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THE EFFECT OF SIGNAL-TO-NOISE RATIO ON VISUAL ACUITY THROUGH NIGHT VISION GOGGLES

Joseph T. Riegler

LOGICON TECHNICAL SERVICES, INC.
DAYTON, OH 45431-7258

James D. Whiteley, Ph.D.
H. Lee Task, Ph.D.
James Schueren, M.S.

CREW SYSTEMS DIRECTORATE
HUMAN ENGINEERING DIVISION

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FOR THE COMMANDER

Kenneth R Boff

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13. ABSTRACT (Maximum 200 words) Since 1971, night vision goggles (NVGs) have been used by the military to enable personnel to perform visual operations in a nighttime environment. The key component of these devices is the image intensifier tube. Currently, no studies were identified which relate the signal-to-noise ratio (SNR) of image intensifiers to human visual acuity. The purpose of the present research was to determine the effect of NVG intensifier tube SNR on visual acuity. Visual acuity, using PVS-7 third generation NVGs, was measured for twelve participants at quarter moon and starlight illumination levels for four intensifier tubes with different SNRs. The range of SNR examined was 11.57 to 17.92. Visual acuity was assessed using Landolt C charts with target contrasts of 20 to 95 percent. The distance at which the acuity targets were resolved was recorded for each of the four illumination and contrast conditions. The results showed that increases in image intensifier tube SNR, illumination level, and contrast affected visual acuity. Regression analyses were performed to obtain estimated equations relating SNR to visual acuity for each experimental condition. The results were used to develop predictive guideline tables to provide approximate percent degradation/improvement in visual acuity based upon intensifier tube signal-to-noise ratio.

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Summary

The purpose of the present research was to determine the effect of NVG image intensifier tube signal-to-noise ratio (SNR) on visual acuity. Visual acuity through PVS-7 NVGs was measured for twelve subjects at quarter moon and starlight illumination levels for four intensifier tubes with different SNRs. The range of SNRs examined was 11.37 to 17.92. Visual acuity was assessed using Landolt C charts with target contrasts of 20 and 95 percent. The results showed that image intensifier tube SNR, illumination level, and contrast had significant effects on visual acuity. Regression analyses were performed to obtain estimated equations relating SNR to visual acuity for each illumination and contrast condition.

The results showed a trend toward SNR having a greater impact on visual acuity at the two lowest illumination conditions than at the higher illumination condition. The results were used to produce guideline tables for estimating percent increases in visual acuity as a function of intensifier tube SNR. Due to the large differences between subjects in visual acuity performance with NVGs, it was concluded that further research should be conducted to examine the correlation between visual acuity obtained for unaided normal room light viewing and NVG viewing.

Preface

This evaluation was completed under work unit 7184-18-07 by members of the Crew Systems Effectiveness Branch, Human Engineering Division, Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio and Logicon Technical Services, Inc., Dayton, Ohio. The authors thank Annette Zobel (LTSI) for her technical support throughout this study and Chuck Goodyear (LTSI) for his assistance with data analysis and interpretation.

Contents

List of Figures

List of Tables

Introduction

Night vision goggles (NVGs) have been developed by the US Army for use in night military operations. The key component of these devices is the image intensifier tube. The image intensifier tube is basically a light amplifier that is sensitive over the spectral region of about 600nm to 900nm (for the third generation intensifier). There are a number of parameters that are used to characterize the image intensifier such as gain, resolution, brightness, distortion, signal-to-noise ratio, etc (see Csorba [1]). Measurement procedures exist for determining the value of these parameters and others. However, there have been very few studies that relate these parameters to their impact on human visual performance with the NVGs. Specifically, no studies could be found that related the signal-to-noise ratio (SNR) with human visual acuity even though there exist specifications as to the SNR required for image intensifiers.

The purpose of the study described herein was to determine the effect of SNR on visual acuity. Four PVS-7, third generation image intensifier tubes were acquired that had four different SNRs. The PVS-7 tube was chosen because the PVS-7 NVGs use a single objective lens and a single image intensifier that is imaged to both eyes via beamsplitting optics and two eyepieces. This allowed the subject to observe the image through the NVGs with both eyes.

Visual acuity is normally measured by determining the minimum angular subtense of a specified test character (e.g. Landolt "C", tumbling "E", or Snellen letter) at which an observer can determine the orientation of the character (Landolt "C", tumbling "E") or be able to read the character (Snellen letters). A typical eye chart used for this type of measurement consists of lines of characters of different sizes. However, these charts are designed for use in vision screening and, due to the character size increments, are not very well suited for research.

Two other factors that affect visual acuity (both direct view and through night vision goggles) are contrast and illumination level. Visual acuity tends to be poorer for lower contrast levels and lower illumination levels.

Based on this information, it was decided to investigate visual acuity with the PVS 7 NVGs for two different illumination levels and two different contrasts. It was also necessary to develop a methodology by which the angular subtense of the visual acuity test character could be made continously variable to permit more accurate determination of acuity. Since angular subtense depends on the distance from the subject to the test target, a technique was used that continuously varied this distance in a controlled fashion. The subject was seated in a cart that moved at a uniform speed along a track toward the test target. This methodology provided an excellent means of getting a sensitive measure of visual acuity.

