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Evaluation of Night Vision Goggle: Visual Acuity Degradation While Wearing the FV-9 Laser Eye Protection Spectacle

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Evaluation of Night Vision Goggle Visual Acuity Degradation Wearing the FV- 9 Laser Eye Protection Spectacle

INTRODUCTION

Of all man's senses, vision is recognized as the most critical for aviators to safely fly their aircraft (Tredichi, 1985). Since the introduction of night vision goggles (NVGs), night operations continue to become more demanding as aircrews continue to expand the night operational envelope. As mission variety expands, hazards likewise multiply allowing decreased margins for distraction, error or disorientation without deadly catastrophic consequences. NVGs provide an intensified image of night scenes illuminated by ambient energy in the red and near-infrared portion of the electromagnetic spectrum, which is abundant in the night sky. The intensified imagery is roughly 2,000 to 7,000 times brighter than the original scene, depending upon the type of intensifier tube used, and provides the user with a field of view ranging from 30 – 45 degrees (Kotulak & Rash, 1992). The explosion of NVG users attests to the fact that this technology greatly enhances the ability to conduct night operations. Goggles are used extensively in both rotary and fixed-wing aircraft. Law enforcement, immigration service and military aircrews increasingly rely on night vision devices when darkness restricts normal vision. NVGs work best when the ambient illumination is relatively intense (e.g., full moon) and the contrast of the scene is high. However, scene rendering is significantly degraded when ambient illumination decreases and/or scene contrast decreases (Kotulak & Rash, 1992).

NVGs used in conjunction with other aircraft and mission equipment allow the employment of visual nighttime tactics which can more closely emulate the more precise daytime operations. A recent complement to NVG operations has been the introduction of the hand-held laser pointer. Until recently, airborne laser applications have largely been restricted due to size and/or cost (Demitry, 1998). Sophisticated laser devices were integrated into only a few airborne systems - most notably for navigation, range finding and target designation. Operator safety was generally guaranteed by externally installing the laser with gimbal limiters preventing accidental self-lasing back into the cockpit. With the introduction of very lightweight systems, such as the Air Commander's Pointer (ACP), which easily fits onto a pilot's finger (Demitry & Stiles, 1997), the proliferation of very small, yet extremely hazardous, finger-mounted mobile laser pointers has already occurred. These devices are currently in use in military and law enforcement rescue forces, utilized for pointing out critical positions for other aircraft or ground observers. Despite their small sizes, these pointers are hazardous ANSI - 3B lasers operating at power levels nearing 100mW in the infra-red (IR) spectrum. The value of these lasers lie in the fact that although the IR energy is invisible to the naked eye, the emitted IR beam is easily visible from great distances when viewed through NVGs. Industrial Hygiene analyses calculate that Nominal Ocular Hazard Distances (NOHD) can exceed 500 feet - posing a serious ocular hazard to those employing these devices (Keppler, 1997). Since no acceptable engineering controls are currently available to control the hazards of these highly mobile devices within these dynamic flight regimes, personnel employing these lasers require personal protective equipment (PPE), such as laser eye protection. It is inevitable that the simultaneous use of these newest laser pointers employed with NVGs and additional personal eye protection are becoming commonplace throughout military and law enforcement aviation units.

The most common type of available Laser Eye Protection (LEP) contains absorption characteristics that protect the eye from specific frequency laser energy. Because LEP limits the energy transmitted to the eye, the potential for visual performance degradation exists and has previously been measured with older types of LEPs (Thomas, Garcia, & Mayo, 1993). The effect of LEP on NVG-aided visual acuity (VA) was first assessed by Sheehy and Gish (1989). Their results revealed that resolution loss increased as illumination and contrast decreased, and they theorized that the magnitude of this loss was related to phosphor efficacy. This study was performed using older technology NVGs, and losses in resolution ranged from 11 – 21 %. More recently, Reising (1995) investigated the effect of LEP on NVG-aided VA using F4949C NVGs and an Army Prototype NVG with an LEP approved for flight. These results showed that improvements in NVG performance significantly reduced the LEP effect on NVG aided VA. In that study, an 11% visual acuity degradation (VA) was reported with medium and low contrast targets (Reising 1995). Operationally, these LEPs were found to be objectionable under some flight conditions and were not approved for certain flight conditions in some high performance aircraft. Common criticisms included difficulty by some crews in seeing color displays and instruments. The dark filter intensity caused several pilots to complain about using the LEPs at night both with and without NVGs. (Thomas et al, 1993). These complaints led the Laser Optical Radiation Division of the Air Force Research Laboratory to the development of the FV-9 LEP, designed to provide the same laser protection as previous LEPs, but with higher photopic transmission for better low light use.

