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U.S. Army Sunglasses: Issues and Solutions (Reprint)

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Some military aviators have reported difficulty discriminating the color of cockpit warning lights when wearing plastic sunglasses. This difficulty could be due to lenses that are too dark or are nonneutral and thus alter color vision. A study was performed to identify the origin of this problem, recommend solutions, and determine a sunglass transmittance that optimizes visual performance. Five pairs of plastic sunglasses (-4 to +4 D) were ordered from each of seven military optical laboratories (70 lenses total). Each laboratory was instructed to dye the lenses neutral gray with 21 percent transmittance. Light transmittance and color distortion were evaluated across laboratory and lens power. Spatial and color vision were assessed through a range of sunglass transmittances. There was no systematic effect of lens power, but light transmittance and color distortion varied widely across laboratories (transmittance = 1 to 30 percent; $p<0.001$). Because light transmittance and color distortion were related inversely, it was believed that both factors could be corrected by accurate verification of transmittance, but commercial transmittance meters proved to be inaccurate. The high transmittance of deep red and infrared light through plastic lens dyes is read as visible light by

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transmittance meters, making readings too high. A filter was identified that provides accurate readings when used with transmittance meters. A sunglass transmittance of 23 percent resulted in minimal decrease in visual performance relative to normal clinical test conditions.

U.S. Army sunglasses: issues and solutions

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ABSTRACT

BACKGROUND

Some military aviators have reported difficulty discriminating the color of cockpit warning lights when wearing plastic sunglasses. This difficulty could be due to lenses that are too dark or are nonneutral and thus alter color vision. A study was performed to identify the origin of this problem, recommend solutions, and determine a sunglass transmittance that optimizes visual performance.

METHODS

Five pairs of plastic sunglasses (-4 to +4 D) were ordered from each of seven military optical laboratories (70 lenses total). Each laboratory was instructed to dye the lenses neutral gray with 21 percent transmittance. Light transmittance and color distortion were evaluated across laboratory and lens power. Spatial and color vision were assessed through a range of sunglass transmittances.

RESULTS

There was no systematic effect of lens power, but light transmittance and color distortion varied widely across laboratories (transmittance = 1 to 30 percent; $p<0.001$).

CONCLUSIONS

Because light transmittance and color distortion were related inversely, it was believed that both factors could be corrected by accurate verification of transmittance, but commercial transmittance meters proved to be inaccurate. The high transmittance of deep red and infrared light through plastic lens dyes is read as visible light by transmittance meters, making readings too high. A filter was identified that provides accurate readings when used with transmittance meters. A sunglass transmittance of 23 percent resulted in minimal decrease in visual performance relative to normal clinical test conditions.

KEY WORDS

sunglasses, tinted lenses, lens meters, verification, transmittance

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In the past, military spectacles were fabricated from glass, but now most are made from (CR-39) plastic lenses. Plastic weighs significantly less than glass, making spectacles lighter and more comfortable. The lower weight of plastic is more compatible with transport to and optical fabrication in field environments. Plastic also provides more consistent impact resistance than glass.[1] While glass lenses are supplied to optical laboratories in clear or tinted form, plastic lenses arrive as clear lens blanks. Each laboratory must chemically dye the lenses to produce sunglasses.

It is well established that tinted (sunglass) lenses are useful for reducing harmful radiation,[2,3] adverse effects on night vision,[4,5] and glare and related visual symptoms in bright environments.[6,7] Sunglasses are important in aviation environments where scene luminance may be increased at higher altitudes, and critical decisions must be made in very brief time periods. Military aviators are issued sunglasses to be used as needed for daytime flight. The luminous transmittance of these sunglasses is specified to be 15 percent, and neutral across the visible spectrum. Recent reports from operational environments, however, indicate that some aviators are experiencing difficulty discriminating the color of warning lights on instrument displays while wearing plastic sunglasses. This difficulty could be due to lenses that are too dark, or nonneutral in transmittance and thus distort color vision.

The purpose of this study was to evaluate the spectrophotometric transmittance of plastic lenses tinted at U.S. Army optical fabrication laboratories. Light and color transmittance of sunglasses from various laboratories were evaluated across a range of lens powers. Commercially available sunglass transmittance meters were tested to evaluate their accuracy. Recommendations were provided to enhance the precision and reliability of tinting and verification procedures. Psychophysical measures of spatial and color vision were conducted through a range of sunglass transmittances to determine the transmittance level that optimizes visual performance relative to clinical test conditions.

Method

Physical measurements

Five pairs of plastic sunglasses (-4 D to +4 D in 2 D steps) were ordered from each of seven military optical laboratories (70 lenses total). Each laboratory was instructed to dye the lenses neutral grey with 21 percent light transmittance, the most commonly used transmittance level for military personnel. Laboratory personnel were informed that a problem existed with plastic sunglasses but were encouraged to use their normal procedure of tinting lenses. They also were asked to complete a questionnaire describing their technique of dyeing and verification. They were assured that all information about specific laboratories and personnel would remain confidential.