Method

2.1 Subjects

Twelve male volunteers participated in this study. The subjects ranged in age from 18 to 34 years (mean = 23.8, SD = 5.0). Each subject reported good ocular health and visual acuity of at least 20/20 corrected in each eye for distance vision.

2.2 Facilities and Equipment

The facility used for data collection was the zoom lane, see Figure 2.1, located in the Visual Dynamics Facility, Armstrong Aerospace Medical Research Laboratory, Human Engineering Division, Wright-Patterson AFB, Ohio. The equipment comprising the zoom lane was an electronically controlled cart powered by an electric motor and operated via a retractable cable system. The cart itself contained a height adjustable, high-backed seat, a side stick controller to input cart stop commands and an armrest to reduce arm fatigue during the experiment. A black plexiglass board was positioned on the front of the cart such that it could be raised to occlude vision between experimental runs. The subject was seated inside the cart, which traveled along a 12.2 meter (m) track. System control was provided by a Zenith 248 computer, which allowed the experimenter to input movement commands (e.g., starting, stopping, velocity and direction) and data collection functions from a remote control panel.

A moonlight simulator was used to approximate the spectral characteristics and luminance intensity levels of different phases of the moon. It was mounted on a tripod which was adjusted to provide calibrated illumination on the surface of the Landolt C charts used as visual stimuli for assessing visual acuity. A Photo Research PR-1980b Pritchard Photometer was used to measure the photometric luminance of the charts and background. This was performed several times during each session to verify that the luminance of the

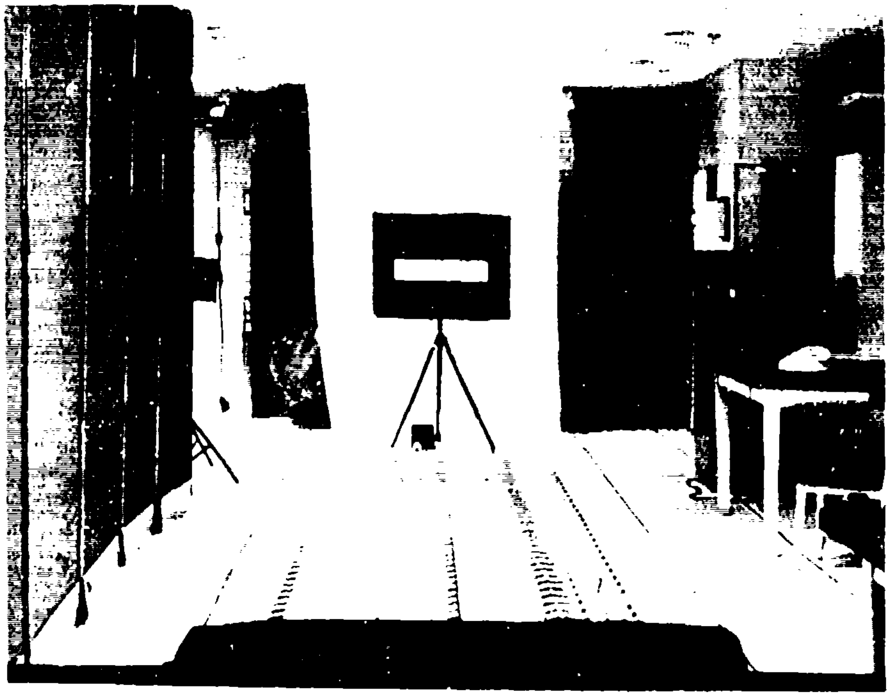

Figure 2.1: AAMRL Zoom Lane Laboratory

chart remained constant.

A pair of ITT AN/PVS-7B biocular night vision goggles (NVGs) were used as the optical test platform for this research. Four ITT third generation image intensifier tubes with similar characteristics, but different signal-to-noise ratios were used.

The AN/PVS-7B NVGs, like most NVGs, have a relatively fast (low F/number) objective lens to gather as much light as possible to enhance performance of the NVGs. However, this low F/number also reduces the depth of focus of the NVGs which, for the present experimental procedure, posed a problem. Since the dependent variable of this experiment was the angular subtense of the acuity target obtained by varying the distance from the observer to the chart, a large depth of focus was required. The depth of focus needed to be sufficiently large that the quality of the image would not be degraded over the zoom lane cart distance range (12.2 to 3.05 m; see Fig 2.2).

Depth of focus can easily be increased by reducing the objective lens aperture of the NVGs. However, this reduces the irradiance produced by the lens at the input side of the image intensifier tube. This effect can be corrected by increasing the radiance of the target to compensate for the light energy lost due to reducing the objective lens aperture. Since the irradiance at the image plane of a lens (the input side of the NVGs in this case) is proportional to the square of the clear aperture of the lens (usually the lens diameter), then the revised radiance necessary can be calculated from the square of the ratio of the original lens diameter to the modified lens system diameter (the aperture placed over the lens). The PVS-7 lens has an effective diameter of 20.8 mm. and the aperture used to increase depth of focus was 4 mm. Thus the target radiance was increased by a factor of $(\frac{20.8}{4})^2$ or 27. Table 2.1 lists some converted values used for this study.

