USAARL Report No. 96-26

Image Contrast and Visual Acuity Through Night Vision Goggles

By

Jeff C. Rabin

Aircrew Health and Performance Division

May 1996

U.S. Army Aeromedical Research Laboratory
Fort Rucker, Alabama 36362-0577

Notice

Qualified requesters

Qualified requesters may obtain copies from the Defense Technical Information Center (DTIC), Cameron Station, Alexandria, Virginia 22314. Orders will be expedited if placed through the librarian or other person designated to request documents from DTIC.

Change of address

Organizations receiving reports from the U.S. Army Aeromedical Research Laboratory on automatic mailing lists should confirm correct address when corresponding about laboratory reports.

Disposition

Destroy this document when it is no longer needed. Do not return it to the originator.

Disclaimer

Human use

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRMC Reg 70-25 on Use of Volunteers in Research.

Reviewed:

RICHARD R. LEVINE
LTC, MC
Director, Aircrew Health and Performance Division

Released for publication:

JOHN A. CALDWELL, JR.
Chairman, Scientific Review Committee

DENNIS F. SHANAHAN
Colonel, MC, MFS
Commanding

Unclassified
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. 96-26	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION U.S. Army Aeromedical Research Laboratory 6b. OFFICE SYMBOL *(If applicable)* MCMR-UAD	7a. NAME OF MONITORING ORGANIZATION U.S. Army Medical Research and Materiel Command
6c. ADDRESS *(City, State, and ZIP Code)* P.O. Box 620577 Fort Rucker, AL 36362-0577	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	3M162787A879	B6	164

11. TITLE *(Include Security Classification)*
(U) Image Contrast and Visual Acuity Through Night Vision Goggles

12. PERSONAL AUTHOR(S)
Jeff Rabin

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT *(Year, Month, Day)*	15. PAGE COUNT
Final	FROM TO	April 1996	8

16. SUPPLEMENTAL NOTATION

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
Night vision goggles, visual acuity, contrast, night vision aids, luminance

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

Night vision goggles (NVGs) intensify ambient illumination making it possible to see in the dark despite insufficient light for normal vision. NVGs are used for military and civilian operations, and as visual aids for night blindness. The quality and quantity of vision achieved through NVGs depends on several factors including the intensity of ambient radiation, the integrity of NVG electro-optical components, and the luminance, contrast and resolution of the NVG display. The purpose of this study was to investigate effects of display contrast and luminance on visual resolution through NVGs. Computer-generated letter charts were used to measure visual acuity across the range of luminances and contrasts one can encounter when viewing an NVG display. The results indicate that display luminance cannot, in itself, account for the level of acuity achieved through NVGs. An attenuation of contrast through NVGs better explains the level of resolution obtained. Understanding the contrast and luminance transfer of NVGs is important for predicting human visual performance, and for developing improved night vision devices.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Chief, Science Support Center	22b. TELEPHONE *(Include Area Code)* (334) 255-6907 22c. OFFICE SYMBOL MCMR-UAX-SI

DD Form 1473, JUN 86 *Previous editions are obsolete.*

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

Abstract

Night vision goggles (NVGs) intensify ambient illumination making it possible to see in the dark despite insufficient light for normal vision. NVGs are used for military and civilian operations, and as visual aids for night blindness. The quality and quantity of vision achieved through NVGs depends on several factors including the intensity of ambient radiation, the integrity of NVG electro-optical components, and the luminance, contrast and resolution of the NVG display. The purpose of this study was to investigate effects of display contrast and luminance on visual resolution through NVGs. Computer-generated letter charts were used to measure visual acuity across the range of luminances and contrasts one can encounter when viewing an NVG display. The results indicate that display luminance cannot, in itself, account for the level of acuity achieved through NVGs. An attenuation of contrast through NVGs better explains the level of resolution obtained. Understanding the contrast and luminance transfer of NVGs is important for predicting human visual performance, and for developing improved night vision devices.

Key words: night vision goggles, night vision aids, visual acuity, contrast, luminance

Table of contents

List of figures

Introduction

Night vision goggles (NVGs) amplify ambient illumination making it possible to see at night when there is insufficient light for normal vision. NVGs are used for military aviation and ground operations, law enforcement, and as low vision aids for patients with night blindness (Wiley, Glick, & Holly, 1983; Verona, 1985; Verona & Rash, 1989; Rash, Verona, & Crowley, 1990; Berson, Mehaffey, & Rabin, 1974; Hoover, 1983). Notwithstanding their utility, NVGs present an isochromatic view of the world limited in contrast and detail. It is important to understand both the benefits and limitations of these devices so that performance can be predicted across a range of environmental conditions.