The purpose of this research was to develop and execute an experimental research protocol to investigate what degree - if any - visual acuity degrades when aircrews simultaneously wear state-of-the-art night vision goggles with the FV-9 laser eye protection spectacle (Figure 1). Elucidation of visual acuity degradation is critical in determining operational risks associated with such combinations. Two models of the F4949 NVG were used in this investigation, the F4949C and the F4949P. These models represent current operational NVGs used by pilots employing the ACP laser pointer. The F4949P is a newer model than the F4949C, and has better image quality due to increased gain, resolution in-line pairs, and a higher signal to noise ratio. Also, the P-model uses a P43 phosphor while the C-model uses a P-22 phosphor. Two ambient illumination conditions and two contrast levels, representative of the night sky environments, were selected for this experimental protocol based upon previous published studies.

METHODS

Participants. The criteria for subjects to be entered into the study cohort was that each participant was required to have medically documented 20/20 vision, and have been certified as 'proficient' in the use and operation of 4949 NVG goggles. (Certification was in accordance with Air Force training syllabi used in certifying pilots as proficient in NVG operations.) Twenty male pilots, ranging in age from 26 to 51, volunteered for this experiment. Each completed informed consent forms in accordance with the Institutional Review Board (IRB) approved protocol. All pilots had flight surgeon documented 20/20 photopic visual acuity and training on F4949 NVG adjustment procedures in accordance with current Air Force training guidelines (Antonio & Berkley, 1993). Each pilot was previously certified by the US Air Force for solo low altitude night flight and had routinely demonstrated proficiency using night vision goggles. Two pilots had extensive flight experience with NVGs and currently are NVG instructor pilots at the US Air Force night vision training laboratory. Each participant obtained at least 20/35 NVG-aided VA after initial NVG adjustment on a high contrast background. This study sample represented a typical demographic sample of both experience and age from what would be expected in a United States 'front-line' aviation squadron. It would be expected that the results from this study could be legitimately generalized to other operational units who use these technologies in the field.

Apparatus and Stimuli. NVG-aided visual acuity (VA) was assessed using square-wave grating resolution patterns (Figure 2) placed at eye level, 20 ft from the subjects' eye-point. Two distinct resolution chart contrast levels (53% and 10%) (Figure 3) and two distinct illumination levels, (.25 moon, and clear starlight) were examined. The patterns were illuminated by a Hoffman LM-33-80 Night Sky Projector. Illumination levels were defined according to Night Vision Imaging System (NVIS) Radiance values as described in ASC/ENFC 96-01, Lighting, Aircraft, Interior, Night Vision Imaging System (NVIS), Compatible, March 22, 1996. The NVIS radiance theoretically represents the amount of energy within the spectral response of the NVG that would be reflected from a defoliated tree under various ambient illumination conditions. Radiance was measured from the white portion of the resolution chart with a Photo Research 1530-AR spot photometer with a Class A filter and verified with a Hoffman NVG-103 Inspection Scope. The NVIS radiance values calculated for the two illumination levels using the response of Class A NVGs were as follows:

$$\mathbf{0.25\ Moon = 5.9 \times 10^{-10}\ NR_A}$$

$$\mathbf{Starlight = 1.7 \times 10^{-10}\ NR_A}$$

Resolution patterns were randomly distributed on charts similarly as the NVG Resolution Chart developed by Armstrong Laboratory (DeVilbiss & Antonio, 1994). Each chart contained 16 horizontally and vertically oriented patterns varying in five-ft increments of Snellen acuity (acuity ranged from 20/20 to 20/100), and each pattern was presented twice on the chart (Figure 2).

