USAARL Report No. 92-9

AD-A248 786

Visual Acuity with Second and Third Generation Night Vision Goggles Obtained from a New Method of Night Sky Simulation Across a Wide Range of Target Contrast

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92-09623

January 1992

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United States Army Aeromedical Research Laboratory
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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) USAARL Report No. 92-9	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION U.S. Army Aeromedical Research Laboratory 6b. OFFICE SYMBOL (If applicable) SGRD-UAS-VS	7a. NAME OF MONITORING ORGANIZATION U.S. Army Medical Research and Development Command
6c. ADDRESS (City, State, and ZIP Code) P.O. Box 577 Fort Rucker, AL 36362-5292	7b. ADDRESS (City, State, and ZIP Code) Fort Detrick Frederick, MD 21702-5012
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
0602787A	3M162787879	BG	164

11. TITLE (Include Security Classification) Visual Acuity With Second and Third Generation Night Vision Goggles Obtained from a New Method of Night Sky Simulation Across a Wide Range of Target Contrast

12. PERSONAL AUTHOR(S)
Kotulak, John C., and Rash, Clarence E.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM ____ TO ____	1992 January	31

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
20	06	
23	02	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
night vision goggles (NVG), field-of-view, night sky conditions, target contrast, NVG generation, night sky simulation

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The purpose of this investigation was to study the primary factors which influence visual acuity (VA) with night vision goggles (NVGs). These factors are: night sky condition, target contrast, and NVG generation. Improved methods were used to simulate the night sky and to control for differences in target contrast which result from dissimilarities in spectral sensitivity between NVG generations. The new simulation method used combinations of spectrally flat (neutral density) and wavelength selective (blue glass) filters to reproduce the spectral distribution of the night sky across the entire NVG response range. Between-generation differences in target contrast were eliminated by weighting the incident

(Continued)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Chief, Scientific Information Center	22b. TELEPHONE (Include Area Code) (205) 255-6907 22c. OFFICE SYMBOL SGRD-UAX-SI

DD Form 1473, JUN 86 Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. ABSTRACT (Continued)

radiant flux by the sensitivity of the detector. It was found that the difference in VA between the two generations widens under two conditions: (1) when target contrast is constant and night sky irradiance decreases, and (2) when night sky irradiance is constant and target contrast decreases. Furthermore, it was found that for a given NVG generation, VA falls off more rapidly for a low contrast target than for one of high contrast when night sky irradiance decreases. Finally, by comparing our results to those of other studies, we were able to conclude: (1) for both second and third generation NVGs, our simulation method produces results similar to those obtained under actual night sky conditions, and (2) for second generation NVGs, a simpler and less expensive method of night sky simulation, i.e. using neutral density filters with a cathode ray tube, produces results similar to those obtained with the more elaborate method used in this study. We were not able to conclude that the simulation method used in this study produces results similar to those obtained with incandescent sources and spectrally flat filters, especially when night sky irradiance is below quarter moon.

Acknowledgments

The authors wish to thank MAJ David J. Walsh, formerly of this Laboratory and now assigned to the U.S. Army Medical Materiel Development Activity, Fort Detrick, Frederick, Maryland, for acquiring the night sky projector, and for his advise concerning the specification of target contrast. In addition, we would like to acknowledge the contributions of the following individuals from this Laboratory: LTC Thomas J. Frezell for assisting with the experimental design; Dr. Roger W. Wiley, for providing his raw data for statistical analysis; Dr. Isaac Behar, for assisting with the experiment design and with photometry; Dr. Lynn Caldwell, for providing statistical advise; SGT Kim Ray, for assisting with photometry; SPC Angelia D. Mattingly for recruiting subjects; and Mr. Simon C. Grase for providing technical assistance with all phases of the study.

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Introduction

The main purpose of this study was to investigate the primary factors which influence visual acuity (VA) with night vision goggles (NVGs). These factors are: night sky condition, target contrast, and NVG generation. Secondary factors, such as target motion (Bloom and Zwick, 1981), self motion (Ohlbaum, O'Briant, and von Gierke, 1971), visual noise (Riegler et al., 1991), windscreen absorption (Decker, 1988), and artificial lighting (Pollehn, 1988; Stefanik, 1989) were excluded.

VA with second generation NVGs already has been thoroughly scrutinized. Three studies have examined VA with these devices across a wide range of night sky conditions and target contrasts (Levine and Rash, 1989a and 1989b; Wiley, 1989). Other studies with second generation NVGs have analyzed how VA is influenced by exogenous and endogenous factors. The exogenous factors included wearing nuclear flashblindness protection (Levine and Rash, 1989a and 1989b) and wearing chemical protective masks (Miller et al., 1989). The endogenous factors were astigmatism (Kim, 1982) and eye disease (Berson, Rabin, and Mehaffey, 1973; Hoover, 1983). In addition, VA has been evaluated under actual night sky conditions with second generation devices (Miller et al., 1984).

Less is known about VA with third generation NVGs. The effects of signal-to-noise ratio (Riegler et al., 1991) and the influence of wearing protective masks (Miller et al., 1989; Donohue-Perry, Riegler, and Hausman, 1990) have been explored with these devices. In addition, Miller et al., (1984) have investigated VA with third generation NVGs under actual night sky conditions in the field. Studies of VA with third generation NVGs have been limited to a narrower range of night sky conditions and target contrasts than similar studies with second generation devices.

Studies of VA with either generation of NVGs have had to cope with the problem of providing adequate night sky conditions. This problem is not trivial, even in the field. The vagaries of weather, technical difficulties with measuring night sky emissions (Stefanik, 1989), and the inability to find sites where there is no contamination by artificial light (Pollehn, 1988; Stefanik, 1989) are significant hindrances in field studies. In the laboratory, the main hurdles are selecting representative night sky spectra and duplicating them faithfully.

The problem of choosing representative spectra exists because there is no standard night sky spectral distribution. The latter requires measurements of night sky radiation that are not only valid, but which are varied with respect to lunar, geographical, and meteorological conditions. The most recent night sky field survey of suitable scope was by Vatsia, Stich, and Dunlap (1972). However, Vatsia's results may underestimate the amount of irradiance in the long wavelength visible and short wavelength infrared regions of the spectrum (Stefanik, 1991).

Reproducing spectral distributions in the laboratory may be less a problem of technology than of knowing what degree of simulation is necessary. Present technology allows for two levels of approximation of night sky radiation. The first level, which we call "first order," refers to simulations in which a standard laboratory light source is attenuated by a spectrally flat filter (in some cases, the filter may not be flat outside of the visible region). First order simulations match the overall level of radiation present in various night sky conditions (at least as determined by photometric sensors), but neglect its distribution by wavelength. We use the term "second order" to refer to simulations which match not only the overall level of night sky radiation, but also its spectral distribution. Second order simulations are achieved through the use of combinations of spectrally flat and wavelength selective filters, which are effective over the entire NVG response range.

Historically, cathode ray tubes (CRTs) or incandescent lamps have been used with neutral density filters to produce first order simulations. However, many CRTs fail to give off long wavelength visible and short wavelength infrared radiation (Optical characteristics of cathode ray tube screens, 1975). Wiley (1989) has demonstrated that the output of the P4 CRT phosphor lies mostly outside the sensitivity range of third generation NVGs (Figure 1).

Incandescent sources, on the other hand, are less susceptible to mismatches between their output and NVG sensitivity. This is because the spectrum of a tungsten filament is more or less fully contained within the response range of either NVG generation. However, tungsten sources lack the short wavelength visible radiation (RCA handbook, 1974) that is present in moonlight (Vatsia, Stich, and Dunlap, 1972).