2.3 Stimuli

Visual Acuity Charts

The Landolt C chart format was chosen as the visual stimulus for measuring acuity in this study. Visual acuity was assessed for two levels of positive letter-to-background contrast, 20 and 95 percent. Modulation contrast (C) was calculated using the following equation:

$$C = \frac{Backgrnd_{Lum} - Target_{Lum}}{Backgrnd_{Lum} + Target_{Lum}}$$

A visual acuity of 20/20 represents detection of a gap width (open end of C) subtending 1 minute of arc, using the Landolt C procedure. The Landolt C letter size is five times its gap width. Two letter sizes were used to ensure that both the high and low contrast letters would remain in focus and could be resolved within the zoomlane range (12.2 m to 3.05 m). Letters having gap widths of 4.7 mm and 7.6 mm were used for the high and low contrast conditions, respectively. These represented Snellen fraction sizes of 20/36 and 20/57 at a distance of 9.1 m (30 ft.). The Landolt Cs were displayed on acuity charts which measured 0.15 m by 0.61 m and contained high contrast or low contrast letters on a white background. The letters were separated by a distance of 70 mm.

Each trial was initiated at a distance of 12.2 m from the acuity chart. The trial ended when the subject was able to determine the orientation of each C on the chart. The change in angular subtense of the Landolt C gap as a function of distance from the acuity chart is plotted in Figure 2.2 for both high and low contrast letters.

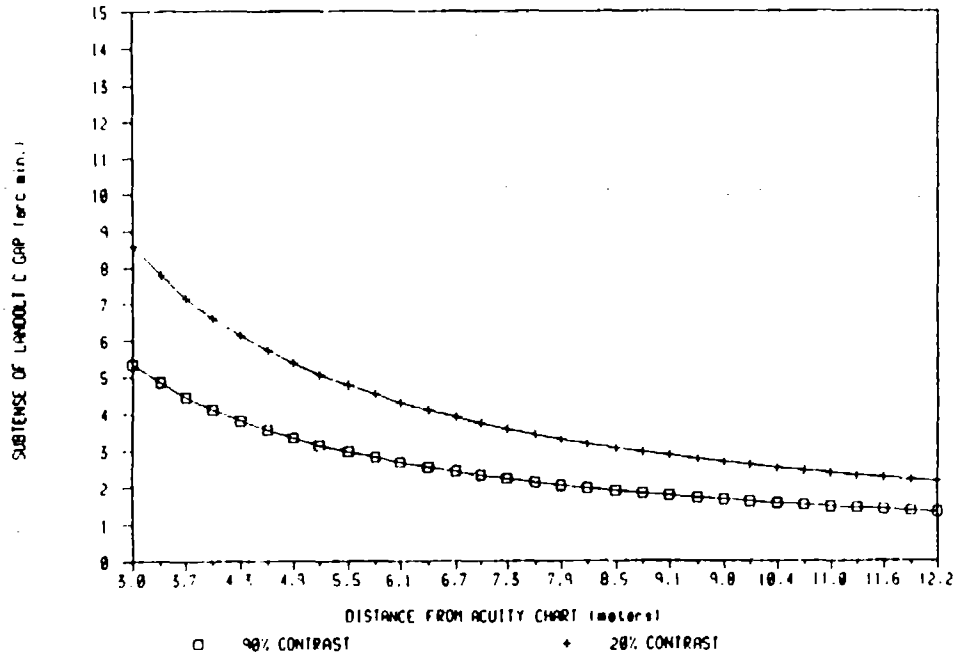

Figure 2.2: Change in Landolt C gap angular subtense as a function of zoomlane distance for 20% and 95% letters

Luminance Levels

The Landolt C target stimuli were presented on white foam core boards having a reflectance of approximately 100 percent. Since there is a convention in the night vision goggle community to relate illumination levels to fraction of moon illumination, it was necessary to make some assumptions in order to arrive at an appropriate reflected luminance level from the target test chart.

The first concern was determining what level of illumination was considered to be "full moon". From the RCA Electro-Optics Handbook [2], a value of 0.0235 foot-Candles (ft.-C) illumination is listed as maximum full moon illumination. It should be noted that actual moon illumination depends heavily on weather conditions (light haze can reduce illumination considerably), moon elevation level above the horizon, and orientation of the surface illuminated. Further, the vast majority of naturally occurring objects have a reflectance factor considerably less than unity, thus reducing the apparent luminance of the object. For purposes of this study, it was decided to have the white areas of the stimulus target simulate a 30% reflective Lambertian (fully scattering) surface. Due to the way English units of luminance and illuminance are defined, one foot-candle of illumination gives rise to one foot-Lambert of luminance for illumination falling on a perfect Lambertian reflector with unity reflectance.

Table 2.1: Moon illumination and acuity chart luminance values used in present experiment

MOON ILLUM. LEVEL	DESIRED ILLUM. (Ft.-C)	ASSUMED REFLECT. (percent)	DESIRED LUM. (Ft.-L)	ADJUST. FACTOR	REQ. CHART LUMINANCE (Ft.-L)
Full	0.0235	50	0.0118	27	0.3186
0.25	0.00588	50	0.00294	27	0.0794
0.01	0.000235	50	0.000118	27	0.0032

Based on these assumptions: 1) full moon illumination is 0.0235 ft.-C, 2) the stimulus target is Lambertian (perfectly diffusing); and 3) a 50% reflective surface is desired, the simulated moon illumination source should, for full moon illumination, be adjusted to provide an illumination of 0.0235/2 or 0.0118 ft.-C, which gives rise to 0.0118 ft.-L luminance, at the white areas of the target. This value is for the NVGs with no aperture over the lens. If the aperture is in place, this value needs to be increased by a factor of 27 as discussed earlier. Table 2.1 lists the fractional moon illumination levels, the corresponding target luminance that would result from a 50% reflective surface, and the luminance that was required to compensate for the 4mm aperture over the objective lens of the NVGs.