Experimental Design. The experiment employed a 2 x 2 x 2 x 2 'within-subjects' repeated measures design. As such, subjects were compared both to themselves with and without the LEP and also were compared to the entire sample. The independent variables were NVG TYPE, (F4949C and F4949P models), ILLUMINATION (0.25 Moon and Starlight), CONTRAST (medium and low), and LEP (NVG without LEP and NVG with FV-9 LEP). The dependent variable in each case was NVG-aided VA (visual acuity) expressed as the Snellen value denominator.

Procedure. The procedure for determining NVG-aided VA using square wave grating charts is taken from DeVilbiss and Antonio (1994). Each subject "read" the resolution patterns from left to right and top to bottom under each of the four possible chart orientations. Thus, each pattern was viewed eight times (four vertically and four horizontally). The subjects reported whether a pattern was vertical, horizontal, or could not be resolved. The number of correct vertical and horizontal responses was totaled, and VA values were determined via a 75% correct criterion. For example, if a subject correctly identified the 20/55 pattern 100% of the time (8 of 8), the 20/50 pattern 75% of the time (6 of 8), and the 20/45 pattern 62.5 % of the time (5 of 8), the subject's VA was assessed as 20/50.

Each participant was tested in one session lasting approximately two hours. The order of the two NVG types within a session was counterbalanced across the twenty participants. A fifteen-minute break was provided at the completion of the first NVG type. The order of LEP (with or without) was randomized within each NVG type. Following a fifteen minute dark adaptation period and a ten minute NVG focusing period, NVG-aided VA was measured in the following order for all subjects under each LEP and NVG type condition: 0.25 moon/medium contrast, 0.25 moon/low contrast, starlight/medium contrast, starlight/low contrast. A progressively dimmer order of illumination/contrast condition was chosen to avoid any disruption in dark adaptation that might be caused by switching from low illumination to higher illumination repeatedly in the same session. The output brightness range for NVGs is approximately 2.0 fL for 0.25 moon to 0.03 fL for clear starlight.

LEP transmissivity data were obtained using a Photo Research SpectraScan PR-703A/PC spectroradiometer in conjunction with a Photo Research 4700 K Reference Light Source. The transmission data were compared to NVG phosphor emission data supplied by ITT Electro-Optical Products Division.

RESULTS

Each of the original 20 volunteers completed the study. There were no data drop-outs. Snellen VA scores were recorded for each individual at each experimental condition. These values were then converted to log minimum angle of resolution (MAR) for subsequent data analyses (MAR = 1 / Snellen fraction). The logarithmic representation of the MAR has been recommended for scaling visual acuity since it provides a good approximation to an equal discriminability scale across VA levels ranging from high (e.g. 20/20) to low vision (e.g. 20/100), (Westheimer, 1979; Bailey, 1980). Log MAR mean and standard deviation NVG-aided VA and mean Snellen VA, averaged across the twenty participants, are presented in Table 1 for each NVG type, LEP condition, illumination, and contrast level.

In order to describe the reduction in NVG-aided VA from baseline due to LEP, percent degradation was computed as the mean difference (in log MAR units) between NVG baseline and NVG+LEP VA divided by NVG baseline. Thus, reductions in mean VA's of 20/50 to 20/55; 20/70 to 20/80; and 20/30 to 20/31.3 all represent approximately a 10.5% degradation in VA. The average percent degradation in NVG-aided VA resulting from LEP wear is provided in the last row of Table 1. NVG-aided VA means are displayed in Figure 4 in Snellen and log MAR units.

As expected, reductions in illumination and contrast resulted in poorer VA for all conditions, with overall mean reductions of 21% from 0.25 moon to clear starlight, and 35% from medium to low contrast. Of primary interest, visual acuity for the NVG+LEP viewing condition was degraded relative to baseline NVG for all experimental conditions, resulting in an overall reduction of 9% with means of 20/54.0 and 20/49.8, respectively.