The present experiment marks the first use of a second order night sky simulation in vision research with NVGs. We employed an off-the-shelf commercial night sky projector, which was manufactured by Hoffman Engineering Corporation*. The Hoffman

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* See list of manufacturers.

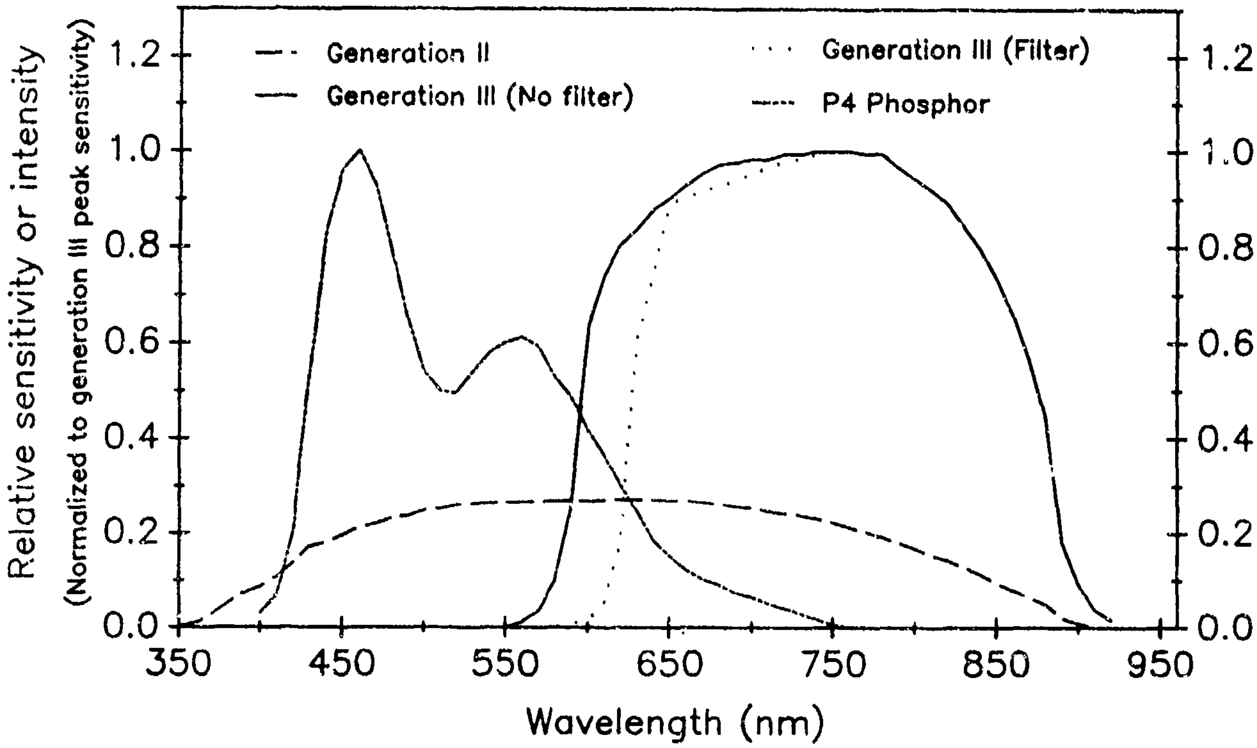

Figure 1. Comparison of generation III sensitivity to P4 phosphor spectral output.

device incorporates spectral data collected by Vatsia. The use of the Hoffman projector allowed us not only to study the primary factors which influence VA with NVGs, but also to learn whether second order simulations produce results that match those obtained under actual night sky conditions and with first order simulations.

Methods

Subjects. Twenty adult volunteers, who had VAs correctable to 20/20 in each eye, served as subjects. Ametropic subjects wore their spectacles during the experiment. The subjects ranged in age from 22 to 58. Sturr, Kline, and Taub (1990) have shown that, within this age range, VA does not vary significantly with age at the luminance levels used in this study (Table 1). The mean age was 30±9 years, while the medium was 28.

Experimental design. The only dependent variable, VA, was studied across four night sky conditions, three target contrasts, and two NVG generations. Although much is already known about

Table 1.

Photometrically measured display luminance.

Night sky condition	Display luminance (fL)			
	Second generation		Third generation	
	Letter	Background	Letter	Background
Full moon	0.40	0.77	1.02	1.54
Quarter moon	0.20	0.40	1.03	1.64
Starlight	0.11	0.28	0.60	0.98
Overcast	0.08	0.16	0.42	0.68

the influence of night sky condition and contrast on VA with second generation NVGs, their inclusion in this study was mandated by our desire to explore generation-specific interactions with the other independent variables. Altogether, 480 thresholds were measured (20 subjects X 24 thresholds/subject). Stimulus presentation was counterbalanced for contrast and generation. However, for a given combination of contrast and generation, the night sky conditions were presented serially from worst to best to control for the effects of memorization. This was necessary because only 5 distinct charts were available to measure the 24 thresholds/subject.

Visual acuity. VA letter charts, based on the design principles of Bailey and Lovie, were used (Bailey and Lovie, 1976). The Bailey-Lovie design principles are: (1) the test task should be the same for each size level, and (2) the letter sizes should change according to a logarithmic progression. Design principle (1) results in size being the only significant variable from row to row. This is achieved by using: (1) letters of equal legibility, (2) the same number of letters in each row, and (3) uniform between-letter and between-row spacing. The logarithmic progression is achieved by varying the size of successive rows by 0.1 log units. The use of charts following the Bailey-Lovie design principles allowed us to: (1) analyze our data with parametric statistics (Lovie-Kitchin, 1988), and (2) change test distances without inadvertently changing scale intervals (Ferris et al., 1982). Parametric statistics require either an interval or ratio scale, while Snellen-like charts provide only an ordinal scale (Wild and Hussey, 1985). Snellen-like charts have irregular progressions of letter size, which cause the scale to change with changes in viewing distance (Bailey and Lovie, 1976). In addition, charts of the Bailey-Lovie design have a scale that is 5 times finer than, and test-retest 95 percent confidence limits half as big as Snellen-like charts (Bailey et al., 1991).

Night sky conditions. A commercial device was used to simulate the night sky (Hoffman Engineering Corporation model LM-33-41 NVG night sky projector) (Figure 2). This projector was equipped with four quartz halogen lamps and various combinations of neutral density and blue glass filters. A separate lamp was used to simulate each of the following conditions: full moon, quarter moon, clear starlight, and overcast starlight.

The projector was positioned so that its beam was normal to the VA chart plane. The distance between the projector and the chart plane coincided with the projector's focal length of 20 ft. We calibrated the projector using a radiometer designed for night sky irradiance levels (Hoffman Engineering Corporation model TSP-90-A radiometer*) (Figure 3). Table 2 shows to what extent we modified the current to each lamp to achieve the desired irradiance. Current modifications of this magnitude do not lead to unintended changes in spectral distribution (McCarter, 1990). Table 3 gives the measured irradiance values of the night sky projector, as well as radiance and luminance values provided by the projector's manufacturer. The irradiance values are similar to those reported for the night sky by other sources (RCA handbook, 1974; Stefanik, 1989). The radiance values came from the field measurements of Vatsia, Stich, and Dunlap (1972), upon which our simulations were based. Figures 4 and 5 depict the spectral distributions of the irradiance and radiance, respectively, for each night sky condition.

Contrast. High, medium, and low contrast stimuli were generated by charts* described by Bailey and Lovie (1976), Bailey (1982), and Regan and Neima (1983), respectively. Each of these charts followed the design principles of Bailey and Lovie (1976). The high and medium contrast charts had a range of thresholds extending from 20/12 to 20/250 at 10 feet, and from 20/25 to 20/500 at 5 feet. Thresholds with the low contrast chart extended from 20/10 to 20/100 at 10 feet, and from 20/20 to 20/200 at 5 feet. The high and medium contrast charts were available in two versions each. For a fixed contrast level, the two versions differed only in letter sequence. Only one version of the low contrast chart was available.