2.4 Procedure

Training Trials

Prior to data collection each subject participated in one block of eight trials; two at each illumination and contrast condition. These trials served to familiarize subjects with the task while allowing for dark adaptation. Each subject was individually tested following the same procedure outlined for the data collection trials. On each training trial, subjects were presented a chart containing four Landolt Cs of diminishing size. Subjects stopped the cart and called out the orientation of each C in succession, starting with the largest. The cart was advanced forward until each C orientation was correctly identified.

Data Collection Trials

Each subject performed the experiment seated in the cart which moved at a constant velocity of 0.25 meters per second toward the acuity chart. At the beginning of each trial, the cart was positioned so that the subject's eyes were at a distance of 12.2 m from the acuity chart. During data collection, all the Landolt Cs on a given chart were the same size. After verifying that the subject was ready and the NVGs were properly focussed, the experimenter initiated cart movement from the computer workstation. Upon cart movement, the subject lowered the vision occluder and viewed the acuity chart. The subject stopped the cart by depressing the trigger switch on the side stick controller when he was "virtually certain" he could determine the orientation of all of the Cs. After stopping the cart, the subject read aloud the orientation of each C. If the subject's responses were correct, the distance was recorded and the cart returned to the starting position. If an incorrect response was made or the experimenter was uncertain of the subject's response, the subject was asked to read the entire chart again If the response was incorrect, the cart was advanced forward until the subject could correctly determine the orientation of each letter or until the end of the track was reached. After each trial, the subject raised the vision occluder and rested while the cart was returned to the starting position.

2.5 Experimental Design

This study incorporated a 2x2x4 repeated measures experimental design. The independent variables were the illumination level (0.01 and 0.25 moon), the contrast of the acuity charts (20 and 95 percent) and the signal to noise ratio (SNR) of the four image intensifying tubes (17.92, 15.28, 13.71 and 11.37). The dependent variable was visual acuity (measured as the minimum angle of resolution computed from the distance from the acuity targets when the subject correctly identified the orientation of all Cs. Each subject participated in 32 data collection trials, two at each experimental condition. The trials were grouped across the four image intensifier tubes and presented in blocks of eight. The order of presentation of the four blocks was counterbalanced across the twelve subjects.

Results

The distance from the NVG objective lens to the acuity chart was recorded on each trial and used to compute the mean resolution angle in minutes of arc for each condition. The data was then transformed to 1/min. of arc as a measure of visual acuity. For ease of interpretation, visual acuity will be used instead of resolution angle when describing the results and conclusions.

3.1 ANOVA Results

An analysis of variance (ANOVA) was conducted on the visual acuity data (1/min. of arc). The independent variables in the ANOVA were SNR of the image intensifier tube (4), illumination level (2), and contrast (2). SNR was considered a categorical independent variable in the ANOVA, since the signal-to-noise ratio may not be the only factor differentiating the four tubes tested. F tests involving effects with more than one degree of freedom in the numerator had a Geisser-Greenhouse correction performed [3]. All pairwise mean comparisons were done using paired t-tests from reduced models.

The mean visual acuity obtained for each intensifer tube as a function of contrast and illumination is in Figure 3.1. The results of the ANOVA showed significant main effects of SNR (P=0.0021), illumination (P=0.0001), and contrast (P=0.0001) on visual acuity, with increases in each variable resulting in increased visual acuity. The ANOVA revealed significant interactions for SNR by illumination (P=0.0061) and illumination by contrast (P=0.0183). A summary table of the ANOVA results is provided in Appendix A.

Tests for simple interactions were performed within the SNR by illumination interaction (displayed in Figure 3.2) to isolate the source of the interaction. The tests showed significant interaction (P=0.0131) only when tube SNR = 15.28 was used with each of the other levels of SNR, indicating that the effect of illumination was consistent across the three remaining tubes tested.