The percent luminous transmittance of each sunglass lens was measured using several techniques. In the initial approach, the luminance of a tungsten light source driven by a regulated power supply (color temperature 2850°K, 140 cd/m^2) was measured with a Pritchard Model 1980 photometer (Kolmorgen Corp., Burbank, CA) with and without the sunglass lens in the optical path. Percent transmittance was determined by taking the ratio (luminance through sunglass lens/luminance of source) multiplied by 100. These values later were confirmed with a Humphrey Instruments Model 360 Lens Analyzer with Spexan™ spectroradiometer (Humphrey Instruments, Inc., San Leandro, CA). Additional measures of light transmittance, described in subsequent sections, were obtained from commercially available lens transmittance meters.

Spectral transmittance of each lens was measured from 200 to 900 nm in 2 nm increments with a Gilford Response™ spectroradiometer (Corning Laboratory Sciences Co., Oberlin, OH). The Judd Daylight Duplication Method, as described in Military Specification 43511C,[8] was used to compute percent deviation from spectral neutrality. This technique involves taking the average transmittance for each 60 nm band (from 430 nm to 730 nm), and determining the percent deviation of each band from the transmittance at 520 to 580 nm. These values then are multiplied by luminosity weighting factors, and mean spectral transmittance deviation across all bands is computed. This computation provides a quantitative measure of the deviation from color neutrality using illuminant C as the standard.

Psychophysical measurements

Spatial and color vision were measured through a range of sunglass transmittances to determine the level that produces minimal degradation of visual performance relative to normal clinical findings. Spatial vision tests included high contrast visual acuity (VA) and small letter contrast sensitivity (SLCS) to evaluate high spatial frequency processing, and large letter contrast sensitivity (Pelli-Robson test) to assess processing of low to moderate spatial frequencies. Color vision was evaluated with the pseudo-isochromatic plates (PIP; Richmond Products, Boca Raton, FL), Farnsworth lantern test (Macbeth Corporation, Newburgh, NY), and Lanthony desaturated D-15 test (Lunea Ophthalmologie, Chartes, France).

VA and SLCS were measured with computer-generated letter charts displayed on a video monitor at a distance of 4.8 m in an otherwise dark room.[9] The VA chart, patterned after the Bailey-Lovie charts,[10] consisted of seven rows of black, high contrast (93 percent) letters on a white background (116 cd/m^2; five letters per row) with letters becoming smaller, by row, in 0.1 log steps (6/15.1 to 6/3.8; 0.4 to -0.2 logMAR). The SLCS chart consisted of letters of constant, small size (6/7.5 or 20/25), but contrast decreased, by row, in 0.1 log unit steps (from 93 percent to 5 percent). Three versions of VA and SLCS charts were generated so that letter sequence could be varied from trial to trial by software control to discourage learning effects. The Pelli-Robson chart,[11] which consists of larger letters with three letters per 0.15 log CS step, was administered at the recommended viewing distance of 1 m with a chart luminance of 85 cd/m^2. Two different versions printed on each side made it possible to vary letter sequence from trial to trial. For all letter chart testing, credit was given for each letter read correctly (0.02 log units per letter for VA and SLCS; 0.05 log units per letter for Pelli-Robson). As recommended by the manufacturer, the Farnsworth lantern test was administered at a distance of 8 feet (2.44 m) under normal room illumination. The PIP and desaturated D-15 were

