33.59
13	OD	19.05	28.84	16.60	16.60	20.89	20.89	15.14	18.20	23.99	13.18	18.20	20.89	22.91	27.54	17.74	20.48	19.05	33.59
	OS	17.38	20.89	16.60	15.85	18.20	21.88	15.85	22.91	19.05	17.38	20.89	21.88	20.89	31.62	15.70	15.70	17.38	33.59
14	OD	14.45	22.91	16.60	17.38	16.60	16.60	15.14	13.18	13.80	13.18	18.20	19.05	17.38	16.60	14.97	14.97	14.45	33.59
	OS	15.14	18.20	14.45	17.38	19.05	21.88	14.45	13.80	14.45	14.45	21.88	18.20	20.89	20.89	14.97	14.97	15.14	33.59
15	OD	13.80	19.05	15.14	19.95	12.59	18.20	13.80	13.18	14.45	12.02	18.20	18.20	17.38	17.38	14.97	14.97	13.80	36.06
	OS	15.85	17.38	15.14	19.95	12.59	16.60	16.60	13.80	13.80	12.59	18.20	17.38	15.85	18.20	14.97	14.97	15.85	33.59
16	OD	17.38	21.88	16.60	15.85	20.89	19.05	16.60	13.18	14.45	13.80	21.88	19.05	16.60	23.99	14.97	14.97	17.38	33.59
	OS	15.14	22.91	16.60	14.45	17.38	17.38	15.85	16.60	15.14	17.38	19.95	20.89	19.95	26.30	15.70	15.70	15.14	33.59
AVERAGE		16.55	22.29	16.29	16.43	19.70	20.10	15.99	15.89	16.36	16.81	21.38	20.33	20.65	25.89	16.69	16.45	16.55	33.81
STD DEV		2.10	5.10	2.48	2.86	4.52	3.66	2.08	2.38	2.64	2.95	4.37	2.98	3.26	10.92	3.05	2.53	2.10	0.73
VARIANCE		4.42	25.97	6.14	8.16	20.43	13.43	4.35	5.67	6.96	8.70	19.08	8.88	10.64	119.33	9.28	6.41	4.42	0.53
MAXIMUM		20.89	38.02	26.30	27.54	36.31	30.20	20.89	22.91	23.99	26.30	34.67	27.54	26.30	69.18	25.72	24.95	20.89	36.06
MINIMUM		13.18	15.14	13.18	13.18	12.59	15.85	13.18	13.18	13.18	12.02	14.45	16.60	15.14	16.60	14.97	14.97	13.18	33.59

Table 3: De Boer Rating Values for Each Glare Tester

SUB #	EYE	PENLIGHT	BAT			MCT 8000	MNGT
			LOW	MED	HI		
1	OD	8	8	7	4	8	9
	OS	8	8	7	4	8	9
2	OD	9	7	7	5	5	9
	OS	9	7	7	5	5	9
3	OD	3	6	4	3	3	7
	OS	3	6	4	3	3	7
4	OD	9	9	9	7	9	9
	OS	9	9	9	7	9	9
5	OD	8	6	5	3	4	9
	OS	8	6	5	3	4	9
6	OD	5	5	3	1	3	7
	OS	5	5	3	1	3	7
7	OD	5	6	3	1	5	5
	OS	5	6	3	1	5	5
8	OD	5	9	6	3	9	9
	OS	7	9	6	3	9	9
9	OD	9	9	6	4	8	9
	OS	9	9	6	4	8	9
10	OD	6	4	3	2	6	8
	OS	6	4	3	2	6	8
11	OD	4	9	6	4	4	7
	OS	9	9	7	5	5	7
12	OD	6	9	5	3	6	7
	OS	6	9	5	3	6	7
13	OD	5	8	6	3	5	9
	OS	5	8	6	4	5	9
14	OD	4	8	5	3	5	5
	OS	4	8	5	3	5	5
15	OD	8	7	5	6	7	4
	OS	8	7	5	6	7	4
16	OD	5	9	7	3	3	9
	OS	5	9	7	3	3	9
AVERAGE		6.41	7.44	5.47	3.50	5.66	7.63
STD DEV		1.98	1.61	1.67	1.59	2.01	1.68
MAXIMUM		9.00	9.00	9.00	7.00	9.00	9.00
MINIMUM		3.00	4.00	3.00	1.00	3.00	4.00