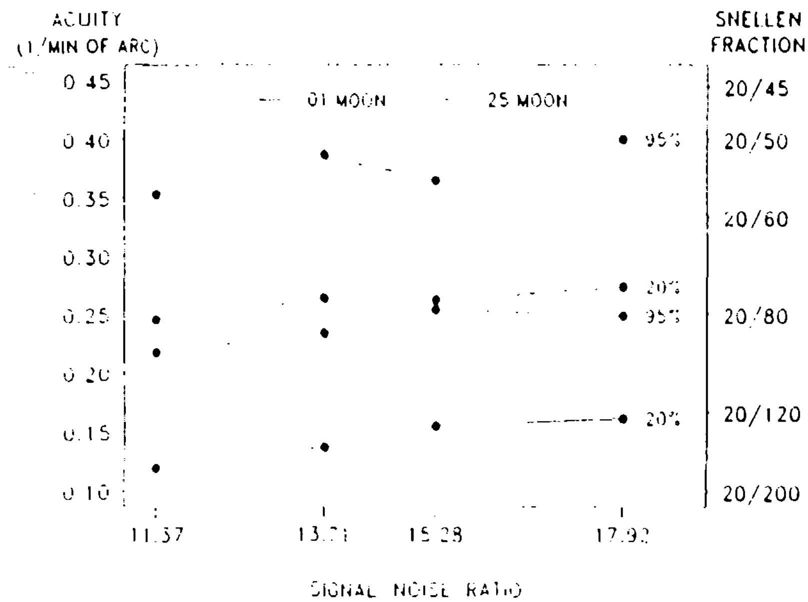

Figure 3.1: Mean visual acuity as a function of SNR, illumination, and contrast

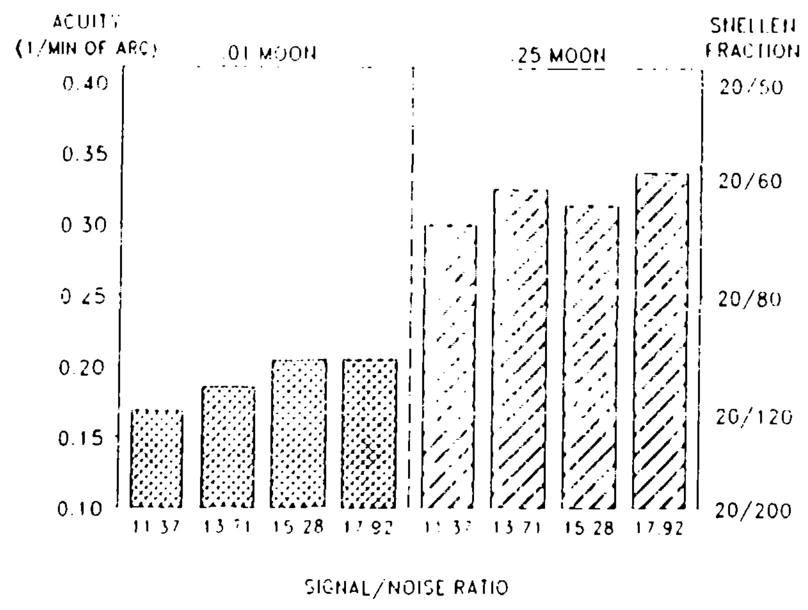

Figure 3.2: Mean visual acuity as a function of tube SNR and illumination averaged across contrast

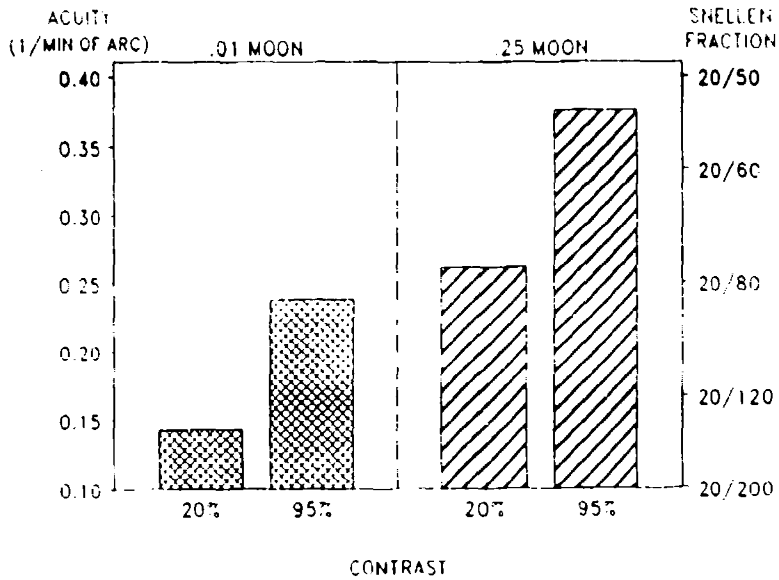

Figure 3.3: Mean visual acuity as a function of illumination and contrast averaged across SNR

Inspection of the significant illumination by contrast interaction (Figure 3.3) indicates that the mean difference in visual acuity between the two contrast conditions was significantly greater at the 0.01 moon illumination than at the 0.25 moon level. T-tests also revealed that for each level of SNR and contrast, visual acuity was significantly greater at the 0.25 moon illumination level at the 0.001 significance level.

3.2 Regression Analysis

Regression analyses were performed on the visual acuity data to obtain an estimated equation relating intensifier tube SNR to visual acuity. Separate regressions were performed for each of the four illumination and contrast conditions. In each regression, the independent variable was 1/SNR and the dependent variable was acuity in 1/min. of arc. The reciprocals were used since the relationship between SNR and acuity is asymptotic, and they provided a better fitting curve to the data than a linear model. The estimated equations are listed in Table 3.1 for each illumination and contrast condition. Plots of each estimate are displayed in Figure 3.4. Analysis of covariance indicated that the estimates describing the relationship between SNR and visual acuity did not differ significantly across the four illumination and contrast conditions, ($P = 0.016$).

The equations listed in Table 3.1 were used to produce tables of guidelines for predicting percent increases in acuity for a range of SNRs from 10 to 20, (Tables 4.1 through 4.4). Relative percent increases in visual acuity predicted for the SNRs tested in this study are listed in Table 3.2 for each condition. The values in this table represent the percent increase in acuity predicted when increasing from a specific SNR value (left column) to a higher SNR value (top row). Due to the significant interaction involving tube SNR 15.28, the regression analysis was performed again without this tube included. The estimated equations for this regression are listed in Table 3.3.

