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Effects of Laser Eye Protection and Aircraft Windscreens on Visual Acuity through Night Vision Goggles

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ABSTRACT

The combined use of hand-held laser pointers and night vision goggles (NVGs) is prevalent in nighttime tactical flight operations. Laser eye protection (LEP) is required during these missions to protect the eye from exposure to laser energy. The effects of the fielded FV-9 LEP visor and two prototype Wardove LEP spectacles on NVG-aided visual acuity (VA) were assessed. VA measurements were made through four types of aircraft transparencies using two different NVGs (4949C and 4949P) to determine if there were any interactions between the LEP, windscreens, and NVGs in their effects on VA. The results showed a correlation between the percent loss of NVG light due to the aircraft windscreens and the percent degradation in NVG VA (r=0.88). Also, the results revealed a small (8.5%), but statistically significant, degradation in NVG-aided VA with the FV-9 LEP for both NVG models. Neither Wardove spectacle had a statistically significant effect on NVG-aided VA compared to the no-LEP condition.

INTRODUCTION AND BACKGROUND

One of the primary performance characteristics associated with the use of NVGs is the level of visual acuity obtained when viewing through the NVGs. It has been shown that the VA obtained when viewing through NVGs depends on the light level of the scene being viewed (Pinkus and Task, 1998b). Previous studies have demonstrated NVG VA loss due to aircraft windscreens (Pinkus and Task, 1997) and due to LEPs (Riegler & Fiedler, 1998). The primary objective of this effort was to determine the amount of NVG VA loss that could be expected due to viewing through currently fielded aircraft windscreens and currently fielded LEPs and prototype LEPs under consideration for fielding.

METHOD

Participants.

Six NVG-experienced pilots, ranging in age from 32 to 46 years, participated in the evaluation. All participants had at least 20/20 unaided VA and demonstrated at least 20/35 NVG-aided VA at full moon equivalent illumination after NVG adjustment and focus.

Apparatus and Stimuli.

The evaluation was conducted at the Air National Guard Air Force Reserve Test Center (AATC) and Davis Monthan AFB, Tucson AZ using three F-16C and one A-10 aircraft on four consecutive nights. The aircraft were positioned in a suitably darkened hangar throughout the duration of each test. Each aircraft was equipped with a different canopy type. Two F-16 aircraft canopies had indium-tin oxide (ITO) coatings (Sierracin Type II and Texstar Type V). The third F-16 aircraft was equipped with a Texstar II gold-coat canopy.

The A-10 aircraft tested had uncoated acrylic "quarter panels" through which the observers viewed the visual acuity charts. The NVG-weighted transmission coefficient and haze was assessed for each canopy prior to NVG-aided VA data collection. Although the haze measurement technique was experimental, the transmission measurement was made using ASTM Standard Test Method F1863-98 for Measuring the Night Vision Goggle-Weighted Transmissivity of Transparent Parts. The device based on this test method that used to make these measurements is shown in Figure 1.

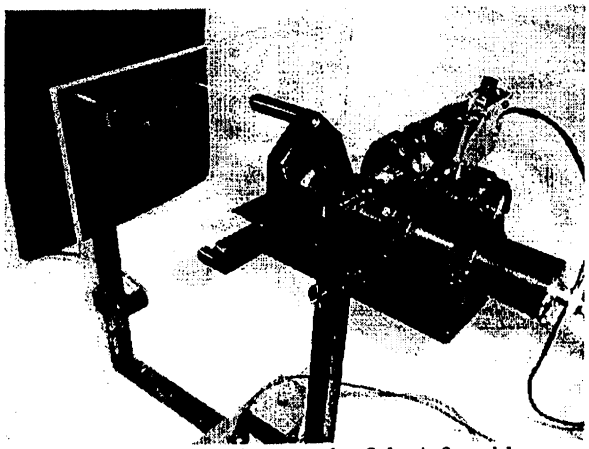

Figure 1. A close-up photograph of the infrared haze and transmission (IRH&T) measurement device used to measure the infrared (NVG spectrum) transmission coefficient of the aircraft windscreens used in this study.