1) UNBEARABLE
3) DISTURBING
5) JUST ACCEPTABLE
7) SATISFACTORY
9) JUST NOTICABLE

Table 4: Clinical Factors of Individual Glare Tests Evaluated

	Penlight	BAT	MCT 8000	MNGT
Cost (<$2000)	+	+	-	-
Training required	+	+	-	-
Space required	-	-	+	+
Ease of operation	+	+	-	+
Ease of scoring	+	+	-	-
Test duration	+	+	-	+
Luminous flexibility	-	+	+	-
Vision performance measure flexibility	+	+	+	-

diagnosis by neutralizing the effects of uncorrected refractive error (4). The normal mechanics of the human optical system creates its own pinhole when exposed to a light source. As the pupil constricts, the eye's depth of field (focus) increases, collimating the image-carrying light rays and concentrating them on the fovea. The retinal fovea is where acuity is maximized due to the high cone density in this area (29). The pinhole or miotic pupil may correct other anatomical or refractive irregularities, such as: irregular astigmatism, para-central corneal scars, peripheral cortical cataracts, and posterior capsule opacities (27). Since test subjects were evaluated with their best subjective refractive corrections, and comprehensive eye examinations found them to be free of visual pathway abnormalities, the improved acuity scores with high-contrast targets are probably the result of corrected irregular peripheral astigmatism by the pinhole effect. Acuity through a pinhole or miotic pupil with low-contrast targets may be affected by the same anatomical or refractive irregularities as high-contrast targets, or there may be a differential refractive effect between targets of dissimilar contrast (30). In other words, when performing a refraction, high-contrast targets are normally used to evaluate vision, but the resulting refractive error may not be the same with targets of different contrast. The change in vision through the light-induced pinhole pupil was found to be clinically insignificant for both high- and low-contrast targets with corrected lenses.

In our study, the BAT possessed the clinical features and test sensitivity for glare testing that would be required if such tests became a part of the aeromedical certification examination of pilot applicants by an AME. Positive clinical features of the BAT, included: low cost; minimal specialized training; ease of operation and score interpretation; test duration; variable glare source intensity; and the flexibility to test with Snellen or alternative forms of acuity targets. A negative feature of the BAT is the space requirement between the subject and the visual acuity chart, which can be up to 20 feet. However, using the Bailey-Lovie, or similar acuity system, may alleviate this problem since its test distance is adjustable.

The BAT has been shown in previous clinical trials to effectively predict outdoor acuity (22,31,32). In our study, the BAT produced data that were relatively consistent and stable compared to the other test procedures. Relative to the non-glare score, the average glare acuity for high-contrast targets improved slightly with the BAT-L glare setting. This suggests that this low luminance setting was too dim to adversely affect visual performance, which supports a previous study

(32), but is bright enough to produce a pinhole effect in many subjects with normal ocular health. Reduction in average acuity obtained with the BAT-M and BAT-H glare setting suggests a direct relationship between visual performance and the intensity of the glare source (32). However, since the BAT-H glare setting has been shown to overestimate glare acuity loss in the natural environment (31), we recommend using the BAT-M glare setting to test airman applicants. Average acuity scores with low-contrast targets improved with both the BAT-L and BAT-M glare settings, but decreased with the BAT-H glare setting. This differs from the results observed for high-contrast targets in which improved average acuity was only found with the BAT-L glare setting. The SD value increased to almost three times its non-glare value with the BAT-H glare setting, indicating substantial variability with increased luminance for low-contrast targets. Our results suggest that using the BAT-M glare setting and low-contrast targets to test airmen applicants would require a greater reduction in visual performance than with high-contrast targets.