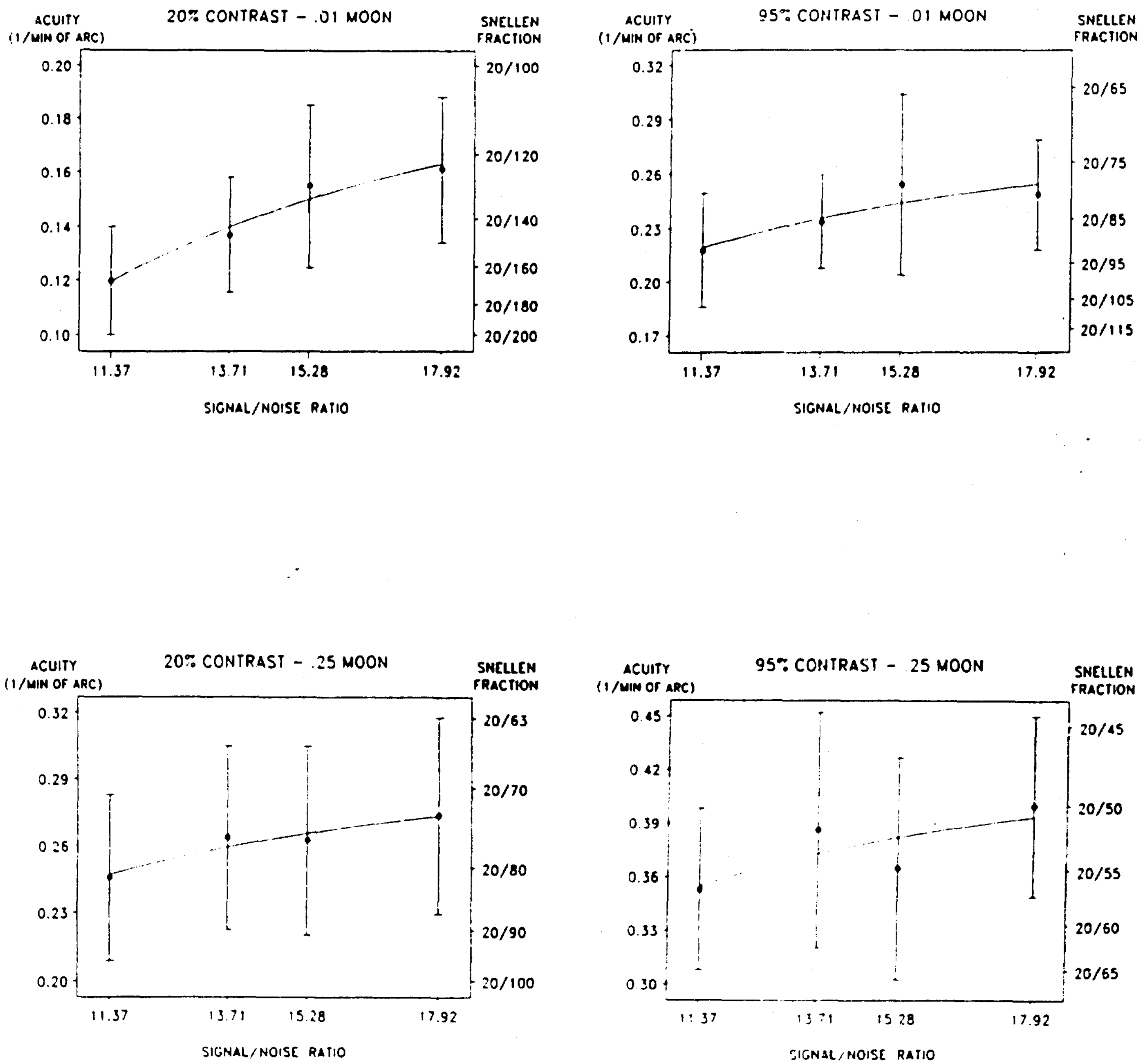

Figure 3.4: Estimated equations depicting relationship between SNR and visual acuity for each illumination and contrast condition

Table 3.1: Estimated Equations for each illumination and contrast condition

ILLUM. LEVEL	CONTRAST	ESTIMATED EQUATION	CORR	P
0.01 MOON	20%	0.2390 - 1.3596/SNR	0.98	0.0172
0.01 MOON	95%	0.3151 - 1.0875/SNR	0.91	0.0935
0.25 MOON	20%	0.3193 - 0.8217/SNR	0.96	0.0378
0.25 MOON	95%	0.4614 - 1.2107/SNR	0.78	0.2185

Table 3.2: Percent increase in visual acuity from a lower SNR (left column) to a greater SNR (top row) between the SNRs used in this study

		SNR		
CONDITION	SNR	13.71	15.28	17.92
Illum. = 0.01 Contrast = 20%	11.37	15%	20	27
	13.71		7	14
	15.28			8
		13.71	15.28	17.92
Illum. = 0.01 Contrast = 95%	11.37	7%	10	14
	13.71		3	7
	15.28			4
		13.71	15.28	17.92
Illum. = 0.25 Contrast = 20%	11.37	5%	7	10
	13.71		2	5
	15.28			3
		13.71	15.28	17.92
Illum. = 0.25 Contrast = 95%	11.37	5%	7	10
	13.71		2	5
	15.28			3