Also, the percent degradation in VA (in log MAR) observed for NVG+LEP viewing relative to baseline NVG was only slightly larger for the 4949C (9.3%) relative to the 4949P (8.3%).

A four-way (2 x 2 x 2 x 2) repeated measures within-subjects analysis of variance (ANOVA) was conducted on the log MAR VA data using SPSS for Windows Release 8.0. The ANOVA results summary is provided in Table 2. The ANOVA revealed significant main effects of NVG type ($F_{(1,19)} = 167.13$, $p < .0001$, LEP ($F_{(1,19)} = 63.13$, $p < .0001$, illumination ($F_{(1,19)} = 210.40$, $p < .0001$ and contrast, $F_{(1,19)} = 457.85$, $p < .0001$. A significant two-way interaction between illumination and contrast ($F_{(1,19)} = 9.58$, $p = .006$, indicated that contrast had a more detrimental effect on VA under starlight illumination relative to 0.25 moon conditions. The ANOVA also revealed a significant two-way illumination x LEP interaction ($F_{(1,19)} = 7.14$, $p < .015$, indicating that the degradation in VA due to the LEP varied as a function of illumination level. No other interactions were significant at the $p < .05$ level.

DISCUSSION

The authors believe this study represents the largest sample size to date investigating Visual Acuity degradation of aircrews using Night Vision goggles while simultaneously using LEP personal protective equipment (Figure 1).

The sample cohort selected in this experimental design sought pilots who were both ‘vision-normal’ and highly proficient in NVG usage. This sample along with the optimum laboratory conditions created a ‘best-case’ opportunity for the dependent variable to tend towards the null hypothesis (ie, no effect). Results of significance are therefore conservative – minimizing any adverse effects of selection bias. As environmental conditions / human factors degrade, visual acuity reduction would logically also worsen – increasing the statistical significance reported in this study.

The results of this investigation demonstrated that the FV-9 LEP resulted in an average VA reduction of 9% from the NVG-aided baseline (no LEP) condition. Furthermore, this mean percent loss in VA due to LEP did not significantly differ between the 4949C (9.3%) and 4949P (8.3%) models. The degradation in NVG-aided VA due to LEP was larger under starlight illumination relative to 0.25 moon illumination. This effect also did not significantly vary between the two model types.

NVG-aided VA scores obtained with the FV-9 LEP are comparable to the VA values measured at the same illumination and contrast levels for the FV-6 Minus Ruby LEP, (Reising, 1995). A comparison of the means and standard deviations obtained in this study and the Reising experiment reveal no notable differences in NVG-aided VA. Therefore, the increase in photopic luminance transmission of the FV-9 over the FV-6 Minus Ruby appears to have no significant impact on NVG-aided VA over the ranges of illumination and contrast examined for each study.

Reising (1995) failed to find an effect of LEP on NVG-aided VA for the ULTRA NVG prototype. The current results, in contrast, did show a significant effect of LEP for each NVG type tested, underlining the importance of empirically measuring and quantifying the effects of LEP for separate NVG systems. Although the 4949P model provides better image quality in terms of signal to noise ratio, resolution, and higher gain than the 4949C, similar VA reductions (measured as percent loss from baseline no LEP conditions) should be expected.

The present results are also consistent with those reported in previous investigations of NVG-aided VA with LEP in that the amount of VA degradation attributable to the LEP increased with decreases in illumination (Reising, 1995; Sheehy and Gish, 1989). These findings also demonstrate the importance of testing VA with LEP under realistic illumination and contrast conditions as indicated by Sheehy and Gish, (1989).

In the present study, reductions in NVG-aided VA due to LEP were minimal at the 0.25 moon and medium (53%) contrast conditions for each NVG type averaging about 5% However, under clear starlight illumination and the same contrast level, VA losses due to LEP averaged about 13% across NVG types.