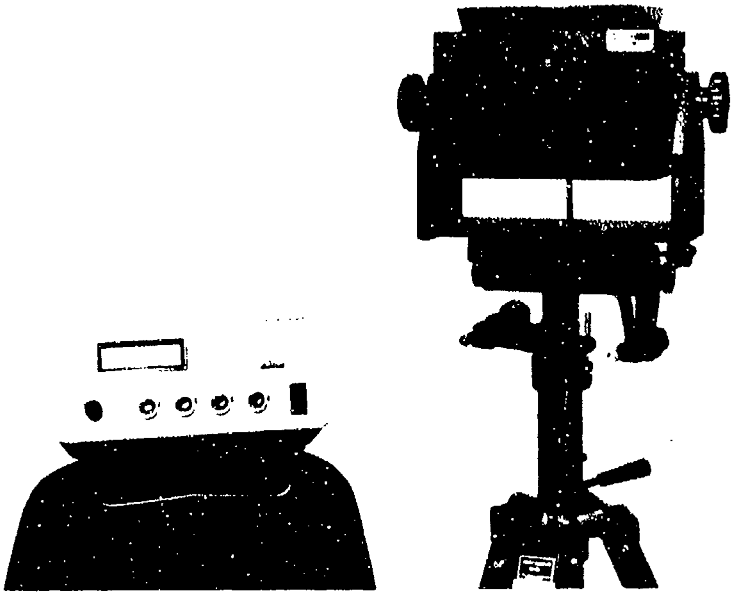

Figure 2. Night sky projector.

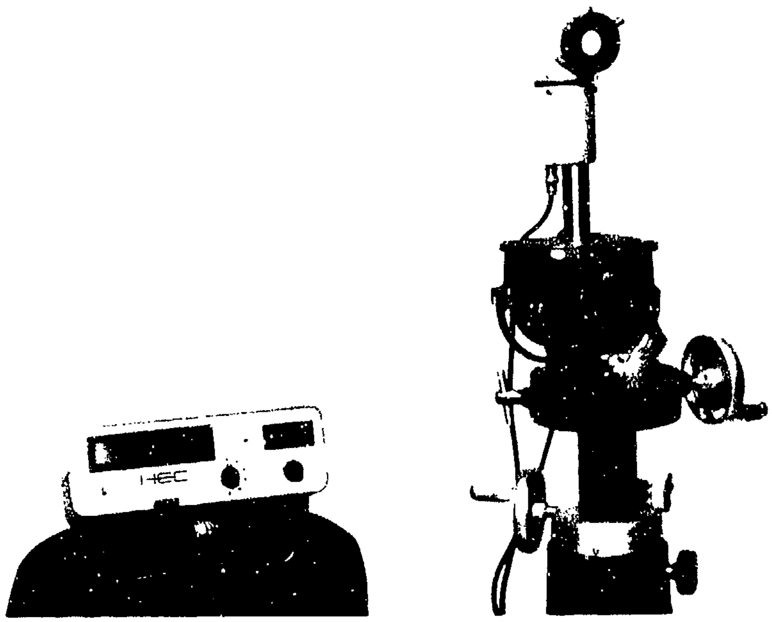

Figure 3. Radiometer used to calibrate the night sky projector.

Table 2.

Night sky projector calibration data.

Night sky condition	Design current (A)	Actual current (A)	Change in current (%)
Full moon	2.185	2.186	0.05
Quarter moon	1.712	1.718	0.35
Starlight	1.543	1.530	0.84
Overcast	1.556	1.603	4.70

Table 3.

Night sky radiometric and photometric data.

Night sky condition	Irradiance (W/cm^2)	Radiance ($W\ cm^{-2}\ ster^{-1}$)	Luminance (cd/m^2)
Full moon	1.128×10^{-8}	3.20×10^{-9}	1.006×10^{-2}
Quarter moon	2.080×10^{-9}	5.90×10^{-10}	1.377×10^{-3}
Starlight	5.852×10^{-10}	1.66×10^{-10}	2.393×10^{-4}
Overcast	5.852×10^{-11}	1.66×10^{-11}	2.393×10^{-5}

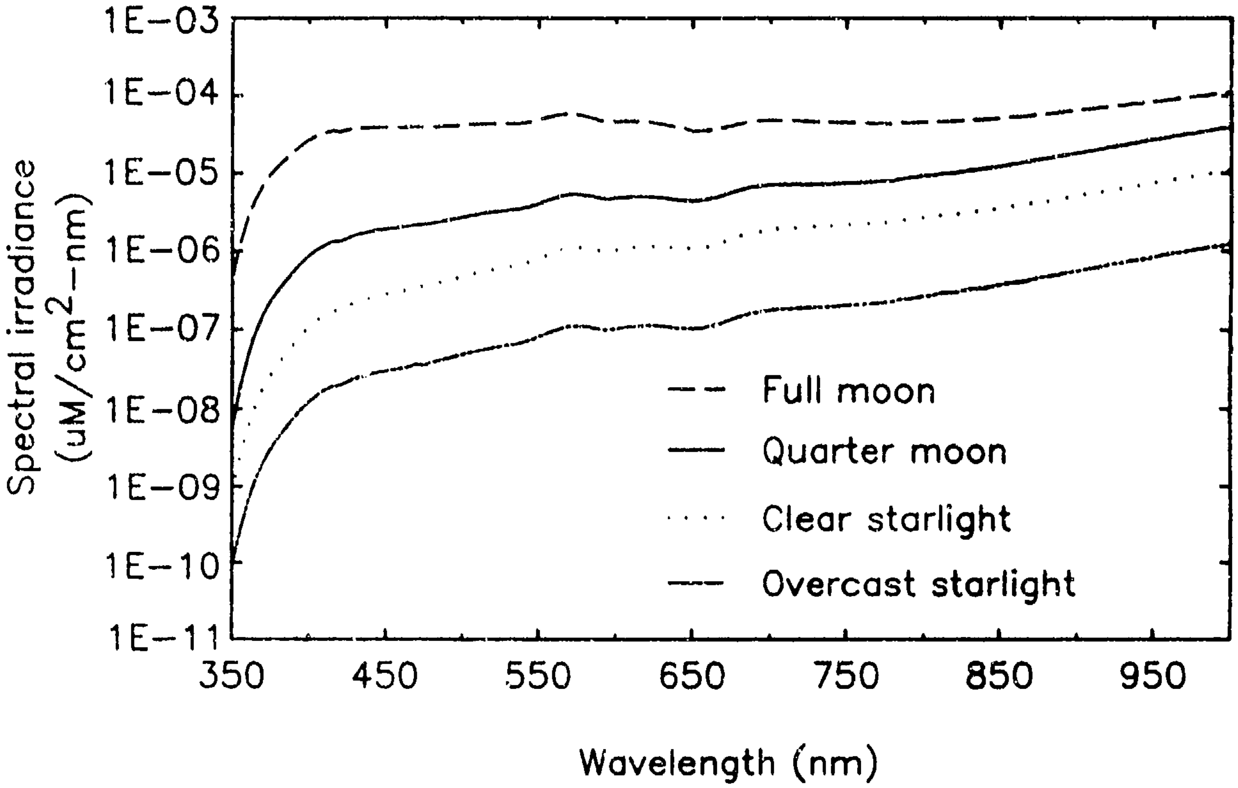

Figure 4. Spectral irradiance curves of night sky projector.