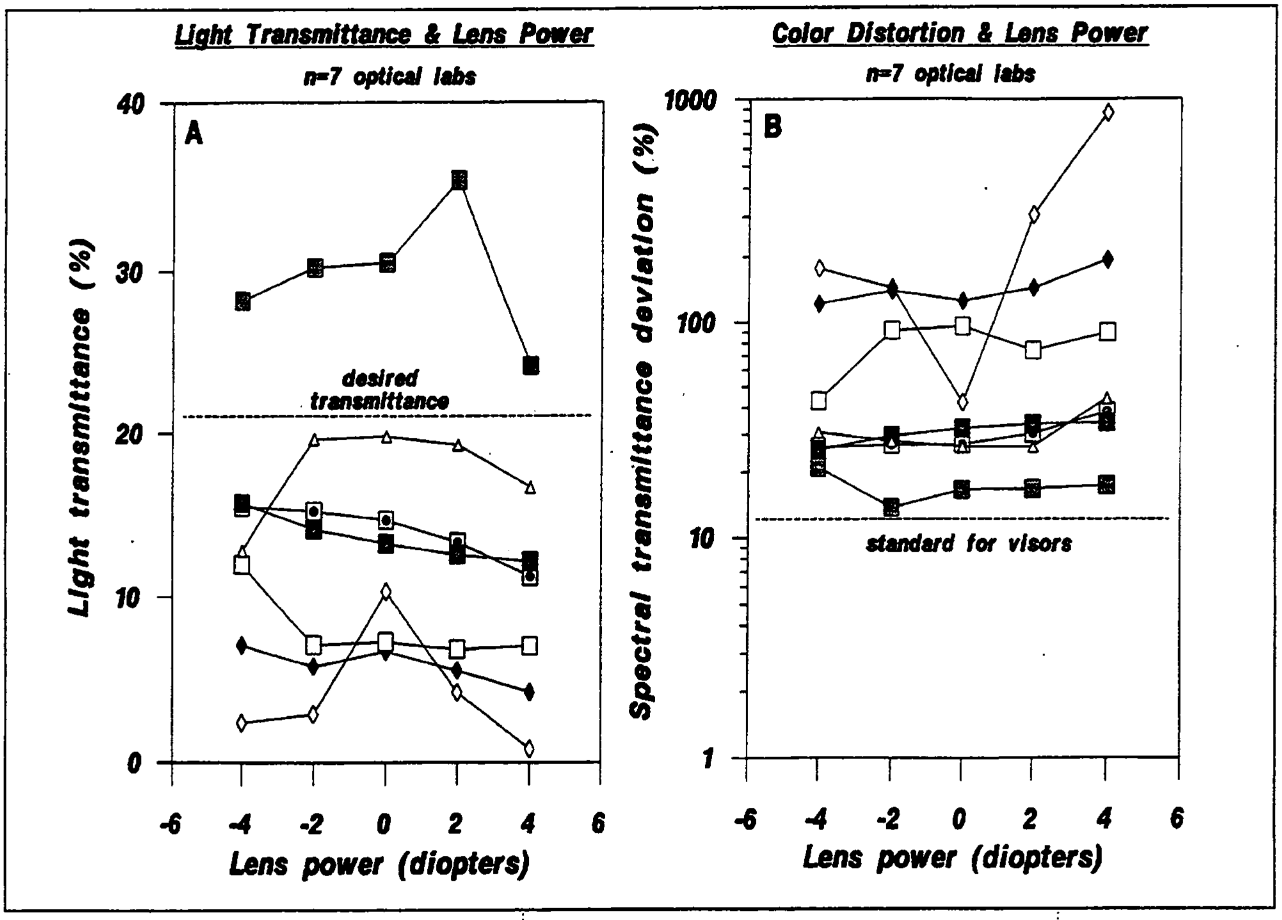

Figure 1

Percent (%) light transmittance (1A) and spectral transmittance deviation (1B) are plotted against lens power (diopters) separately for each of seven optical fabrication laboratories. Each data point is the mean of right and left lenses from each pair of sunglasses. The desired light transmittance (21 percent) and standard for aviation grey visors (12 percent) are indicated.

illuminated by a MacBeth Easel lamp and given at near (55 cm).

All measurements were performed monocularly on the subject's right eye. Sunglass lenses with transmittances ranging from 1 percent to 95 percent in approximately 1.6x steps were selected from those obtained from the laboratories. Each lens was fitted in the right eye of a plastic military frame while the left eye was occluded. This procedure allowed subjects to wear the sunglass lenses comfortably during testing, with a Halberg clip on the right side to hold lenses that corrected refractive error. The battery of spatial and color tests were repeated with each sunglass transmittance and administered in order of ascending transmittance (from darkest to lightest) to reduce the time required for light adaptation and minimize learning effects.

Seven subjects (age 18 to 34 years) with vision corrected to at least 20/20 and normal ocular health were tested. Informed consent was obtained from all subjects after protocol approval by the institutional review committee.

Results

Physical measurements

Fig. 1A shows percent luminous (light) transmittance plotted against lens power for each of the seven optical laboratories. Two-way analysis of variance (ANOVA) across laboratory and lens power revealed no systematic effect of lens power ($F_{4,24}=2.34$, $p>0.08$), but light transmittance varied widely across laboratories (from 1 to 30 percent), and this effect was highly significant ($F_{6,24}=63.07$, $p<0.001$). Surprisingly, none of the labs achieved the desired value of 21 percent transmittance.

Similar effects were observed for color neutrality. Fig. 1B shows percent deviation from color neutrality (spectral transmittance deviation) plotted against lens power for each of the seven laboratories. High values of spectral transmittance deviation indicate a lack of color neutrality. Two-way ANOVA revealed no significant effect of lens power ($F_{4,24}=1.35$, $p>0.28$), but