The basic components of an NVG are shown in Figure 1. After passing through objective optics, ambient radiation strikes a photocathode sensitive to long wavelength visible and near infrared light (600-900 nm). Electrons from the photocathode then strike the microchannel plate (intensification element) which increases electron flow. The electrons then impinge upon the phosphor screen resulting in the release of green (P20 phosphor), visible light. Light is intensified 2000x making vision and performance possible in an otherwise dark environment.

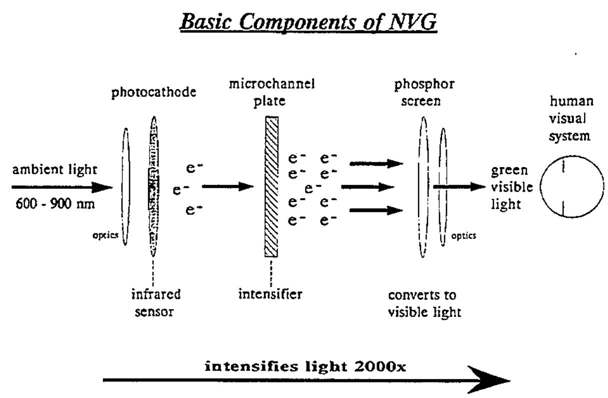

Figure 1. The internal components of a night vision goggle. Ambient radiation (600-900 nm) strikes a photocathode element which releases electrons to the the image intensifier (microchannel plate). This results in an increased number of electrons which then impinge upon the phosphorescent display releasing green, visible light.

While the NVG diagram in Figure 1 is straightforward, the level of vision achieved through NVGs depends on numerous factors including the luminance, contrast, and resolution of the visual display (Verona, 1985; Verona & Rash, 1989). The luminance of the display changes as function of input (ambient) illumination which spans a 3 log unit range between full moon and overcast starlight (RCA Electro-Optics Handbook, 1974). The luminance is also subject to internal feedback mechanisms which control the brightness of the display (Stefanik, 1988). Contrast is determined by the modulation transfer function of electrical and optical components, and visual effects of electro-optical noise. Display resolution is governed by the spacing between elements of the microchannel plate which allow for visual acuity of about 20/40 under optimal ambient conditions. However, acuity through NVGs declines with decreasing night sky illumination (Vollmerhausen, Nash, & Gillespie, 1988; Wiley, 1989; Levine & Rash, 1989; Donohue-Perry, Riegler, & Hausman, 1990; Riegler, Whiteley, Task, & Schueren, 1991; Kotulak & Rash, 1992); the specific origin of this effect is unclear.

The purpose of this study was to investigate the effects of display luminance and contrast on visual acuity through NVGs. This was done by simulating the viewing conditions of the NVG display, and measuring visual acuity across a range of luminances and contrasts. The results indicate that display luminance cannot, in itself, account for the level of acuity achieved. An attenuation of contrast through NVGs must be invoked to explain the level of resolution obtained. Understanding limitations imposed by the amount of contrast and luminance transferred through NVGs is essential for predicting visual performance, and for developing improved night vision devices.

Methods

Visual acuity was measured with computer generated letter charts displayed on a color monitor. Temporal presentation, contrast, and chromaticity were under software control. Luminance was measured with a calibrated photometer and stored in tabular form. The green gun of the color monitor was used to display the letter charts in order to simulate the green phosphor of NVGs. The letter charts and methods of measurement were based on the work of Bailey and colleagues (Bailey & Lovie, 1976; Bailey, Bullimore, Raasch, & Taylor, 1992). Three charts having different letter sequences were produced. This made it possible for the experimenter to change charts between trials in order to minimize memory and learning effects. Letter luminance appeared as decrements relative to the background, and letter contrast was varied on different charts by varying the luminance of the letter relative to the background. Chart luminance was also controlled with neutral density (ND) filters placed in a filter holder immediately in front of the subject's eye.

The letter chart displays were viewed monocularly in a darkened room from a distance of 2.7 meters. Two sets of measurements were obtained from each subject to evaluate the effects of luminance and contrast on visual acuity. In the luminance evaluation, the charts were presented at maximum (97 percent Michelson) contrast, and luminance was varied with ND filters placed directly before the subject's eye. The luminances tested ranged from 0.006 fL to 46.2 fL in 0.3 log unit (i.e., 2x) steps. The series of luminances was presented in ascending order to minimize light adaptation and learning effects. The subject initially adapted to the lowest luminance for about 5 minutes, and then attempted to read each line of the acuity chart starting at the top. As noted earlier, the letter sequence was changed between trials to reduce learning effects.

To evaluate the effect of letter contrast on visual acuity, charts were presented at six different contrasts ranging from 4.8 percent to 71.3 percent in approximately 1.8x steps. The luminance of these charts was constant (0.2 fL), corresponding approximately to a third generation NVG display in starlight ambient conditions. The charts were presented in ascending order of contrast to minimize learning effects. Since acuity improves with contrast, visual acuity was scored by letter in logarithmic units and converted to Snellen equivalents.