CONCLUSION

The present findings and those obtained by Reising (1995) indicate that the FV-9, FV-6 MR and the HGU-56/P all produce comparable degradation in NVG-aided VA with the F4949C model. Given the trend of these results and those of previous LEP investigations, it is possible that VA levels obtained for NVGs predating the F4949C technology (e.g. ANVIS AVS/6) may differ for each LEP type under some illumination and contrast conditions. Operationally, the FV-9 LEP may be preferred by pilots and other crew-members during NVG operations because of it's higher photopic and scotopic transmission, which should improve unaided VA in a dark cockpit.

The loss in NVG aided VA incurred by the FV-9 LEP averaged 9% across all conditions. The operational relevance of this loss is not measurable, but the loss seems small when compared to the degradation in NVG aided VA caused by other things such as canopies and windscreens. For instance, the degradation caused by an F-16 Gold Coat Canopy has been measured at 25% (Berkley, 97), and the degradation caused by a C-130 H-3 windscreen has been measured at 26 % (Berkley, 97). The operational significance of all these numbers combined appears relevant in environmental conditions that cause relatively poor NVG performance such as starlight flight over low contrast terrain. In these conditions, it is possible that the loss in NVG aided VA due to LEP, combined with the loss due to windscreen transmissivity and/or poor cockpit lighting could conspire to significantly impact the probability of successful mission accomplishment.

Improvements in intensifier tube resolution, signal to noise ratio, and gain all contribute to improvements in NVG-aided VA performance both with and without LEP. This is evident from the superior performance relative to the F4949C model for the F4949P model in the present study and the ULTRA prototype in the Reising, 1995 study. Improvements in NVG imaging technology and LEP transmission levels may combine to render NVG-aided VA degradation due to LEP less of a concern for future systems. However, these improvements in technology do not alleviate the requirement to strictly adhere to proper NVG adjustment procedures to ensure optimal system performance.