The Penlight Test with high-contrast targets resulted in a minor reduction in average acuity and a small increase in the standard deviation compared to non-glare visual acuity. With low-contrast letters, the test results exhibited a similar pattern. Exaggerated acuity improvements shown by some subjects (possibly from a pinhole effect) decreased the overall SD. The Penlight Test could serve as a convenient and inexpensive glare test, provided careful attention is given to its limitations, which include: proper positioning of the penlight is difficult to standardize; light scattering opacities may be missed if they are not located between the glare source and the subject's retinal image of the target, which make repeatability and false negative results inherent liabilities; and effective evaluation of glare sensitivity may require repeated tests at several scattering angles (Note: Multiple testing procedures diminish the value of any screening test of numerous applicants.).

The MCT 8000 average acuity improved with glare. This may be the result of the low luminance of the glare source inducing a pinhole effect or the insensitivity of high-contrast optotypes used to measure visual performance. Using the variable contrast sine-wave gratings, available with the MCT 8000, may improve test sensitivity. However, we chose not to use sine-wave gratings due to their inherent problems, which include: less familiar to patients and most physicians; difficult to convert test results to the more familiar Snellen acuity notation; increased test duration (25); more variability than letter optotypes under same luminous conditions; overprediction of glare disability when compared with letter optotypes (31); and specialized technical training required for examining personnel. Additionally, the sine-wave gratings are positioned in different orientations, and small refractive errors can result in a preferred orientation of resolution for one of these gratings (4,33). Since a refraction is not routinely performed during an airman medical certification examination, uncorrected refractive conditions would contaminate sine-wave grating test results, while letters are less affected by uncorrected refractive error (2). The MCT 8000 offers multiple glare sources (central, peripheral, point, diffuse) and various visual targets (Snellen letters, sinusoidal gratings). It may provide valuable clinical diagnostic information to secondary and tertiary eye care practitioners. However, prohibitive cost and relative insensitivity (34) limit its value for glare test screening, and as a simulated distant vision test, the MCT 8000 could be biased by proximal accommodation (4).

Our results, and those of other studies, indicate the MNGT lacks sensitivity to measure glare acuity in subjects with normal ocular health (31,35,36). The lack of sensitivity of the instrument may be due to the use of a single large acuity target (20/400), resulting in the best calculated visual acuity measurement equivalent to 20/33, and a relatively weak and unalterable diffuse glare source. Translation to visual acuity measurements requires a graphical analysis, which may be a source of errors. Also, the test is performed at a near vision distance where differences in subjects' accommodation may influence results. The MNGT may be better suited for monitoring eye diseases that result in substantial glare sensitivity. These patients are more often found in secondary or tertiary eye care clinical practices.

The de Boer subjective rating of the different glare test light sources demonstrated a weak correlation with the observed changes in high contrast acuity scores. Rating of the most (BAT-H) and least (MNGT) disturbing glare source corresponded to the largest and smallest relative change in visual performance, which is similar to findings by Olson and Sivak (37). However, the large variation in de Boer ratings for any particular glare source between our subjects, suggests its use to estimate change of any individual visual performance would be inappropriate. Reduction of this variability may be achieved through careful stratification of a larger subject population with repeated trials. Our results suggest that the de Boer Glare Rating system may be a better indicator of subjective discomfort, rather than disability glare.

Our test results revealed several clinical concerns of glare test technology and methodology as it currently exists. These include:

1) There is a lack of standards for commercially available glare testers that results in difficulty when directly comparing test data from one instrument to another. For example, the instruments evaluated in our study had different types (point, diffuse) and intensities of glare sources, methods to distribute light to the eye, performance measurement units (Snellen letters, sine wave gratings, Landolt C) and contrasts of target optotype, and geometrical and mechanical properties.

2) High-contrast targets, such as standard Snellen acuity charts, are less sensitive to the effects of glare.

3) Traditional Snellen acuity measurements are inaccurate, since measured acuity is normally by line of optotype identified, even when some optotypes are missed on that line. Glare acuity changes may be very subtle and require accurate measurements of both non-glare and glare acuity. If a glare test is incorporated into the airman evaluation process, the Bailey-Lovie or similar chart is recommended for measuring acuity, since it provides values for each letter identified.

4) Low-contrast targets are more sensitive to the effects of glare. However, low-contrast targets increase the variability of responses, even without glare. Low-contrast testing may require careful refractive corrections to minimize this variance.