Table 3.3: Estimated equations with tube SNR 15.28 excluded from analysis

ILLUM. LEVEL	CONTRAST	ESTIMATED EQUATION	CORR	P
0.01 MOON	20%	RES = 0.2328 - 1.2966/SNR	0.99	0.0396
0.01 MOON	95%	RES = 0.3024 - 0.9572/SNR	0.99	0.0332
0.25 MOON	20%	RES = 0.3234 - 0.8630/SNR	0.98	0.1269
0.25 MOON	95%	RES = 0.4836 - 1.4387/SNR	0.96	0.1753

Discussion

The purpose of this study was to quantify the relationship between NVG image intensifier tube signal-to-noise ratio and human visual acuity. The results showed that increases in intensifer tube SNR resulted in better visual acuity at both quarter moon and starlight illumination for both high and low contrast targets. The functions describing the relationship between SNR and acuity did not statistically differ across the four conditions tested, although there was a trend toward SNR having a greater impact on acuity under lower visibility conditions. This trend failed to reach significance due to the large amount of variability between subjects and the small number of intensifier tube SNRs tested. A study using more subjects and a greater number of SNR levels may be expected to result in a significant effect of SNR on acuity under low illumination and contrast conditions. The effects of target contrast and illumination on acuity were as expected, with higher contrast and illumination levels resulting in better visual acuity.

The results of the regression analyses were used to generate tables of guidelines for predicting percent increases in acuity as a function of SNR. These guidelines, contained in Tables 4.1 through 4.4, allow the user to estimate percent increases in visual acuity performance over an SNR range of 10 to 20. The values in the tables are estimated percent increases in visual acuity as SNR is increased from a lower value (left column) to a greater value (top row).

Inspection of these tables reveals that improvements in visual acuity with increases in SNR vary depending upon the illumination and contrast. For example, Table 4.1 shows that doubling SNR (from 10 to 20) results in a 40% improvement in visual acuity for low illumination and low contrast. However, the same increase in SNR results in only a 15% increase in acuity for both the 20% and 90% contrast targets at quarter moon illumination (Tables 4.3 and 4.4). Therefore, increases in SNR have their greatest impact on visual performance under conditions of lower illumination. This is better illustrated by the following example.

It might be expected that an individual's visual acuity performance with intensifier tubes having an SNR of 20 would be significantly better than the acuity achieved with an SNR of 15 (a 33% difference in SNR). However, the present results show that such an increase results in only an estimated 13% improvement in acuity for 20% contrast targets and a 7% improvement for the 95% contrast targets at .01 moon illumination (Tables 4.1 and 4.2). Likewise, the same increase in SNR for quarter moon illumination improves acuity by only 5% for both levels of contrast (Tables 4.3 and 4.4). This may be a negligible improvement for some NVG scenarios.

It should be noted that the values in the tables are estimated increases predicted from "best case" laboratory viewing conditions. These values also represent average increases derived from the mean acuity of the individuals tested in this study. Operational scenarios, employing other measures of acuity for different individuals, may yield different results.

Subject variability also proved to be a significant factor affecting visual acuity through NVGs in the present study. Although all subjects reported 20/20 visual acuity prior to testing, acuity for NVG viewing ranged from 20/108 to 20/175 in the most degraded visibility condition (low illumination, low contrast) and from 20/42 to 20/65 in the highest illumination and contrast condition. Inspection of the data showed only slight differences in the subjects' rank order acuity performance across the four conditions, indicating that certain subjects were consistently better in their acuity performance than others. This may have been due to differences between subjects in the criterion adopted when responding to the acuity charts. Subjects showing poorer acuity may have been more conservative in responding, causing them to come in closer to the acuity chart before making a decision; whereas, subjects with better acuity may have been less conservative in making their responses and stopped the cart at greater distances from the acuity chart. This subject variability also suggests that an individual's acuity through NVGs may not be correlated with acuity measured for unaided normal room light viewing. This could have implications for NVG selection and training criteria, where a reliable pre-flight method of determining expected acuity levels during NVG flight missions is necessary. Further research should be done to determine if a correlation exists between acuity measured for unaided viewing and NVG viewing.

Table 4.1: Prediction Matrix for SNR-Visual Acuity .01 Moon 20% Contrast

	PERCENT INCREASE IN ACUITY													
SNR	11	11.37	12	13	13.71	14	15	15.28	16	17	17.92	18	19	20
10	11	14	18	23	26	27	31	31	33	35	37	37	38	40
11	-	3	8	14	17	19	22	23	25	27	29	29	31	33
11.37	-	-	5	11	15	16	20	20	22	25	27	27	29	30
12	-	-	-	6	10	11	15	15	17	20	22	22	24	25
13	-	-	-	-	4	5	9	10	13	15	18	18	20	21
13.71	-	-	-	-	-	1	6	7	9	12	14	14	16	18
14	-	-	-	-	-	-	4	5	8	11	13	13	15	17
15	-	-	-	-	-	-	-	1	4	7	9	9	11	13
15.28	-	-	-	-	-	-	-	-	3	6	8	8	10	12
16	-	-	-	-	-	-	-	-	-	3	6	6	8	10
17	-	-	-	-	-	-	-	-	-	-	3	3	5	7
17.92	-	-	-	-	-	-	-	-	-	-	-	0	3	5
18	-	-	-	-	-	-	-	-	-	-	-	-	2	4
19	-	-	-	-	-	-	-	-	-	-	-	-	-	2