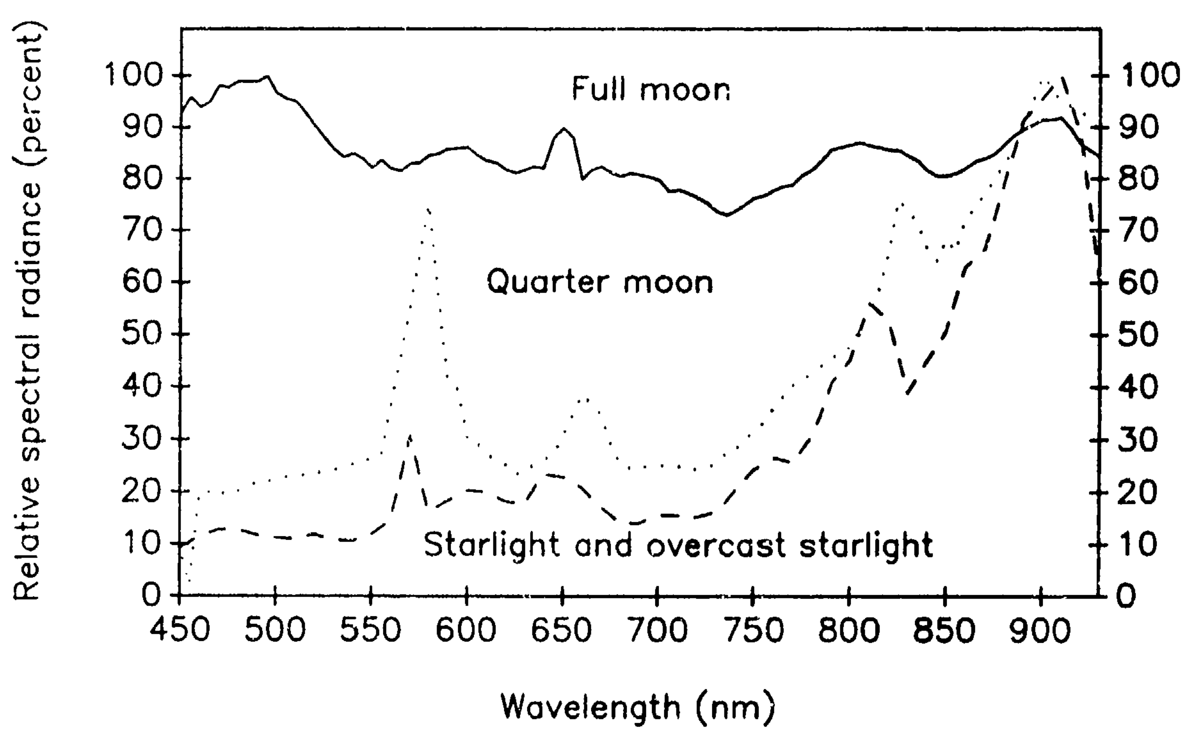

Figure 5. Night sky radiance.

Because the contrast of an object frequently varies between NVG generations (Decker, 1988; Pollehn, 1988) as a result of spectral sensitivity differences between detectors (Figure 6), we adapted a technique from Stefanik (1989) which controls for unwanted between-generation differences in NVG response. This technique weights the radiant flux falling on a detector by the

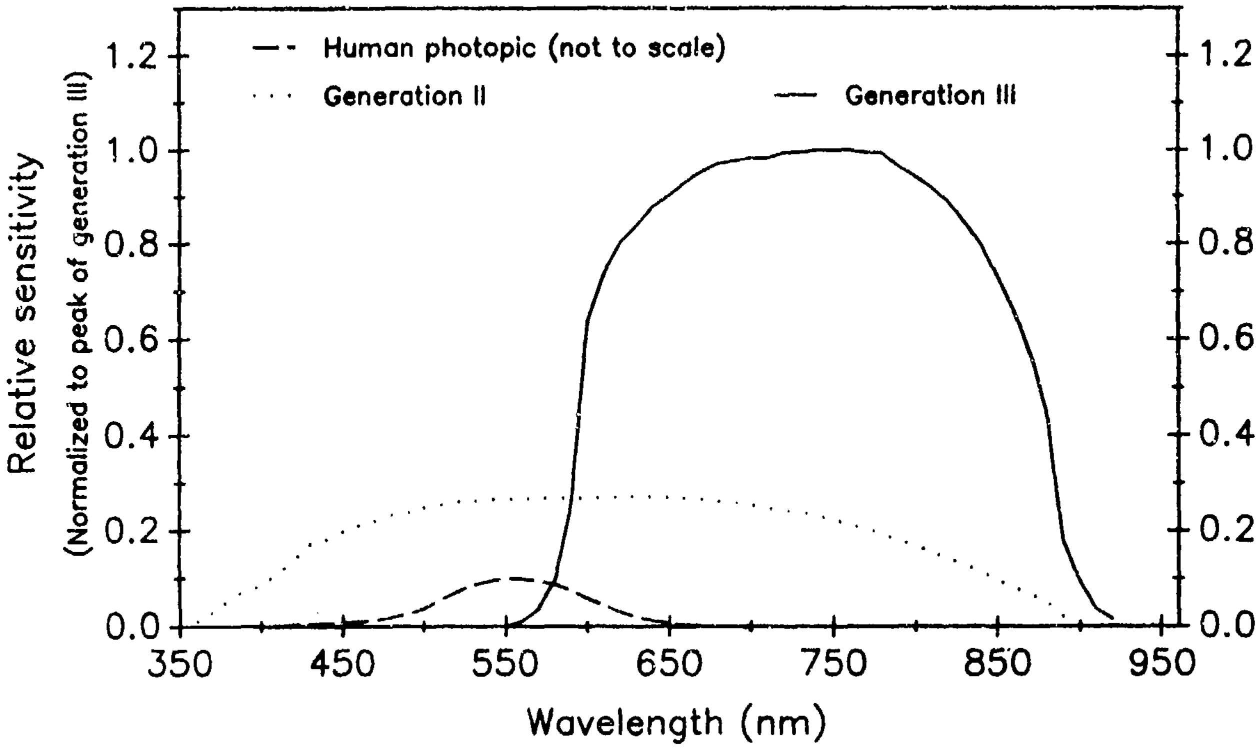

Figure 6. Comparison of spectral sensitivity between humans and night vision goggles.

spectral sensitivity of that detector. To do so, we measured the spectral radiance $N(\lambda)$, in which λ represents wavelength, of three charts (one from each contrast level) under each of the four night sky conditions. We derived the term $N(\delta)$, which represents the weighted spectral radiance of detector δ, by multiplying $N(\lambda)$ by the detector's spectral response function $R(\lambda,\delta)$, and integrating the product over the detector's sensitivity range.

$$N(\delta) = \int R(\lambda,\delta)\, N(\lambda)\, d\lambda$$

The spectral response function $R(\lambda,\delta)$ is plotted for each NVG generation and for the human visual system in Figure 6. For the human observer, the spectral response function is the photopic luminous efficiency function $V(\lambda)$, and the weighted spectral radiance $N(\delta)$ (when multiplied by a constant k) is equivalent to the photometric quantity luminance L.

$$N(\delta)\, k = L = k\int V(\lambda)\, N(\lambda)\, d\lambda$$

Contrast C was calculated separately for each sensor from its respective weighted radiance $N(\delta)$ using the following equation,

$$C = \frac{N(\delta)_{MAX} - N(\delta)_{MIN}}{N(\delta)_{MAX} + N(\delta)_{MIN}} \, X\, 100$$

in which the maximum and minimum values of the weighted radiance correspond to the background and letters respectively. A similar definition of contrast has been used in other NVG studies (Levine and Rash, 1989a and 1989b; Wiley, 1989; Riegler et al., 1991). Tables 4-6 give, for their respective sensors, contrast values for each chart as a function of night sky condition (missing values are due to radiometer noise at low radiance levels). Contrast was constant across the night sky condition, which is not surprising because contrast depends only on the difference between letter and background weighted radiance and not on mean weighted radiance. On the other hand, it is somewhat surprising

Table 4.