5) Increased glare sensitivity has been reported for lighter pigmented individuals (4). Snellen acuity scores for the different glare tests by eye color are presented in Table 5. Poorer average glare acuity scores and greater variability among blue-eyed subjects, compared to those of medium- and dark-eyed subjects, were found. Repeated testing of a large population of normal subjects, carefully stratified by eye color and age, would be required to determine if these differences are significant and a function of eye pigmentation. Until standards are established, the results of glare tests may under or over report vision performance changes, dependent on the subject's eye pigmentation and the type of glare test used.

6) Small improvements in glare acuity, resulting from the pinhole effect, may mask glare sensitivity, even when testing is performed with proper corrective lenses. Fortunately, the pinhole effect is relatively small when subjects use corrective lenses. With uncorrected refractive errors, which may be common for airman applicants, the pinhole effect induced by glare sources may be much larger.

TABLE 5: SNELLEN ACUITY SCORES FOR THE DIFFERENT GLARE TESTS EVALUATED BY EYE COLOR

SUB #	COLOR	EYE	BASE TEST		PENLIGHT HIGH-CONTRAST		PENLIGHT LOW-CONTRAST		BAT HIGH-CONTRAST				BAT LOW-CONTRAST				MCT 8000		MNGT	
			HC	LC	NG	G	NG	G	NG	LOW	MED	HI	NG	LOW	MED	HI	NG	G	NG	G
8	BR	OD	13.80	18.20	16.60	14.45	19.05	15.85	13.18	13.18	13.18	16.60	19.05	17.38	17.38	21.88	15.70	14.97	13.80	33.59
		OS	13.80	16.60	14.45	14.45	18.20	19.95	13.18	13.80	13.80	17.38	18.20	16.60	18.20	26.30	14.97	14.97	13.80	33.59
2	BR	OD	19.05	30.20	16.60	17.38	26.30	26.30	16.60	18.20	17.38	17.38	27.54	22.91	25.12	22.91	25.72	20.71	19.05	33.59
		OS	17.38	22.91	17.38	17.38	19.95	20.89	16.60	16.60	17.38	16.60	21.88	19.05	21.88	20.89	20.71	18.13	17.38	33.59
3	BR	OD	19.05	28.84	18.20	19.05	25.12	25.12	19.05	16.60	18.20	17.38	26.30	26.30	20.89	27.54	19.95	19.95	19.05	33.59
		OS	19.05	23.99	17.38	17.38	22.91	22.91	19.05	16.60	17.38	18.20	20.89	21.88	20.89	23.99	14.97	16.47	19.05	33.59
10	DB	OD	18.20	21.88	15.85	16.60	19.95	19.05	18.20	16.60	18.20	18.20	21.88	22.91	20.89	26.30	17.28	17.28	18.20	33.59
		OS	15.14	19.05	15.14	15.85	16.60	16.60	17.38	17.38	16.60	18.20	22.91	20.89	22.91	26.30	14.97	14.97	15.14	33.59
12	BR	OD	16.60	18.20	13.80	13.80	19.05	18.20	13.18	13.80	13.18	13.80	18.20	18.20	17.38	20.89	14.97	14.97	16.60	33.59
		OS	13.18	15.14	14.45	13.80	18.20	17.38	13.80	14.45	13.18	13.80	17.38	18.20	15.14	18.20	14.97	14.97	13.18	33.59
15	DB	OD	13.80	19.05	15.14	19.95	12.59	18.20	13.80	13.18	14.45	12.02	18.20	18.20	17.38	17.38	14.97	14.97	13.80	36.06
		OS	15.85	17.38	15.14	19.95	12.59	16.60	16.60	13.80	13.80	12.59	18.20	17.38	15.85	18.20	14.97	14.97	15.85	33.59
AVERAGE			16.09	20.50	15.79	16.53	18.76	19.50	15.73	15.25	15.43	15.85	20.65	19.80	19.28	22.30	16.74	16.33	16.09	33.79
STD DEV			2.29	4.76	1.38	2.25	4.23	3.43	2.33	1.80	2.12	2.30	3.36	2.97	3.05	3.57	3.43	2.12	2.29	0.71
MAXIMUM			19.05	30.20	18.20	19.95	26.30	26.30	19.05	18.20	18.20	18.20	27.54	26.30	25.12	27.54	25.72	20.71	19.05	36.06
MINIMUM			13.18	15.14	13.80	13.80	12.59	15.85	13.18	13.18	13.18	12.02	17.38	16.60	15.14	17.38	14.97	14.97	13.18	33.59