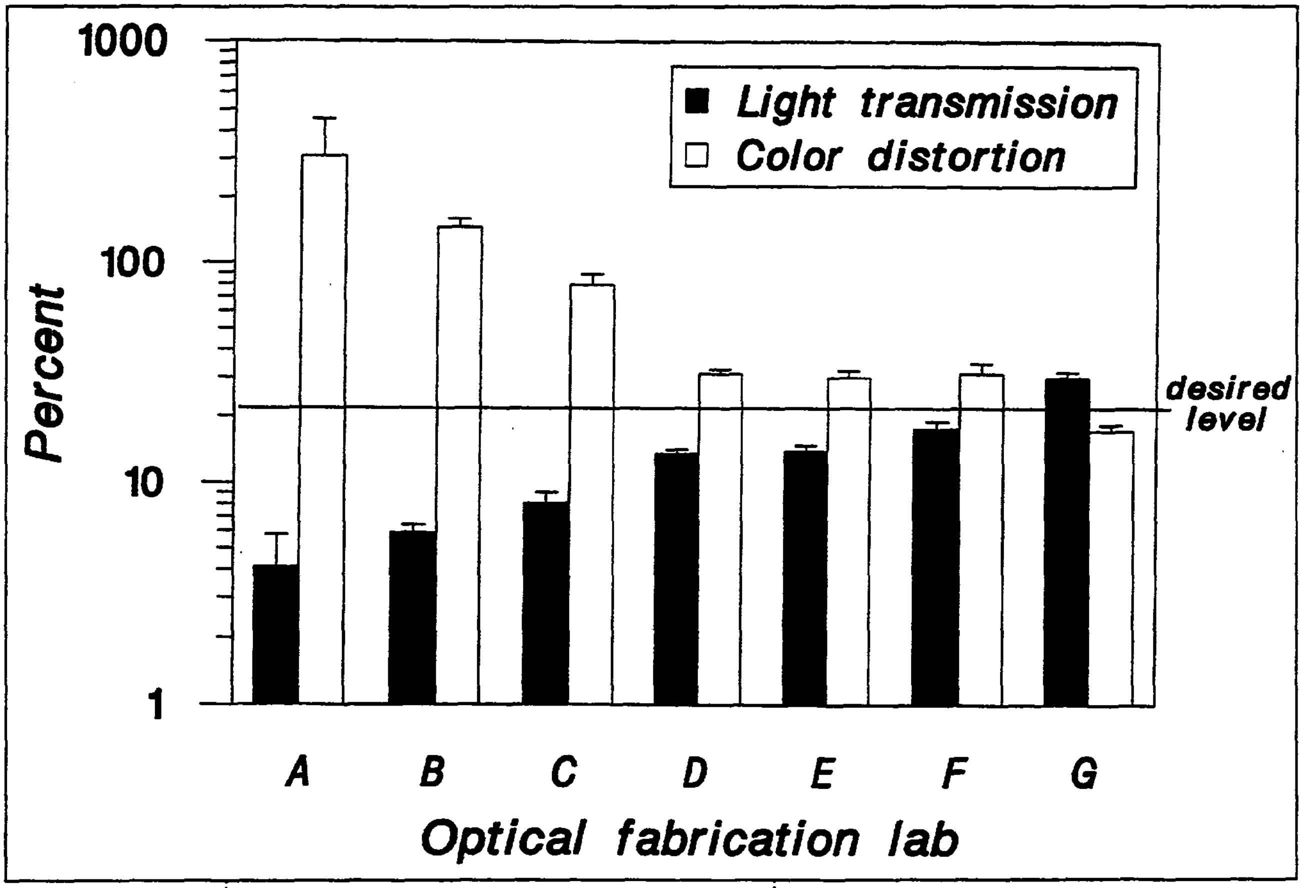

Figure 2

Percent light transmittance and color distortion (spectral transmittance deviation) are plotted for each of seven optical laboratories. Each value represents the mean (±1 SE) of five pairs of sunglasses (-4,-2, plano,+2,+4 diopters) from each lab.

spectral neutrality varied significantly across laboratories ($F_{6,24}$=3.75, $p<0.01$). None of the laboratories achieved the spectral neutrality standard established for gray aviation visors.

Since effects of lens power on light and color transmittance either were small or inconsistent, the data were evaluated across laboratories regardless of power. Figure 2 shows mean (±1 SE) light transmittance and spectral transmittance deviation plotted for each laboratory. Note the inverse relation between light transmittance and color distortion, such that high levels of color distortion occur with low levels of light transmittance. There was, however, no systematic relation between the type of color distortion, as measured by CIE chromaticity, and the percentage light transmittance.

Since light transmittance and color distortion were related inversely, it was believed that both problems could be corrected by accurate verification of transmittance. All optical laboratories were advised to obtain an electronic transmittance meter (available commercially) to ensure that all sunglass lenses have the desired transmittance. However, commercial meters were found to be inaccurate with plastic sunglasses—the meters read too high. This inaccuracy is due to plastic sunglass dyes that transmit a disproportionate amount of deep red and infrared light (Fig. 3). The meters apparently read this radiation as visible light, making readings artificially high. Figure 4 shows transmittance meter readings from several commercially available meters plotted against the laboratory measurement of sunglass transmittance (n=66 lenses). Most data fall above the 1/1 lines, indicating that the meters read too high. The linear equation at the top of each graph shows the relation between meter readings and actual transmittance. While the slope of each equation is approximately unity, the intercept (or constant error) indicates the extent to which each meter reads high (from 2 to 10 percent).

If the high readings are due to meters registering the disproportionate transmittance of long wavelength light through plastic sunglasses, then blocking the long wavelength por-