Four adult volunteers (ages 21-29; mean age = 25 years) participated in this study. Each subject had normal vision with visual acuity corrected to 20/20 during testing.

Results

Figure 2 shows mean (±1SE) high contrast visual acuity from four subjects plotted as a function of display luminance. As reported in previous studies, visual acuity is maximum at moderate to high light levels, but decreases at values <0.6 fL. This reduction in visual acuity with luminance (<1fL) is best described by a power law function:

$$\text{Snellen denominator} = 17.4 \times (\text{luminance})^{-0.31} \qquad r^2 = 0.98$$

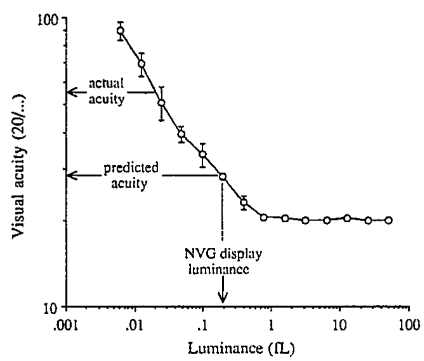

Figure 2. Mean (±1SE) high contrast visual acuity from four subjects plotted against display luminance. The approximate luminance of an NVG display in starlight is indicated. The visual acuity "predicted" from this level of luminance and the "actual" acuity through NVGs under starlight conditions are also indicated.

Figure 2 also shows the approximate luminance of the NVG display in starlight ambient conditions, the visual acuity predicted from this level of luminance, and the actual acuity obtained through NVGs (Kotulak & Rash, 1992). It is clear that the actual acuity through NVGs is 2x less than the value predicted from the luminance of the display. In fact, luminance would have to be 10x less to produce this level of visual acuity. This indicates that the luminance of the NVG display cannot explain the level of resolution achieved.

If display luminance cannot account for the acuity achieved, then other factors such as the contrast of the NVG display must limit visual acuity. To estimate the contrast of acuity letters through NVGs, stimulus luminance was reduced to the level of an NVG display in starlight (0.2 fL), and acuity was measured across a range of letter contrasts. Figure 3 shows mean (±1SE) visual acuity from four subjects plotted against letter contrast at a luminance corresponding to the NVG display in starlight. Visual acuity decreases as a power function of contrast:

$$\text{Snellen denominator} = 119 \times (\text{contrast})^{-0.35} \qquad r^2 = 0.99$$

As shown in Figure 3, this relation is linear on a log-log plot. NVG acuity measured in starlight conditions (Kotulak & Rash, 1992) also is shown in Figure 2 to indicate the letter contrast that would yield this acuity (a contrast of only 9 percent). This suggests that the contrast of acuity letters is substantially attenuated through NVGs.

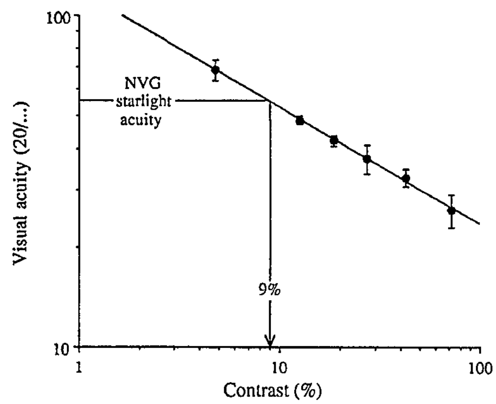

Figure 3. Mean visual acuity (±1SE) from four subjects plotted against letter contrast. The luminance (0.2 fL) was approximately equal to an NVG display in starlight conditions. The least squares regression line is shown (a power function which is linear on log-log coordinates). High contrast visual acuity measured through NVGs under starlight conditions is indicated. The arrow points to the letter contrast that would give this acuity (a contrast of 9 percent).

The results in Figure 3 have been replotted in Figure 4 with NVG acuities from previous studies measured under starlight light levels (Vollmerhausen, et al., 1988; Wiley, 1989; Levine & Rash, 1989; Donohue-Perry, et al., 1990; Riegler, et al., 1991; Kotulak and Rash, 1992). Acuities are plotted against the stimulus contrast specified in each study. Note that acuities through NVGs are lower and thus fall above the power law relation derived in the present study. The arrow pointing leftward indicates that contrast would have to be reduced by an order of magnitude for the NVG acuities to be explained by the present results. This reinforces the notion that the contrast of fine detail is attenuated through NVGs. This attenuation probably reflects limitations imposed by the modulation transfer function of the device, as well as masking effects of electro-optical noise.