1	HZ	OD	14.45	21.88	13.18	13.18	18.20	19.05	15.85	15.14	15.14	15.14	18.20	19.95	19.05	21.88	23.70	22.16	14.45	33.59
		OS	15.14	19.05	13.18	13.18	17.38	18.20	13.80	14.45	14.45	14.45	14.45	18.20	17.38	17.38	16.47	17.93	15.14	33.59
7	HZ	OD	16.60	18.20	13.18	13.18	16.60	16.60	13.18	13.18	13.18	19.95	20.89	17.38	20.89	22.91	15.70	14.97	16.60	33.59
		OS	16.60	22.91	16.60	13.80	16.60	20.89	14.45	13.80	16.60	19.05	19.95	19.05	17.38	38.02	14.97	14.97	16.60	33.59
9	HZ	OD	18.20	20.89	16.60	18.20	21.88	23.99	18.20	15.85	18.20	17.38	20.89	18.20	21.88	20.89	14.97	14.97	18.20	33.59
		OS	17.38	23.99	18.20	15.14	21.88	18.20	17.38	16.60	18.20	17.38	21.88	19.05	21.88	27.54	14.97	14.97	17.38	33.59
11	GR	OD	16.60	26.30	17.38	17.38	21.88	22.91	18.20	16.60	17.38	17.38	23.99	22.91	21.88	31.62	15.70	16.47	16.60	33.59
		OS	16.60	23.99	17.38	15.14	22.91	20.89	15.85	16.60	16.60	19.95	28.84	20.89	23.99	22.91	14.97	14.97	16.60	33.59
AVERAGE			16.41	22.00	15.58	14.79	19.50	19.95	15.76	15.22	16.13	17.48	20.77	19.39	20.42	24.69	16.24	16.27	16.41	33.59
STD DEV			1.18	2.71	2.15	1.97	2.71	2.53	1.95	1.35	1.81	2.05	4.19	1.77	2.38	6.68	2.99	2.56	1.18	0.00
MAXIMUM			18.20	26.30	18.20	18.20	22.91	23.99	18.20	16.60	18.20	19.95	28.84	22.91	23.99	38.02	23.70	22.16	18.20	33.59
MINIMUM			14.45	18.20	13.18	13.18	16.60	16.60	13.18	13.18	13.18	14.45	14.45	17.38	17.38	17.38	14.97	14.97	14.45	33.59
4	BL	OD	19.05	33.11	19.95	20.89	20.89	19.95	19.95	19.05	20.89	26.30	30.20	26.30	26.30	52.48	16.47	15.70	19.05	36.06
		OS	20.89	38.02	26.30	27.54	36.31	30.20	20.89	19.95	20.89	18.20	34.67	26.30	26.30	33.11	17.28	17.28	20.89	36.06
5	BL	OD	18.20	20.89	15.85	16.60	23.99	20.89	15.85	17.38	17.38	19.95	25.12	20.89	26.30	22.91	24.95	24.95	18.20	33.59
		OS	20.89	28.84	19.95	17.38	27.54	30.20	16.60	19.95	19.95	18.20	27.54	27.54	25.12	34.67	18.13	18.13	20.89	33.59
6	BL	OD	14.45	19.05	15.14	15.85	17.38	18.20	14.45	17.38	15.85	19.95	17.38	17.38	25.12	43.65	14.97	14.97	14.45	33.59
		OS	15.14	25.12	15.85	17.38	17.38	17.38	17.38	15.85	17.38	20.89	20.89	22.91	22.91	69.18	19.92	14.97	15.14	33.59
13	BL	OD	19.05	28.84	16.60	16.60	20.89	20.89	15.14	18.20	23.99	13.18	18.20	20.89	22.91	27.54	17.74	20.48	19.05	33.59
		OS	17.38	20.89	16.60	15.85	18.20	21.88	15.85	22.91	19.05	17.38	20.89	21.88	20.89	31.62	15.70	15.70	17.38	33.59
14	BL	OD	14.45	22.91	16.60	17.38	16.60	16.60	15.14	13.18	13.80	13.18	18.20	19.05	17.38	16.60	14.97	14.97	14.45	33.59
		OS	15.14	18.20	14.45	17.38	19.05	21.88	14.45	13.80	14.45	14.45	21.88	18.20	20.89	20.89	14.97	14.97	15.14	33.59
16	BL	OD	17.38	21.88	16.60	15.85	20.89	19.05	16.60	13.18	14.45	13.80	21.88	19.05	16.60	23.99	14.97	14.97	17.38	33.59
		OS	15.14	22.91	16.60	14.45	17.38	17.38	15.85	16.60	15.14	17.38	19.95	20.89	19.95	26.30	15.70	15.70	15.14	33.59
AVERAGE			17.11	24.45	17.31	17.51	20.81	20.81	16.41	17.05	17.51	17.38	22.56	21.54	22.30	31.02	16.95	16.69	17.11	33.99
STD DEV			2.39	6.02	3.22	3.45	5.68	4.56	2.03	2.99	3.21	3.83	5.32	3.37	3.44	15.00	2.91	3.05	2.39	0.96
MAXIMUM			20.89	38.02	26.30	27.54	36.31	30.20	20.89	22.91	23.99	26.30	34.67	27.54	26.30	69.18	24.95	24.95	20.89	36.06
MINIMUM			14.45	18.20	14.45	14.45	16.60	16.60	14.45	13.18	13.80	13.18	17.38	17.38	16.60	16.60	14.97	14.97	14.45	33.59