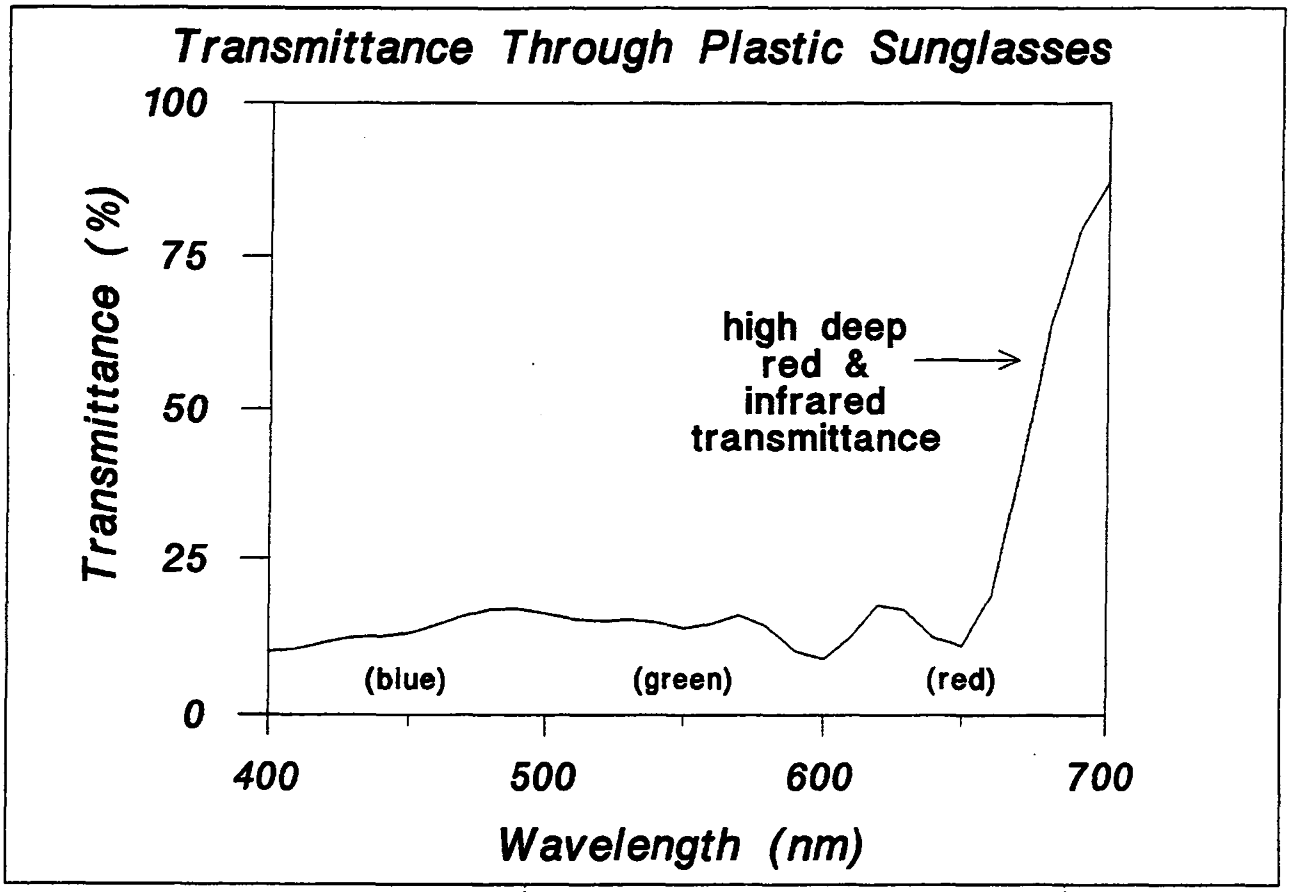

Figure 3

Typical percent (%) light transmittance of plastic sunglasses dyed neutral grey is plotted against wavelength in nanometers (nm). There is a disproportionate transmittance of deep red and near infrared light. Regions of the spectrum corresponding approximately to blue, green, and red are shown.

tion of the spectrum should yield accurate readings. Two meters were reevaluated with a filter which blocks deep red light (Optical Coatings Laboratories, Inc., Santa Rosa, CA, cyan dichroic; <1 percent transmittance above 640 nm). Figure 5 shows sunglass transmittance readings taken with this filter placed in the optical path of each meter. There is much better agreement between meter readings and actual values with the correction filter in place (reading error <1 percent). However, prior to measurement the meters must be recalibrated with the filter in place so that the filtered light represents 100 percent transmittance. This step is readily accomplished since most meters can be calibrated electronically to 100 percent by depressing a button.

Psychophysical measurements

Spatial and color vision were assessed through a range of sunglass transmittances to determine a transmittance level that optimizes visual performance relative to normal findings. Since various measures were obtained, each with separate unrelated units, the data was transformed to standard scores so that its impact on performance could be evaluated using a common criterion. The difference between each score and the mean score under optimal conditions (clear lens) was divided by the standard deviation of the mean. This expresses all scores as standard deviations from best performance and allows for a more direct comparison of results from different tests. Figure 6 shows mean results on each test, expressed as standard deviations from best performance, and plotted against sunglass transmittance. On all tests, performance decreased with decreasing sunglass transmittance, but the decline was most rapid for small letter contrast sensitivity and the desaturated D-15 test. Assuming that performance with sunglasses on standard clinical tests should be within normal limits, the sunglass transmittance was identified at which performance was one standard deviation from best performance on all tests. This criterion was met with a sunglass transmittance of 23 percent. Lower transmittances (darker lenses) may be more suitable for very bright environments such as snowy terrain.[6,7,13]

Discussion

This study demonstrates a wide variation in sunglass transmittance levels across optical laboratories. This was found despite attempts to dye lenses to specific transmittance levels, as determined by subjective comparison to standard sunglass lenses. Even when commercially available meters were used to verify light transmittance, significant errors occurred due to inaccuracies in these meters. To exemplify this issue, one aviator complained that his sunglasses were too dark to wear in flight. With a commercial meter, his sunglass transmittance was 15 percent—the exact value specified for military aviators. However, a careful assessment in a laboratory indicated that the actual visible light transmittance was 6 percent—too dark for flight under most conditions. The variability among laboratories and inaccuracies in transmittance meters have broad importance because equipment and methods for tinting and verification are comparable in military and civilian settings.