Second generation target contrasts.

Night sky condition	Contrast (%)		
	High	Medium	Low
Full moon	98	10	5
Quarter moon	97	14	7
Clear starlight	-	12	6
Mean	98	12	6

Table 5.

Third generation target contrasts.

Night sky Condition	Contrast (percent)		
	High	Medium	Low
Full moon	98	12	7
Quarter moon	97	12	7
Clear starlight	-	13	6
Mean	98	12	7

Table 6.

Human observer target contrasts.

Night sky condition	Contrast (percent)		
	High	Medium	Low
Full moon	98	10	5
Quarter moon	97	11	7
Clear starlight	-	12	6
Mean	98	11	6

that contrast varied little among the three sensors. This suggests that for the VA charts used in our experiments, both the letters and the background had similar reflectivities across the range of wavelengths used. Contrast also was measured with a hand-held spot photometer under photopic conditions using an incandescent light source, which yielded values of 96, 11, and 4 percent for the high, medium, and low contrast charts, respectively. These are in close agreement with the values calculated from radiance measurements under night sky conditions (Table 6). Values of 11-12 percent were selected to represent medium contrast because on a log scale such values are roughly intermediate with respect to our high and low contrast values.

Visual acuity has been shown to be proportional to the log of contrast both for aided viewing with NVGs (Wiley, 1989) and for unaided viewing under photopic (Regan, 1988) and scotopic (Blackwell, 1946) conditions. The target contrast range is consistent with that reported for real world objects (Pollehn, 1988).

NVG generations. The second and third generation devices used in our experiments were an AN/PVS-5 NVG (Figure 7) and an AN/AVS-6 Aviator Night Vision Imaging System (ANVIS) (Figure 8), respectively. Both were tested by an aviation life support equipment technician on a TS-3895/UV ANVIS Test Set, and met the resolution standard for aviation (Table 7). Table 1 lists the average display luminance of the target letters and background for each generation and night sky condition. The values given in Table 1 are consistent with those typically reported in the literature, which give peak luminances of 0.9 and 2.2 footlamberts (fL) for second and third generation NVGs respectively (Verona and Rash, 1989).

Figure 7. AN/PVS-5 night vision goggles.

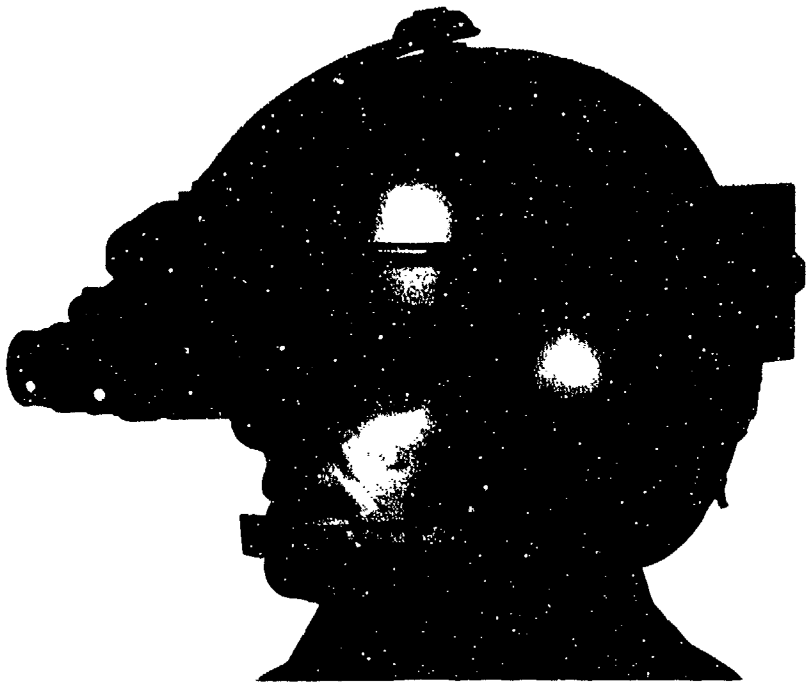

Figure 8. AN/AVS-6 Aviator Night Vision Imaging System.

Table 7.

Resolution test results.

Night vision goggles	Test score			
	Low illumination		High illumination	
	R	L	R	L
AN/PVS-5	6/6	6/6	2/2	2/2
AN/AVS-6	6/6	6/6	2/2	2/2

Experimental procedures. Recent evidence suggests that improper user adjustments adversely affect VA with NVGs (Berkley, 1991). In addition, it has been reported that dioptric blur has a profound influence on VA with letter charts (Thorn and Schwartz, 1990). As a consequence, an investigator adjusted the objective lenses, the eyepiece lenses, and the interpupillary distance of the NVGs prior to each use. Subjects were not allowed to change these adjustments.

During the experiment, each subject was seated in a light-tight room with his head supported by a chin rest. An investigator controlled the experiment from an adjacent room, and communicated with the subject by means of an intercom. A research assistant was stationed in the light-tight room to carry out functions which could not be remotely controlled. Testing was done at 10 feet, but targets that were subthreshold at 10 feet were retested at 5 feet. At the latter distance, the objective lenses were again focused by an investigator.

Thresholds were obtained binocularly, the most common method of reporting VA for grouped data (Coren, 1987). There are minor differences in the way thresholds are determined between Bailey (Ferris et al., 1982) and Regan (Regan, 1988). For the sake of uniformity, we used a single method (Bailey's) to determine threshold regardless of chart type. In Bailey's method, credit is given for each letter read correctly. There was no time limit and no reinforcement.

Results

Overview. Figures 9 and 10 summarize the data for second and third generation NVGs, respectively. These same data appear in tabular form in Appendix B. The data are expressed as thresholds, with smaller values on the ordinate representing better performance. Eight of 12 possible thresholds were obtained with the second generation, while 10 of 12 were obtained with the third. The missing data were the result of elevated thresholds under degraded stimulus conditions, i.e., low night sky radiance and low target contrast. Appendix B provides best case values for each of the missing thresholds.

To achieve symmetrical data for statistical analysis, the overcast starlight and low contrast conditions were deleted. The remaining 12 thresholds (3 night sky conditions X 2 contrasts X 2 generations) were analyzed with analysis of variance with repeated measures. Statistically significant main effects occurred for night sky condition ($df = 2/38$, $F = 241.2$, $p < 0.0001$), contrast ($df = 1/19$, $F = 259.16$, and $p < 0.0001$), and