The LEP devices tested consisted of one FV-9 (absorptive dye) and two WARDOVE (WD1 & WD2 reflective) spectacles (see Figure 2). Each LEP filter tested was mounted in a standard USAF aircrew spectacle frame. NVG luminous transmission was measured at 46% for the FV-9 filter, and 75% for the WD1 and WD2 filters.

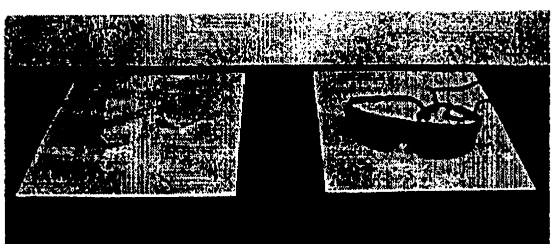

Figure 2. Wardove (left) and FV-9 (right) LEP Spectacles

NVG-aided VA was assessed using two NVG resolution charts composed of circular patches of square-wave gratings. Each chart contained six rows of six patterns (see Figure 3). All patterns on a given row were of the same spatial frequency. Successive rows increased in spatial frequency at relative intervals of approximately 12%. Spatial resolution values on chart "A" ranged (in Snellen notation) from 20/25 to 20/45, and chart "B" patterns ranged from 20/51 to 20/90. The modulation contrast of the patterns (as measured from the intensified NVG image of the pattern) was approximately 38%.

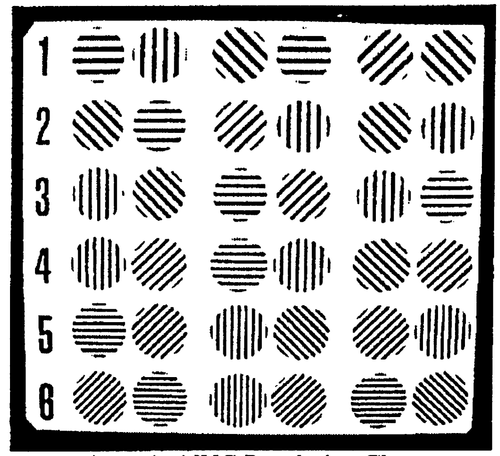

Figure 3. NVG Resolution Chart

Each pattern measured 4 inches in diameter and was positioned so that the bars were oriented either horizontal, vertical, 45° left, or 45° right. During data collection, the chart was mounted at eye-level on an aircraft maintenance stand, positioned 20 feet at a 45° viewing angle from the aircraft "straight-ahead" direction.

The NVG resolution chart was illuminated by a Hoffman LM-33-80 Night Sky Projector. The evaluation was conducted at clear starlight equivalent illumination (1.7 x 10^{-10} NR_B) Night Vision Imaging System (NVIS) radiance value as defined in ASC/ENFC 96-01, Lighting, Aircraft, Interior, NVIS Compatible. NVIS radiance was measured from the white portion of the resolution chart using a Photo Research 1530-AR spot photometer with a Class B filter, and verified with a Hoffman NVG-103 Inspection Scope.

Two models of the F4949 NVG (F4949C and F4949P) were used in this evaluation. These models are representative of current NVGs used by pilots employing laser pointers. The F4949P is a more recent model than the F4949C and has the same specification as the Omnibus IV F4949H and G models. Compared to the F4949C, the F4949P has better image quality due to increased gain, better resolution, and higher signal-to-noise ratio. The P-model also uses a P43 phosphor while the C-model uses a P22 phosphor.

Procedure

Aircraft Canopy Transmission Measurement

With the aircraft in a dark hangar, the NVG-weighted transmission coefficient of the canopy was measured in the general area of the canopy through which the observers would be viewing the visual acuity chart (see Figure 4). These measurements were made using the device described in the Apparatus section.

Figure 4. IRH&T measurement device being used to measure the percentage of NVG transmission of an F-16 canopy using ASTM Standard Test Method F1863-98.