Factors that may affect the density and coloration of sunglasses include the type or manufacturer of the dye, temperature and/or duration of dyeing, the number of days the dye is reused prior to replenishment, and the shelf age of the dye. A review of dyeing techniques, equipment, and verification procedures used

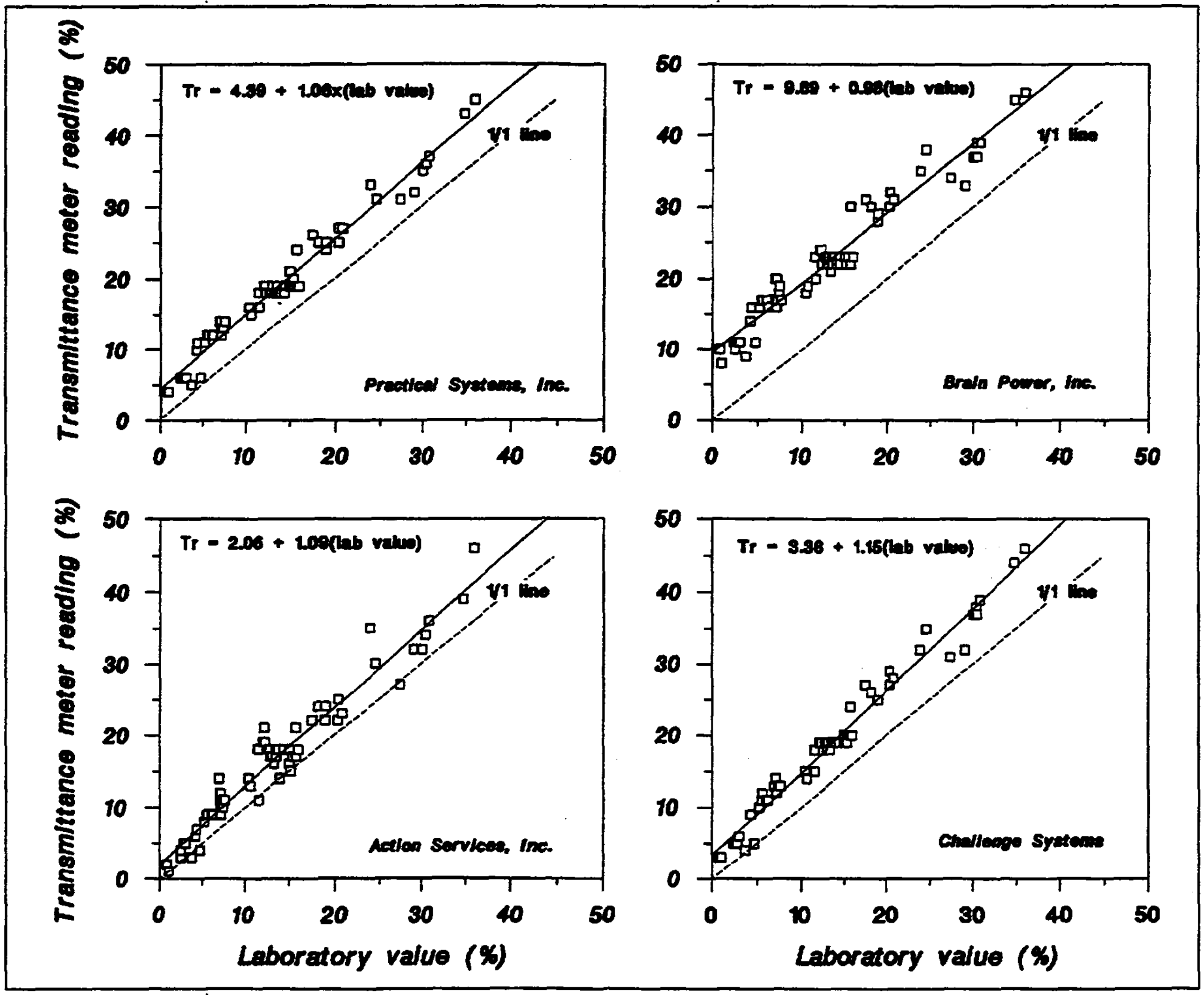

Figure 4

Percent (%) light transmittance through plastic sunglass lenses (n=66), measured with four commercially available meters, is plotted against laboratory measures of transmittance. Each linear equation expresses meter readings (Tr) as a function of laboratory values. Most data fall above the 1/1 lines, indicating that the meters read too high as compared to laboratory measures. While the slope of each equation approximates unity, the intercept provides an estimate of how much higher each meter reads than laboratory values (2 to 10 percent higher).