Figure 1: NVG and FV-9 LEP in place

Figure 2. Visual Acuity Resolution Chart

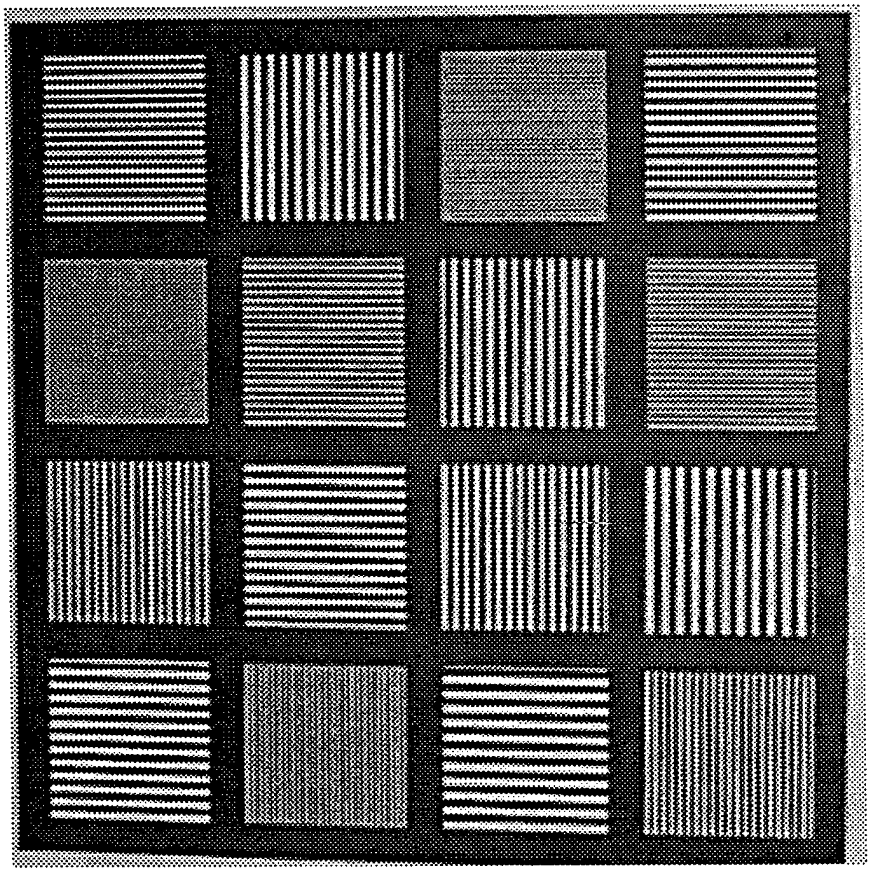
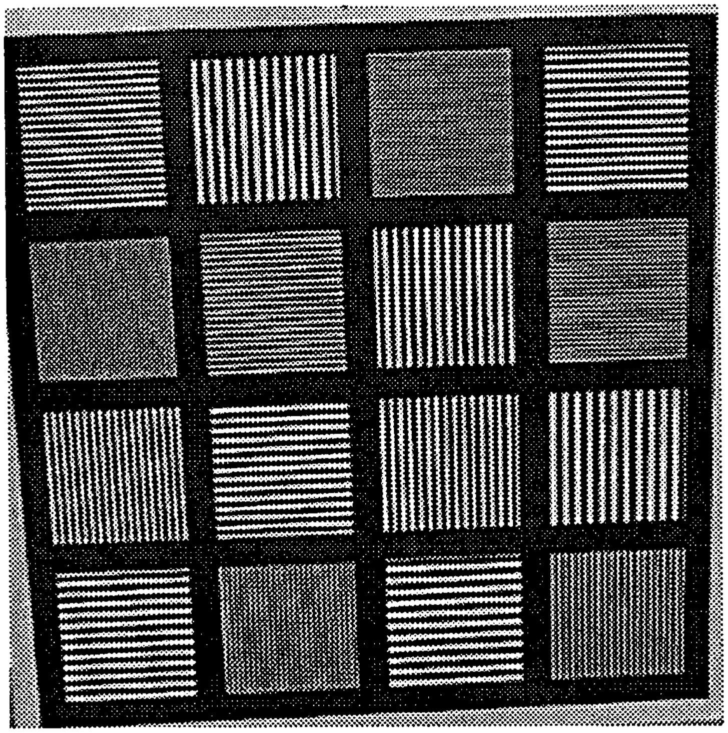