Observer Visual Acuity Assessment

Each observer participated in one one-hour session per aircraft. Only one observer completed the evaluation for all four aircraft. The aircraft (i.e. canopy types) used for the six observers are listed in Table 1.

Table 1. Observer - aircraft combinations

Observer	Aircraft Used
A	A-10
B	Gold
C	ITO (II)
D	ITO(V)
E	Gold, ITO(II), ITO(V)
F	Gold, ITO(II), ITO(V), A-10

Prior to data collection, the hangar was darkened and the luminance ("brightness") of the F-16 cockpit displays was adjusted by an NVG-experienced pilot to a level judged to be operationally representative. The starlight projector was set to provide approximately full moon equivalent illumination of the chart area. The observer was seated in the pilot seat at a 20 foot viewing distance from the resolution chart. The observer then focused each NVG model to obtain maximum VA of a high contrast reference chart with the canopy up. The illumination level was decreased for the remainder of the session so the white area of the NVG resolution test chart had an NVIS radiance of 1.7 x 10^{-10} NR_B (clear starlight illumination).

On each trial, the observer "read" the line on the NVG resolution chart that could easily be resolved. The experimenter verified the accuracy of each response (horizontal, vertical, left, or right) and directed the observer to read successive lines increasing in spatial frequency. This was repeated until the observer reached a line that could not be resolved.

For each session, NVG-aided VA was first recorded with the canopy up using the first NVG model and no LEP. The canopy was then lowered and NVG-aided VA was assessed through the canopy. The canopy remained down for the three NVG + LEP viewing conditions, which were completed in a randomly determined order. After completion of the VA task for the first NVG model, the observer mounted the second NVG model and repeated the same procedure for this NVG. In sum, NVG-aided VA was assessed at five viewing conditions for each NVG model, two without LEP (canopy up and canopy down) and three with NVG + LEP (canopy down).

RESULTS

Aircraft Canopy NVG Visual Acuity Results

Table 2 is a summary of the NVG transmission coefficients measured for each of the aircraft canopies measured. In addition, Table 2 shows the percentage reduction in NVG-sensitive light due to the canopy and the corresponding average decrease in visual acuity caused by viewing through the transparency. The correlation coefficient between percent loss of NVG-light and percent loss of visual acuity was r=0.88. For this analysis, the visual acuity was taken as the smallest size grating for which the observer got at least 5 of the 6 orientations correct without missing more than 1 for any larger size grating row. No LEP was involved in any of these data.

Table 2. Summary of aircraft canopy NVG transmission coefficients and corresponding percentage light loss and visual acuity loss (UP=no canopy, DOWN=through canopy) averaged across the two NVGs used (no LEP).

		UP	DOWN	%	%
Canopy	NVG Trans Coefficient	Avg. VA	Avg. VA	VA decrease	Light Loss
Gold	0.56	39.0	51.9	33	44
ITO (II)	0.81	43.3	53.1	23	19
ITO (V)	0.74	42.5	53.0	25	26
A-10	0.88	40.9	42.9	5	12

An alternative analysis of the windscreen-only data was done to determine if the VA difference between windscreens was statistically significant. For this analysis the acuity value used was the smallest grating size that the subject could correctly identify at least 4 of the 6 target orientations correctly. One acuity value was then used for each combination of observer, aircraft (A-10, Gold, ITO(II), and ITO(V)), windscreen condition (Up, Down, WD-1, WD-2, and FV-9) and NVG (F4949C and F4949P). The windscreen conditions are referred to as LEP (laser eye protection) when the only levels used were

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WD-1, WD-2, and FV-9. Only 1 subject used all 4 aircraft. Table 3 contains the aircraft used by each observer (A through F) along with their mean acuity for the windscreen Up condition.

Table 3. Mean Snellen acuity (20/XX) when the windscreen was Up. There were 2 acuity values for each aircraft used (i.e. one for each NVG).