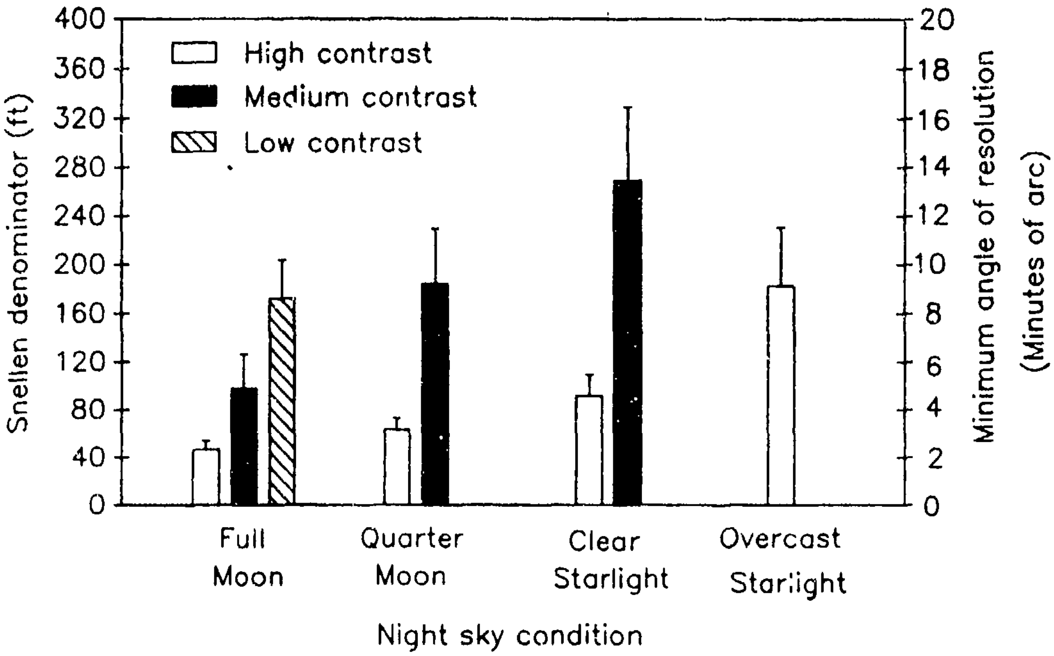

Figure 9. Visual acuity with generation II devices.

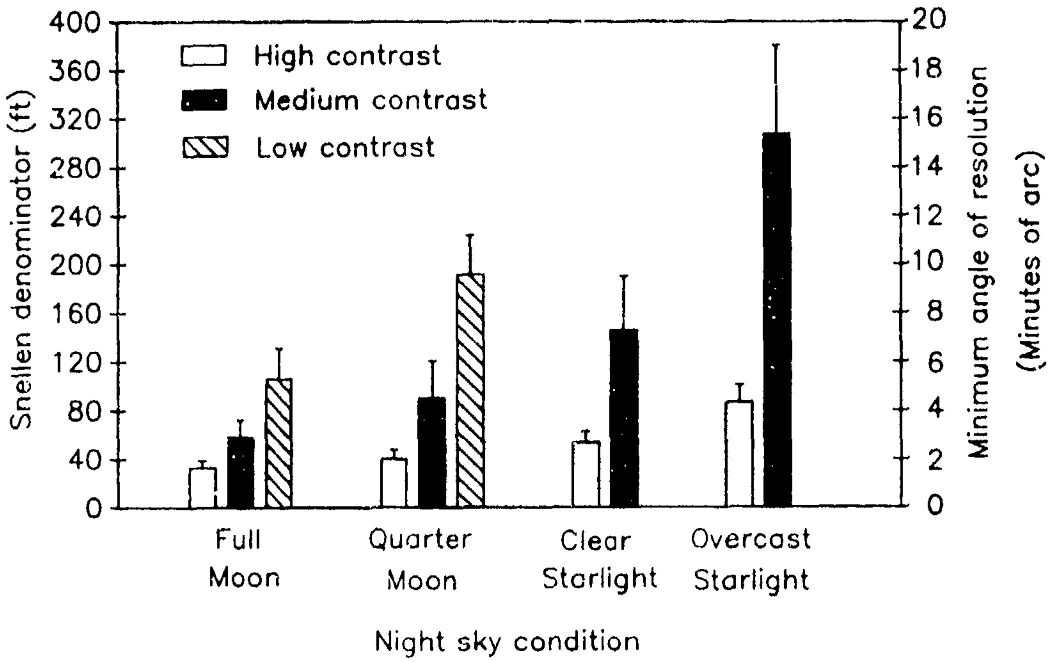

Figure 10. Visual acuity with generation III devices.

generation (df = 1/19, F = 134.49, p <0.0001). The sphericity assumption, however, was violated for night sky condition. Therefore, the p-values for night sky condition (including its interactions with contrast and generation) were adjusted (when necessary) using the Greenhouse-Geisser method (Grieve, 1984).

Generation specific effects. There were statistically significant interactions between generation and night sky condition (df = 2/38, F = 54.39, p < 0.0001), and between generation and contrast (df = 1/19, F = 40.51, p < 0.0001). Figure 11 demonstrates that VA degrades more rapidly with decreasing night sky irradiance with second generation NVGs than it does with third. Figure 12 illustrates that VA degraded in a similar way for contrast.

Contrast specific effects. The interaction between contrast and night sky condition was statistically significant (df = 2/38, F = 107.56, p < 0.0001). Figure 13 shows that VA degrades more quickly with decreasing night sky radiance when contrast was low

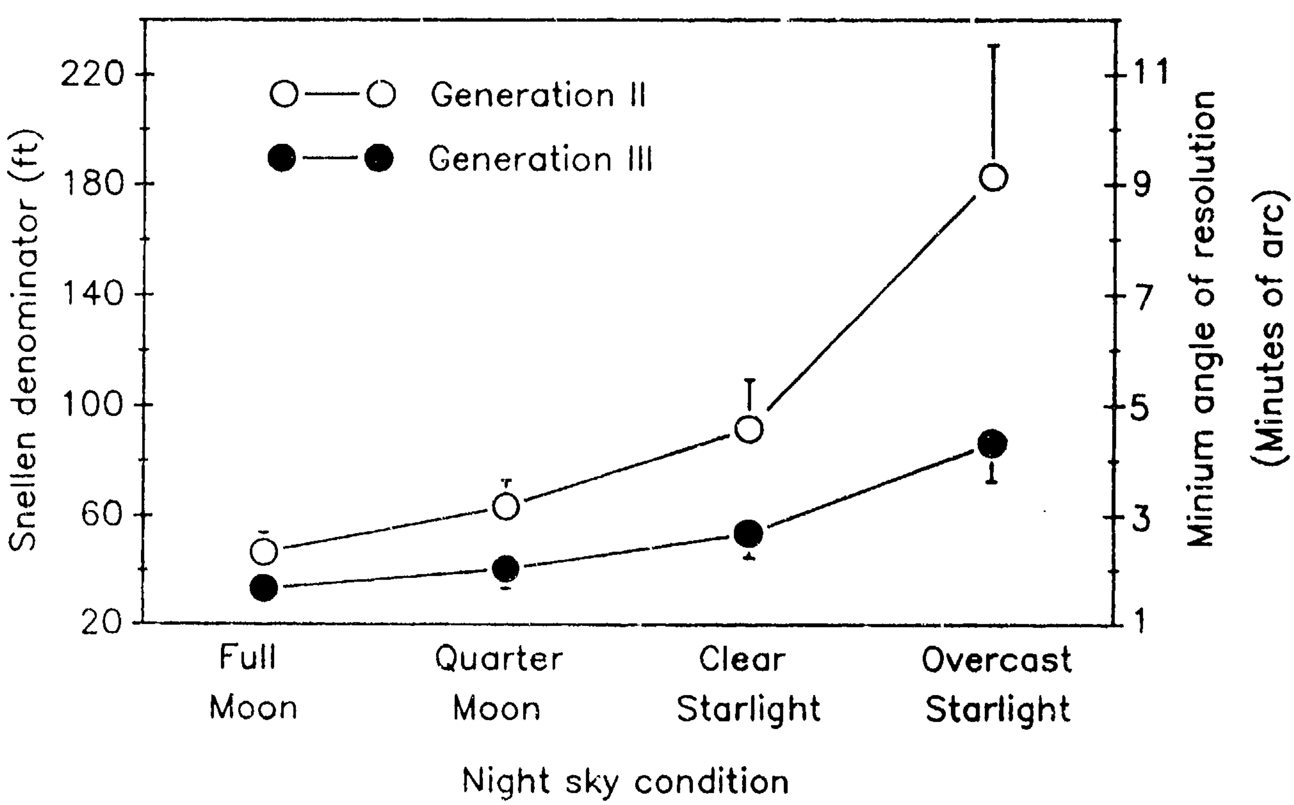

Figure 11. Visual acuity as a function of night sky condition and generation of night vision goggle with high contrast targets.