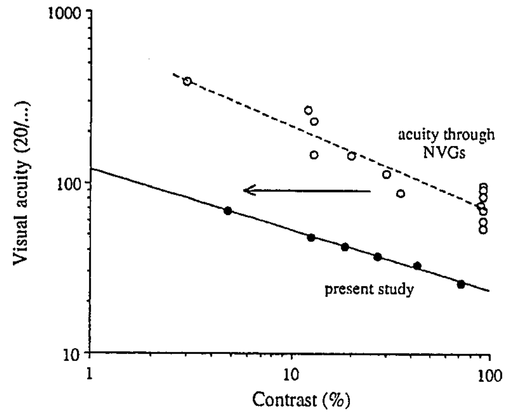

Figure 4. The data from Figure 3 are replotted along with NVG visual acuities from previous studies measured under starlight conditions. These acuities are plotted against the stimulus contrast specified in each study. The arrow pointing leftward indicates that contrast would have to be reduced by an order of magnitude for NVG acuities to be explained by the relation derived in the present study.

Discussion

This study demonstrates that contrast attenuation plays an important role in limiting visual acuity through NVGs. Measurements of acuity across a range of luminances indicated that NVG display luminance cannot readily account for the level of acuity achieved. An attenuation of stimulus contrast must be invoked to explain the resolution obtained.

The amount of contrast attenuation through NVGs is determined by several factors, including the modulation transfer functions of optical and electrical components and visual effects of electro-optical noise. In addition to contrast loss, it is likely that a reduction in the luminance of the NVG display contributes to resolution loss at low levels of night sky illumination. Additional visual factors, such as inaccurate accommodation and increased pupil size, may also limit the level of visual acuity achieved through NVGs.

Physical measurement of modulation transfer through NVGs is challenging since it requires making precise measurements over small areas, often at very low light levels. The present results suggest that contrast attenuation through NVGs and electro-optical noise impose significant constraints on the level of resolution achieved. Understanding the contrast and luminance transfer of NVGs, and how they vary with night sky condition, helps predict performance and contribute to the development of improved night vision devices.

References

Bailey I.L., Bullimore M.A., Raasch, T.W., Taylor, H.R. 1991. Clinical grading and the effects of scaling. Investgative Ophthalmology and Visual Science. 32: 422-32.

Bailey I.L., Lovie, J.E. 1976. New design principles for visual acuity letter charts. American Journal of Optometry and Physiological Optics. 53: 740-45.

Berson, E.L., Mehaffey, L., Rabin, A.R. 1974. A night vision pocketscope for patients with retinitis pigmentosa. Archives of Ophthalmology. 91: 495-500.

Donohue-Perry, M.M., Riegler, J.T., Hausman, M.A. 1990. A compatibility assessment of the protective integrated hood mask with ANVIS night vision goggles. Wright-Patterson Air Force Base, OH: Armstrong Aerospace Medical Research Laboratory. AAMRL Report No. AAMRL-TR-90-030.

Hoover, K.L. 1983. Visual acuity with ITT night vision aid for patients with night blindness. American Journal of Optometry and Physiological Optics. 60: 762-768.

Kotulak J.C., Rash, C.E. 1992. 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 contrasts. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 92-9.

Levine, R.R., Rash, C.E. 1989. Attenuating the output of the AN/PVS-5A night vision goggles and its effects on visual acuity. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 89-24.

Rash C.E., Verona R.W., Crowley, J.S. 1990. Human factors and safety considerations of night vision systems flight using thermal imaging systems. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 90-10.

RCA Electro-Optics Handbook. 1974. Electro-optics handbook technical series EOH-11. Lancaster: RCA Corp.

Riegler, J.T., Whiteley, J.D., Task, H.L., Schueren, J. 1991. The effect of signal-to-noise ratio on visual acuity through night vision goggles. Wright-Patterson Air Force Base, Ohio: Armstrong Laboratory. AL Report No. AL-TR-91-0011.

Stefanik, R.J. 1988. Non-linear gain characteristics of image intensifier tubes. Fort Belvoir, VA: Night Vision and Electro-Optics Directorate.

References (Continued)

Verona R.W. 1985. Image intensifiers: past and present. In AGARD Number 379, Visual protection and enhancement. C1.1-C1.5.

Verona, R.W., Rash, C.E. 1989. Human factors and safety considerations of night vision systems flight. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 89-12.

Vollmerhausen, R.H., Nash, C.J., Gillespie, J.B. 1988. Evaluation of pilotage sensors at Reforger '87. Fort Belvoir, VA: Center for Night Vision and Electro-Optics.

Wiley, R.W. 1989. Visual acuity and stereopsis with night vision goggles. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 89-9.

Wiley, R.W., Glick, D.D., Holly, F.F. 1983. AN/PVS-5 night vision goggles: What you gain, what you lose. Aviation Digest. May: 1-6.