Observer	Aircraft Used	Mean Acuity for 'Up'	N
A	A-10	43	2
B	Gold	38	2
C	ITO	43	2
D	ITO(V)	51	2
E	Gold, ITO, ITO(V)	38	6
F	A-10, Gold, ITO, ITO(V)	38	8

When the observers were exposed to the windscreen Down condition (viewing through the windscreen), the percent increase in target size (decrease in visual acuity) from the windscreen Up condition (no windscreen) ranged from 0 to 41 with a median of 26 (N=22). There were 2 instances of 0 percent increase, both coming from the A-10 aircraft. The dependent variable used in the following analyses was the percent change in target size from the windscreen Down condition. A problem exists in that each subject did not use all aircraft.

Comparison of the aircraft is difficult. Observer E used 3 of the aircraft and observer F used all 4. With these 2 subjects the percent change in acuity was averaged across LEP and NVG for each aircraft. A 1-factor (aircraft) repeated measures analysis of variance using the Gold, ITO(II), and ITO(V) only, with error term observer*aircraft, did not find a significant difference among the 3 aircraft {$F(2,2)=0.01$, $p=0.9996$}. Means were: Gold=2.1, ITO(II)=2.1, and ITO(V)=2.3. Note that for Observer F the mean for A-10 was 2.0.

Laser Eye Protection NVG Visual Acuity Results

It was assumed that there was no interaction between aircraft and either LEP or NVG. For all observers the percent change from the windscreen Down condition was averaged across aircraft. The observers have different N for each mean. A 2-factor repeated measures analysis of variance was performed using this mean as the dependent variable with LEP (WD-2, WD-2, and FV-9) and NVG (F4949C and F4949P) as factors. Observer interactions were used as error terms. Results are shown in Table 4.

The main effect means for the NVGs were F4949C=3.8 and F4949P=4.4. Table 5 contains the mean and standard deviation of observers for the LEPs (after averaging across NVG). P-values are given from a t-test for Ho: mean=0.

Table 4. ANOVA results for NVG VA percent change from windscreen Down.

Source	SSQ	DF	Error SSQ	Error DF	F-Value	P-Value
LEP	379.1	2	142.4	10	13.31	0.0015
NVG	3.2	1	379.7	5	0.04	0.8448
LEP* NVG	49.0	2	264.6	10	0.93	0.4277

Table 5. Mean and std of subjects (N=6) for percent change from windscreen Down. P-value is for Ho: mean=0.

	Percent Change		
LEP	Mean	Std	P-value
WD-1	0.9	3.3	0.5244
WD-2	2.8	5.4	0.2596
FV-9	8.5	3.2	0.0013

Figure 5 contains the mean percent change from windscreen Down for each condition. Using the Bonferroni paired comparisons procedure with a .05 overall error level (per comparison error level=.05/3=0.0167) the minimum significant difference was 4.4 for comparing the means of the percent change from windscreen Down.

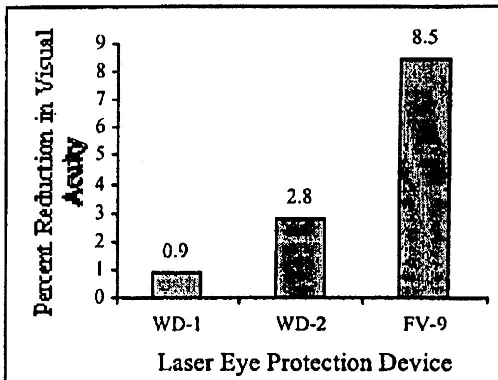

Figure 5. Mean percent change in NVG VA from Windscreen Down (No LEP).