7) In young adults with normal ocular health and appropriate corrective lenses, vision performance losses of greater than or equal to two lines of high-contrast optotypes with any of the glare tests studied would strongly suggest the need for a follow-up eye examination for glare sensitivity.

Should glare testing be incorporated into the aeromedical certification process, the following are recommended guidelines for glare screening:

Instrument Considerations:

1) Easy to operate, requiring a minimum amount of specialized training;
2) Stable intensity of the glare source (Note: A simple means of calibration would be advisable.);
3) Validity and repeatability of results;
4) Performance measurement targets familiar to the general medical community, easily interpreted or convertible to Snellen acuity scores;
5) Minimal office space requirements; and
6) Cost effective.

General Testing Considerations:

1) Reliable and predictable results for normal subjects based on known variables, such as age and eye color, with a minimum of false positives;
2) Test duration of approximately 60 seconds or less;
3) Relatively unaffected by subtle variations in ambient lighting;
4) Minimal variability for those subjects with similar ophthalmologic and physiologic characteristics;
5) Test results pertinent to the aviation environment; and
6) A testing range for complete documentation of mild to severe glare sensitivity (e.g., flexibility to vary target contrast).

In summary, the purpose of this study was to identify an appropriate glare test for the Aviation Medical Examiner in the aeromedical certification examination of pilot applicants. Clinical factors of the instrument and the stability and sensitivity of test results on subjects with normal ocular health status were used as the basis for the selection. The BAT instrument was selected as having the most salient clinical features and test sensitivity for use in clinical screening of civil airman applicants. Vision performance loss of greater than or equal to two lines of high-contrast optotypes with the BAT would suggest the need for a follow-up examination with an eye care specialist. These data may be used in evaluating future glare testers. Guidelines are provided for incorporating glare testing into the aeromedical certification process.

Subsequent research is recommended and being planned to identify specific glare-related problems in the aviation environment, including: distinguishing factors in the cockpit that may add to glare sensitivity; eliminating or minimizing the adverse effects of glare; and identifying individual airmen at increased risk. Clinical glare test measurements will be compared to test results obtained in simulated aviation environments to identify possible correlations. This research should aid in establishing appropriate medical standards and test procedures for determining glare sensitivity in civil airmen.

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