Figure 3. VA Resolution Charts at Differing Contrast Levels

High Contrast



Low Contrast

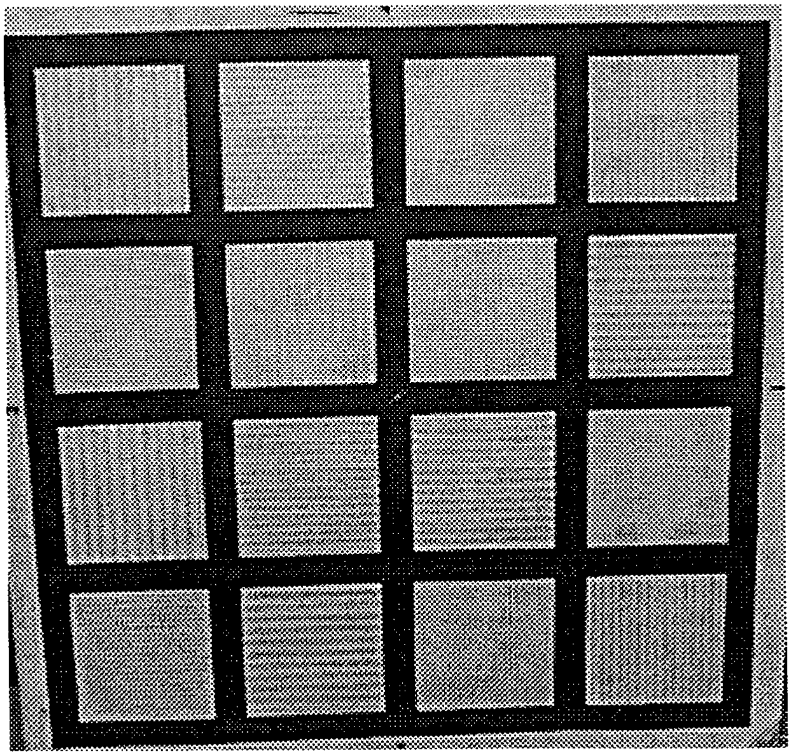
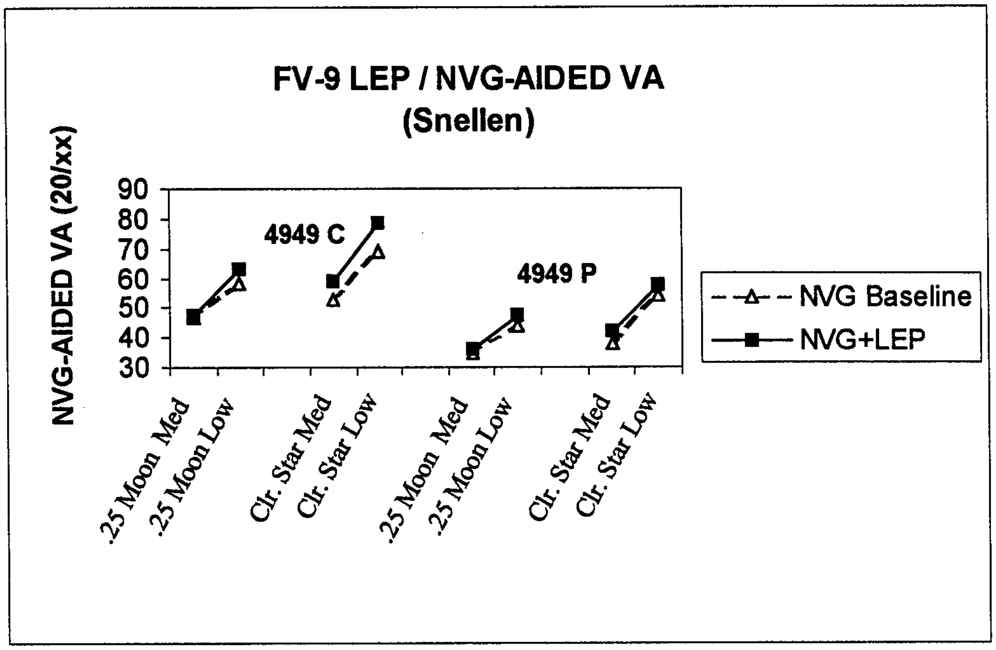


Figure 4. VA means displayed in Snellen and log MAR units.