DISCUSSION and CONCLUSIONS

One major problem of working with visual acuity as a dependent variable is the difficulty in determining what visual acuity should be assigned to a particular observer response to the Visual Acuity chart. The Visual Acuity chart used for this study was intended to make an objective assessment of VA by requiring the observer to identify the direction of the grating patches. Since there were 4 possible orientations for each patch and there were 6 patches for each acuity level this made it essentially impossible for observers to get all correct answers for a single row by guessing. However, the problem arises as to what to use as a cut-off value if the observer does not get all of the orientations right in a particular row. It is possible to calculate the probability of guessing correctly 3, 4, 5, or 6 of the patches in a row so that one may set an objective criteria for determining VA. But, in some cases observers produce strange results. For example, one observer in one of the conditions had the following sequence of responses: for the 20/45.1 row he got all 6 right, then got only 4 right in the 20/40.2 row but bounced back and got 5 in the 20/35.8 row. So what VA score should be assigned to this individual? It is apparent that he did significantly better than chance in all 3 rows but it is also apparent that he missed some indicating his NVG VA shouldn't be counted the same as someone who makes no errors and gets the 20/35.8 row correct. It is beyond the scope of this paper to solve this dilemma, however, this needed to be explicitly addresses as various analyses on the data used different criteria.

For the analysis comparing the effects of the aircraft transparency (by itself) on NVG visual acuity, an observer was given the VA score corresponding to the highest acuity level for which he got at least 5 of the 6 patches correct, but without missing more than 1 patch in any row of lower acuity. In the example above the individual was assigned a score of 20/45.1 since the 5 he got correct for 20/35.8 occurred after he missed 2 in the 20/40.2 row. However, for the LEP analyses a simple criteria of 4 correct was used. Both approaches are defensible and the only reason that there are two approaches here is because two different individuals did the analysis independently on the data and established their own criteria. This is an area that needs further research in that VA is quite often used to assess effects of different conditions but the "fuzziness" of exactly what should be used as a criteria for VA may sometimes make it difficult to assess or compare results.

With the preceding issue in mind, the major conclusions of this effort are that the NVG VA was indeed affected by the aircraft transparencies that were used and this effect was correlated to the transparencies transmission coefficients for NVG-sensitive light. In addition, the LEP effect was minimal (non-significant) for the two LEPs that had the highest luminous transmission (as measured for the NVGs used - about 75%) and statistically significant (although still small) for the LEP that had the lowest luminous transmission (the FV-9 at 46% transmission). These results are encouraging and are in line with past research into the effects of aircraft windscreens and laser eye protection on NVG visual acuity. It should be possible to develop a model based on NVG-weighted transmission coefficients (for the windscreens) and NVG phosphor emission weighted transmission coefficients (for the LEP) to accurately predict NVG VA effects. This is a topic for future work.

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H. Lee Task has been employed as a research scientist for the US Air Force since 1971. He has served as chief scientist for the Armstrong Aerospace Medical Research Laboratory and in March of 1997 was selected as the Senior Scientist for Human-Systems Interface of the new Air Force Research Laboratory at Wright-Patterson AFB, Ohio. He is currently involved in research and development in the areas of helmet-mounted displays, vision through night vision goggles, optical characteristics of aircraft windscreens, vision, and display systems. He has a BS Degree in Physics (Ohio University), MS degrees in Solid State Physics (Purdue, 1971), Optical Sciences (University of Arizona, 1978), and Management of Technology (MIT, 1985) and a Ph.D. in Optical Sciences from the University of Arizona Optical Sciences Center (1978). During his career he has earned 42 patents and has published more than 90 journal articles, proceedings papers, technical reports, and other technical publications.

Joe Riegler has been a human factors research scientist supporting Air Force R&D in the areas of visual performance assessment and crew-system interface evaluation since 1985. He is currently employed by The Boeing Company as a human factors engineer for the NVG Fly by Night Training Team, Warfighter Training Research Division, Air Force Research Laboratory, Mesa, AZ. In this position, he conducts human factors research examining various aspects of visual performance with night vision devices. He has a BA degree in Psychology (Thomas More College, KY 1981) and an MA degree in Human Factors (Wright State University, 1986). During his career, he has (co)authored over 25 technical reports, proceedings papers, and journal articles.

Chuck Goodyear is a statistical consultant. For the past 16 years he has either contracted with or consulted for researchers at the Armstrong Aerospace Medical Research Laboratory at Wright-Patterson AFB, Ohio. He has a BS degree in Mathematics (1977) and an MS degree in Statistics (1982) both from Miami University in Oxford, Ohio.