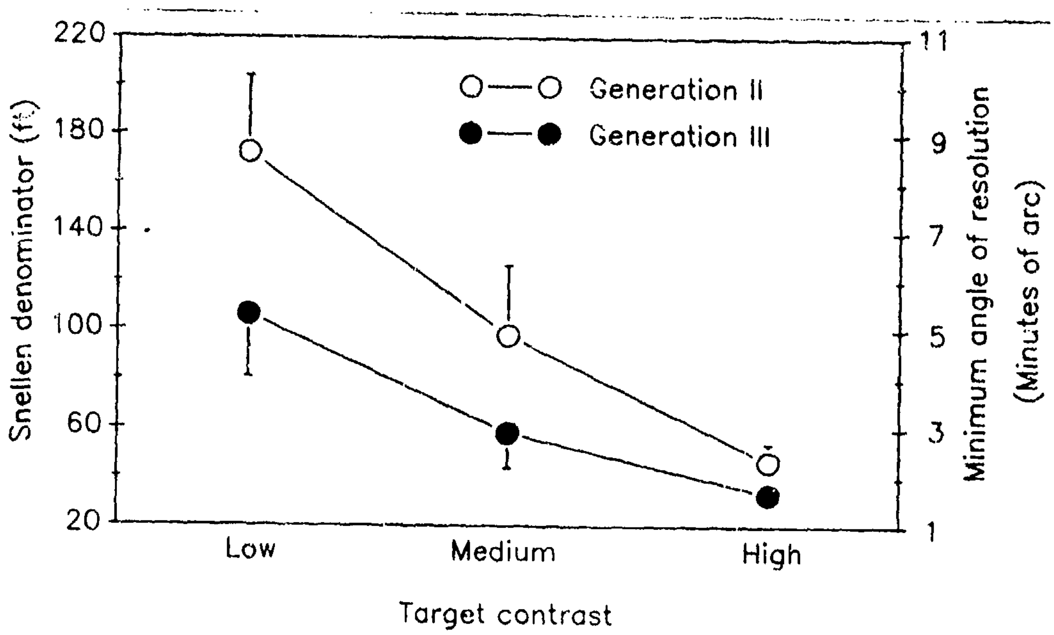

Figure 12. Visual acuity as a function of contrast and night vision goggle generation under simulated full moon radiance.

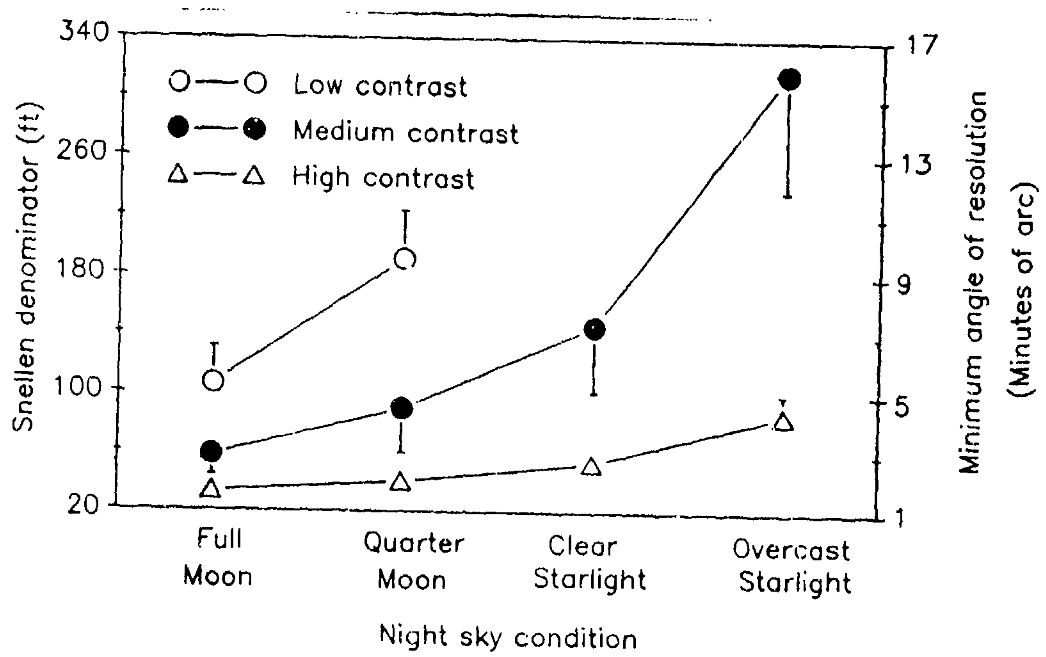

Figure 13. Visual acuity as a function of night sky condition and target contrast with generation III night vision goggles.

than when contrast was high. This effect was more pronounced with second generation NVGs than with third ($df = 2/38$, $F = 16.96$, $p < 0.0001$) (Figures 9 and 10).

Linear and quadratic trends. Too few levels were present for trend analysis of contrast and generation. However, the data for night sky condition fit either a linear ($df = 1/19$, $F = 308.05$, $p < 0.0001$) or quadratic ($df = 1/19$, $F = 5.31$, $p < 0.04$) model. The slopes of the regression lines relating VA to night sky condition are markedly steeper for second generation NVGs than for third ($df = 1/19$, $F = 94.81$, $p < 0.0001$). This was consistent with the generation specific effects described above and plotted in Figure 11. No difference was noted for the non-linear trend across generations ($df = 1/19$, $F = 1.39$, $p > 0.25$). The regression line slopes relating VA to night sky condition were also steeper for medium contrast than for high ($df = 1/19$, $F = 147.62$, $p < 0.0001$) (see generation specific effects above and Figure 12). Again there was no difference in the analogous non-linear trends ($df = 1/19$, $F = 0.08$, $p > 0.78$).

Discussion

This study confirmed that VA with both NVG generations declines monotonically with decreasing night sky irradiance and with diminishing target contrast (Figures 9 and 10). In addition, it demonstrated that, when between-generation differences in contrast are eliminated (see methods), VA is consistently better with third generation NVGs than it is with second (Figures 11 and 12). However, it was learned that the difference in VA between NVG generations widens with decreasing night sky irradiance (Figure 11) and with declining target contrast (Figure 12). Furthermore, we found that VA degraded more rapidly with decreasing night sky irradiance as target contrast was lowered (Figure 13).

The results of this investigation agree with those of the only published field study of VA with NVGs (Miller et al., 1984). Miller and his colleagues reported mean third generation VA was 20/86$\pm$19 for a high contrast target viewed under "slightly overcast starlight." This fits between our means for clear starlight (20/54$\pm$9) and overcast starlight (20/87$\pm$14) for a high contrast target (Figure 11). In addition, Miller's mean second generation VA (for the same conditions) was 20/124$\pm$54, which fits between our clear starlight mean of 20/92$\pm$18, and our overcast starlight mean of 20/183$\pm$48. This suggests our method of night sky simulation produces results for both generations similar to those obtained under actual night sky conditions, at least for a limited range of conditions.