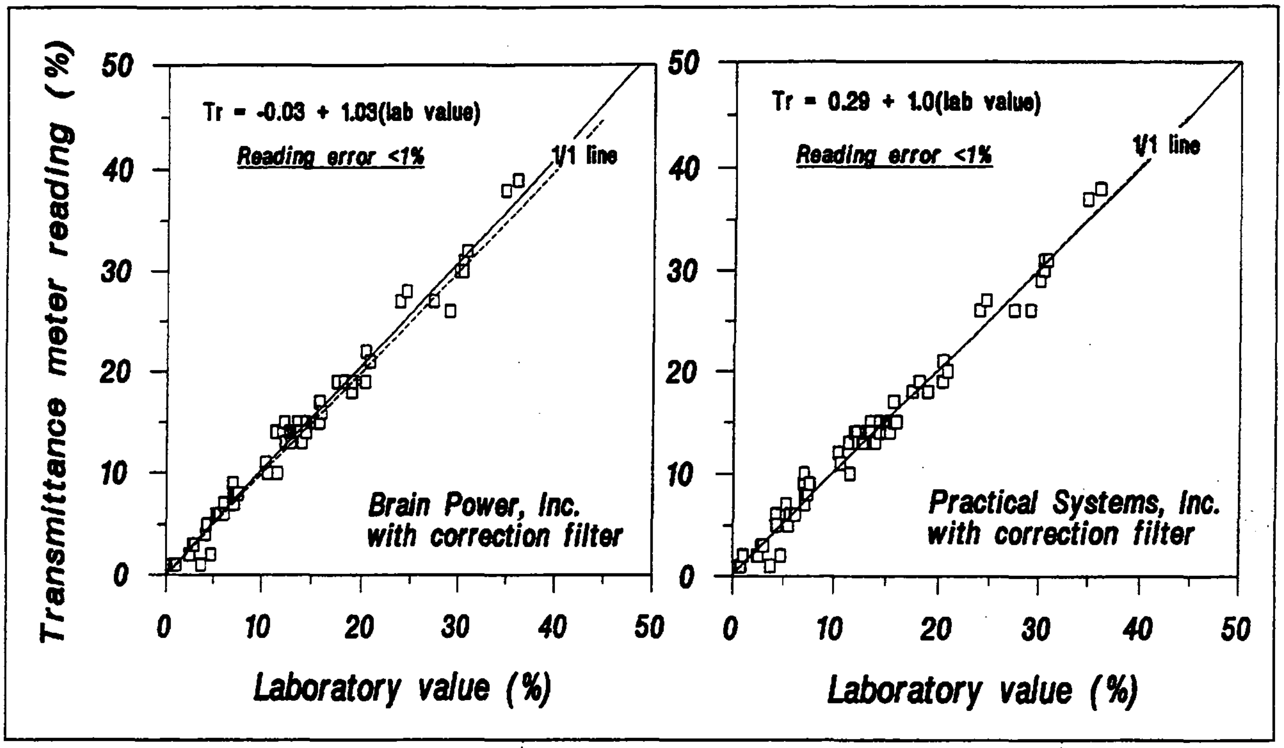

Figure 5

Transmittance meter readings are plotted against laboratory measures of light transmittance through plastic sunglass lenses (n=66). Measures were taken through a correction filter (OCLI cyan dichroic) in the optical path of each meter to attenuate long wavelength visible and near infrared light. There is good agreement between meter readings and laboratory values (reading error <1 percent).

by the laboratories in this study revealed no consistent basis for the wide range of transmittance levels. There was a tendency, however, for lenses to be darker with higher dyeing temperatures (>210 degrees) and reuse of the same dye for more than 4 days. In addition, darker lenses came from laboratories that were not using lens preparatory solution prior to dyeing. This solution facilitates the dyeing process by ionizing the dye and matrix of lens with opposite charge. Some of the darker lenses obtained had a bluish cast, which probably was due to infrequent replenishment of dye.

Perhaps the most troublesome finding of this study was the inaccuracy of commercially available transmittance meters. These meters typically use broad-band light sources and silicon-based photodetectors, which have increased sensitivity for longer wavelengths.[12] Plastic sunglasses transmit a disproportionate amount of long wavelength light (Fig. 4), which is read as visible light by the meters, making readings too high. This deficiency was corrected by placing a selective (low-pass) filter in the optical path of the transmittance meters to attenuate long wavelength light. Other strategies, such as using a light source, filter(s), or both that better match the photopic luminosity function, also may prove useful. While the disproportionate transmittance of long wavelength light through plastic sunglasses does not significantly affect lens color or performance, the dilemma of accurate verification could be solved by developing dyes that transmit uniformly across the spectrum. Apparently this is not an easy task, because a recently developed dye advertised for potential use by military aviators still manifests disproportionate transmittance at longer wavelengths and erroneously high readings on transmittance meters.

The US Army is implementing several measures to correct deficiencies in plastic sunglasses. Standardized procedures for tinting lenses with scheduled replacement of dye has been implemented. Optical labs are procuring electronic transmittance meters, and the U.S. Army Aeromedical Research Laboratory (USAARL) is providing correction filters and guidance to ensure that the meters read accurately. Optometry services are conducting visual inspections to ensure that fielded sunglasses are within standards. USAARL is developing a portable sunglass transmittance meter for use in military and civilian environments.