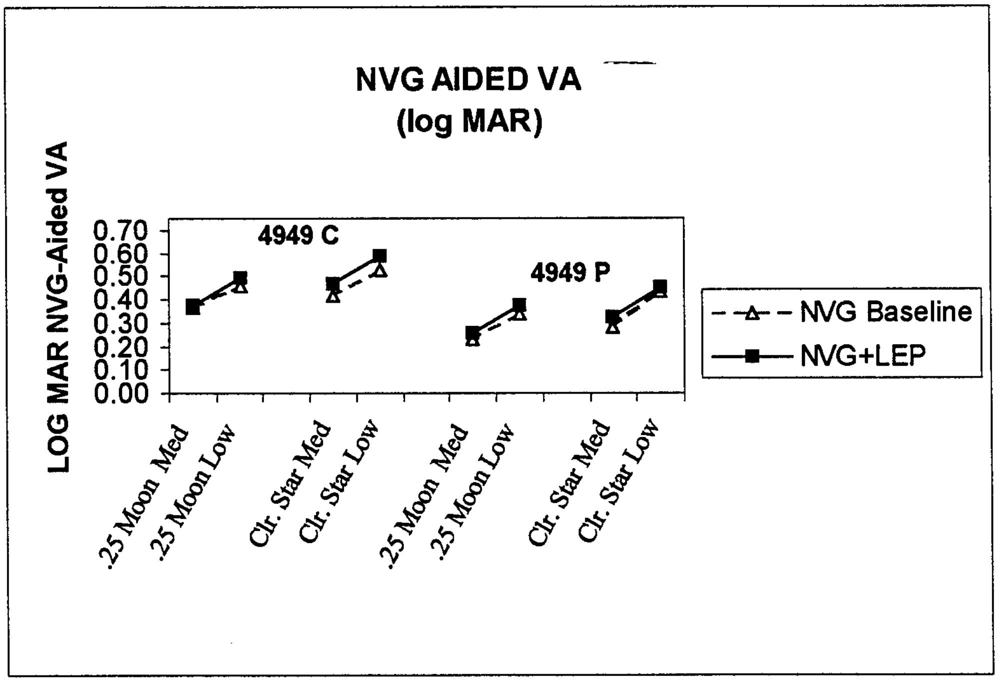


Table 1. Mean and Standard Deviation NVG-Aided Visual Acuity as a Function of NVG Type, LEP, and Contrast for each Illumination Level.

	4949 C				4949 P			
	0.25 Moon		Clear Starlight		0.25 Moon		Clear Starlight	
NVG Baseline	Med	Low	Med	Low	Med	Low	Med	Low
log MAR VA	0.37	0.46	0.42	0.53	0.23	0.34	0.28	0.43
Std. Dev	0.05	0.07	0.05	0.08	0.07	0.06	0.04	0.06
Snellen Denominator	46.75	58.30	53.00	68.75	34.50	44.25	38.25	54.50
NVG + LEP	Med	Low	Med	Low	Med	Low	Med	Low
log MAR	0.38	0.49	0.47	0.59	0.25	0.38	0.32	0.45
Std. Dev	0.06	0.07	0.05	0.07	0.04	0.05	0.06	0.07
Snellen Denominator	47.75	62.80	59.25	78.50	36.00	47.75	42.25	57.75
Percent Degradation from Baseline	2.23	7.05	11.32	11.08	9.32	10.20	14.90	5.21

Table 3. ANOVA Results Summary for NVG-Aided Visual Acuity

SOURCE	Sum Of Squares	Degrees of Freedom	F	p
NVG TYPE	17925.08	1	116.50	< .0001
LEP	1423.83	1	65.65	< .0001
ILLUM	6891.33	1	168.76	< .0001
CONT	16459.45	1	197.59	< .0001
TYPE x ILLUM	236.33	1	12.62	< .002
TYPE x LEP	106.95	1	5.03	= .037
TYPE x CONT	85.08	1	2.00	= .173
LEP x CONT	85.08	1	8.31	= 01
LEP x ILLUM	203.20	1	11.83	= .003
ILLUM x CONT	439.45	1	25.00	< .0001
ILLUM x LEP x CONT	9.45	1	.530	= .476
TYPE x ILLUM x LEP	85.08	1	4.53	= .047
TYPE x ILLUM x CONT	3.83	1	.204	= .657
TYPE x LEP x CONT	41.33	1	3.91	= .063
TYPE x ILLUM X LEP x CONT	9.45	1	.680	= .420
TYPE x SUBJ	2923.36	19	--	--
LEP x SUBJ	412.11	19	--	--
ILLUM x SUBJ	775.86	19	--	--
CONT x SUBJ	1582.73	19	--	--
TYPE x ILLUM x SUBJ	355.86	19	--	--
TYPE x LEP x SUBJ	403.98	19	--	--
TYPE x CONT x SUBJ	807.11	19	--	--
LEP x CONT x SUBJ	194.61	19	--	--
LEP x ILLUM x SUBJ	403.98	19	--	--
ILLUM x CONT x SUBJ	333.98	19	--	--
TYPE x LEP x ILLUM x SUBJ	357.11	19	--	--
LEP x ILLUM x CONT x SUBJ	338.98	19	--	--
TYPE x LEP x CONT x SUBJ	200.86	19	--	--
TYPE x CONT x ILLUM x SUBJ	357.11	19	--	--
TYPE x ILLUM X LEP x CONT x SUBJ	263.98	19	--	--

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