Table 4.2: Prediction Matrix for SNR-Visual Acuity .01 Moon 95% Contrast

	PERCENT INCREASE IN ACUITY													
SNR	11	11.37	12	13	13.71	14	15	15.28	16	17	17.92	18	19	20
10	5	6	8	11	12	13	15	15	17	18	19	19	20	21
11	-	1	4	7	8	9	11	11	13	14	15	15	16	17
11.37	-	-	2	5	7	8	10	10	11	13	14	14	15	16
12	-	-	-	3	5	5	7	8	9	11	12	12	13	14
13	-	-	-	-	2	3	5	5	6	8	9	9	10	11
13.71	-	-	-	-	-	1	3	3	5	6	7	7	9	10
14	-	-	-	-	-	-	2	3	4	5	7	7	8	9
15	-	-	-	-	-	-	-	1	2	3	5	5	6	7
15.28	-	-	-	-	-	-	-	-	1	3	4	4	5	6
16	-	-	-	-	-	-	-	-	-	2	3	3	4	5
17	-	-	-	-	-	-	-	-	-	-	1	1	3	4
17.92	-	-	-	-	-	-	-	-	-	-	-	0	1	2
18	-	-	-	-	-	-	-	-	-	-	-	-	1	2
19	-	-	-	-	-	-	-	-	-	-	-	-	-	1

Table 4.3: Prediction Matrix for SNR-Visual Acuity .25 Moon 20% Contrast

PERCENT INCREASE IN ACUITY														
SNR	11	11.37	12	13	13.71	14	15	15.28	16	17	17.92	18	19	20
10	3	4	5	7	9	9	10	11	12	12	13	13	14	15
11	-	1	2	4	6	6	8	8	9	10	11	11	11	12
11.37	-	-	2	4	5	5	7	7	8	9	10	10	11	11
12	-	-	-	2	3	4	5	6	6	7	8	8	9	10
13	-	-	-	-	1	2	3	4	4	5	6	6	7	8
13.71	-	-	-	-	-	0	2	2	3	4	5	5	6	7
14	-	-	-	-	-	-	1	2	3	4	5	5	6	6
15	-	-	-	-	-	-	-	0	1	2	3	3	4	5
15.28	-	-	-	-	-	-	-	-	1	2	3	3	4	5
16	-	-	-	-	-	-	-	-	-	1	2	2	3	4
17	-	-	-	-	-	-	-	-	-	-	1	1	2	3
17.92	-	-	-	-	-	-	-	-	-	-	-	0	1	2
18	-	-	-	-	-	-	-	-	-	-	-	-	1	2
19	-	-	-	-	-	-	-	-	-	-	-	-	-	1

Table 4.4: Prediction Matrix for SNR-Visual Acuity .25 Moon 95% Contrast

PERCENT INCREASE IN ACUITY														
SNR	11	11.37	12	13	13.71	14	15	15.28	16	17	17.92	18	19	20
10	3	4	6	8	9	9	11	11	12	13	14	14	14	15
11	-	1	3	5	6	6	8	8	9	10	11	11	12	12
11.37	-	-	2	4	5	5	7	7	8	9	10	10	11	11
12	-	-	-	2	3	4	5	6	7	8	8	9	9	10
13	-	-	-	-	1	2	3	4	5	6	6	7	7	8
13.71	-	-	-	-	-	0	2	2	3	4	5	5	6	7
14	-	-	-	-	-	-	2	2	3	4	5	5	6	6
15	-	-	-	-	-	-	-	0	1	2	3	3	4	5
15.28	-	-	-	-	-	-	-	-	1	2	3	3	4	5
16	-	-	-	-	-	-	-	-	-	1	2	2	3	4
17	-	-	-	-	-	-	-	-	-	-	1	1	2	3
17.92	-	-	-	-	-	-	-	-	-	-	-	0	1	2
18	-	-	-	-	-	-	-	-	-	-	-	-	1	2
19	-	-	-	-	-	-	-	-	-	-	-	-	-	1

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Appendix

The results of the ANOVA conducted on the visual acuity data are summarized in Table 5.1 below.

Table 5.1: Analysis of Variance (ANOVA) Summary Table

SOURCE	SUM OF SQ.	NUM DF	DEN DF	F	P	P (G.-G.)	EPSILON
SNR	0.06769	3	33	8.55	0.0002	0.0021	0.639
ILLUM	1.57146	1	11	295.03	0.0001	NA	NA
CON	1.05767	1	11	423.98	0.0001	NA	NA
SNR*ILL	0.01235	3	33	6.00	0.0022	0.0061	0.7431
SNR*CON	0.00116	3	33	0.90	0.4501	0.4287	0.7481
ILL*CON	0.00890	1	11	7.66	0.0183	NA	NA
SNR*ILL*CON	0.00468	3	33	1.67	0.1926	0.2117	0.6609

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