A plastic sunglass transmittance of 23 percent resulted in minimal decrease in visual performance relative to standard clinical measures. The criterion used was that spatial and color vision should be within one standard deviation of mean

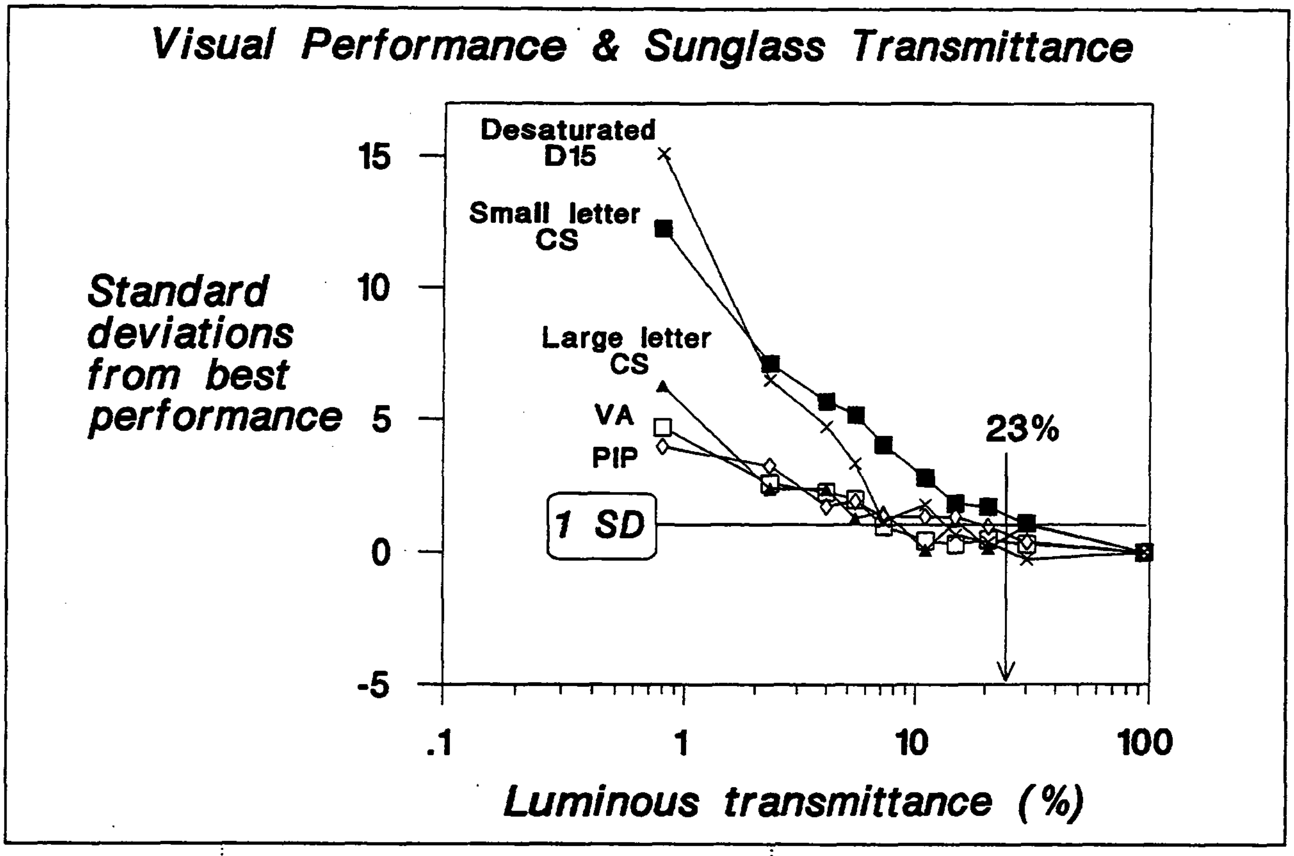

Figure 6

Visual performance, expressed as standard deviations from mean performance at the highest transmittance level (95 percent), is plotted against sunglass transmittance for spatial and color vision tests, as labeled. A sunglass transmittance of 23 percent satisfies the criterion that performance on all tests should be no less than one standard deviation (SD) from the mean.

performance under normal test conditions. Transmittances less than 23 percent produced greater deviation from normal performance (Fig. 6). This unifying approach, in which all scores are standardized relative to the variability of normal performance, facilitates comparison between the results of different tests, and allows for a common criterion to be implemented. Moreover, qualification for aviation and related fields is based on clinical findings obtained under comparable light levels and test conditions. It is possible, however, that lower transmittances (darker sunglasses) may be more suitable in bright environments, such as snowy terrain or in direct skylight at high altitudes.[6,7,13]

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Footnote

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The views, opinions and/or findings contained in this manuscript are those of the author and should not be construed as an official Department of the Army position, policy or decision unless so designated by documentation. In the conduct of research where humans are the subjects, the investigator adhered to the policies regarding the protection of human subjects as prescribed by 45 CFR 46 and 32 CFR 219 (Protection of Human Subjects).

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