In addition, our second generation data are similar to analogous results from a laboratory study which used a CRT (with neutral density filters) to generate stimuli (Wiley, 1989). Wiley's VA means were 20/50±6 and 20/62±11 when a high contrast target was viewed under full and quarter moons respectively, while our means were 20/47±7 and 20/63±9 for the respective conditions. The 2-group T-test indicated that there was no significant difference between the means for either the full moon (df = 28, T = 1.16, $p > 0.25$) or the quarter moon (df = 28, T = 0.49, $p > 0.62$) conditions. This suggests that second generation NVG VA measurements obtained using a second order night sky simulation are not much different from those obtained with a less involved approach. This is probably because the spectral response of second generation NVGs overlaps the spectral output of CRTs and that of any other conceivable light source designed for human vision.

On the other hand, the spectral response of third generation NVGs, and especially ANVIS (with its minus blue filter), does not necessarily overlap the spectral output of photopic light sources (Wiley, 1989). However, incandescent lamps are among those photopic sources whose output does overlap the sensitivity range of third generation NVGs (RCA handbook, 1974). Incandescent sources with spectrally flat filters (first order simulations) have been used in third generation studies which seek to determine the resolution limits of the NVGs themselves (Vollmerhausen, Nash, and Gillespie, 1988), and in studies which seek to measure human VA while the NVGs are in use (Miller et al., 1989; Donohue-Perry, Riegler, and Hausman, 1990; Riegler, Whiteley, Task, and Schueren, 1991). The emphasis of these two types of studies is clearly different, but their methods and results are not. The results of both types of studies, as well as those of the present investigation (second order simulation) are summarized in Figures 14 and 15, which depict data for high (≥90 percent) and medium (between 12-20 percent) target contrasts, respectively. There is no obvious difference between first and second order simulations for full and quarter moon conditions for either level of contrast. However, at clear starlight the results appear to disagree, e.g., there is a statistically significant difference between the results of the present study and those of Donohue-Perry et al. (1990) for high (df = 24, T = 9.66, $p < 0.000001$) and medium (df = 24, T = 4.52, $p < 0.0002$) contrast targets. Insufficient data are available at overcast starlight to draw conclusions.

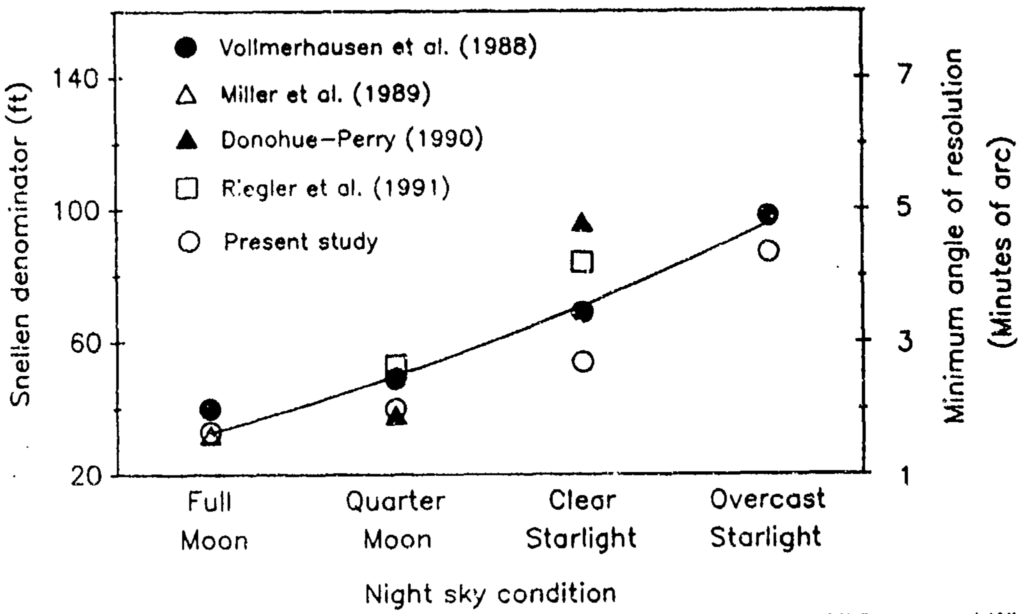

Figure 14. Visual acuity as a function of night sky condition, generation III laboratory data, for high contrast targets.

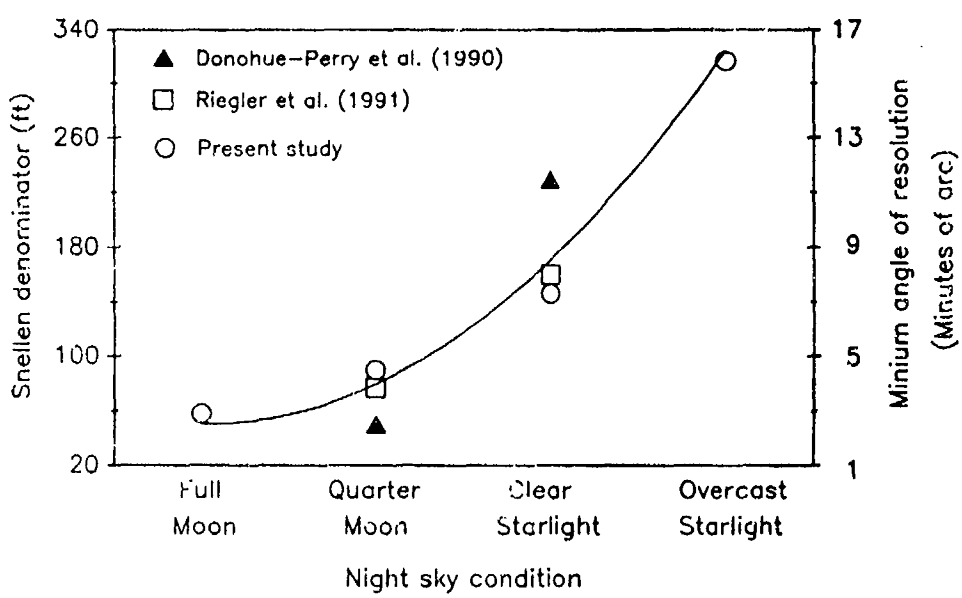

Figure 15. Visual acuity as a function of night sky condition, generation III laboratory data, for medium contrast targets.

Conclusions

1. The difference in VA between second and third generation NVGs widens with:

a. Decreasing night sky irradiance (when target contrast is constant).

b. Decreasing target contrast (when night sky irradiance is constant).

2. For either NVG generation, VA degrades more rapidly with decreasing night sky irradiance for targets of lower contrast than for targets of higher contrast.

3. The night sky simulation method used in this study, which we call a second order simulation, results in VA measurements that are the same as those obtained:

a. Under night sky conditions in the field, regardless of NVG generation (at least for a limited range of conditions).

b. With a first order night sky simulation method, which uses a CRT with spectrally flat filters (at least for a limited range of conditions).

4. It is not clear whether the night sky simulation method used in this study results in VA measurements that are the same as those obtained with incandescent sources and spectrally flat filters.

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Appendix A.

List of equipment manufacturers.

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Appendix B.

Experiment data in tabular form.

Table B-1.

Visual acuity (±1 standard deviation).

Second generation night vision goggles.

Night sky condition	Contrast (percent)		
	High	Medium	Low
Full moon	20/47±7	20/98±29	20/172±32
Quarter moon	20/63±9	20/185±45	>20/250
Starlight	20/92±18	20/269±68	>20/250
Overcast	20/183±48	>20/600	>20/250

Table B-2.

Visual acuity (±1 standard deviation).

Third generation night vision goggles.

Night sky condition	Contrast (percent)		
	High	Medium	Low
Full moon	20/33±6	20/58±14	20/186±25
Quarter moon	20/40±7	20/90±30	20/191±32
Starlight	20/54±9	20/146±44	>20/250
Overcast	20/87±14	20/317±88	>20/250

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