REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)

2. REPORT DATE
Dec 94

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
An Image Quality Analysis of ANVIS-6 Night Vision Goggles

5. FUNDING NUMBERS

6. AUTHOR(S)
Derek H. Abel

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
AFIT Students Attending:
Virgina Polytechnic Institute

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT/CI/CIA
94-146

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
DEPRTMENT OF THE AIR FORCE
AFIT/CI
2950 P STREET
WRIGHT-PATTERSON AFB OH 45433-7765

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for Public Release IAW 190-1
Distribution Unlimited
MICHAEL M. BRICKER, SMSgt, USAF
Chief Administration

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

19950103 039

14. SUBJECT TERMS

15. NUMBER OF PAGES
62

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT

18. SECURITY CLASSIFICATION OF THIS PAGE

19. SECURITY CLASSIFICATION OF ABSTRACT

20. LIMITATION OF ABSTRACT

An Image Quality Analysis of ANVIS-6 Night Vision Goggles

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Industrial and Systems Engineering

(ABSTRACT)

This study was undertaken in an effort to relate ANVIS-6 Night Vision Goggle image quality to user performance. The purpose was to determine which of five image quality metrics best related to performance tasks. The image quality metrics examined Modulation Transfer Function Area (MTFA), Integrated Contrast Sensitivity (ICS), Square Root Integral (SQRI), Resolution, and Signal-to-Noise Ratio (SNR). The performance tasks were detection and recognition of targets under various levels of moon illumination. The metric that best related to target detection was SNR. The SNR results are consistent with visual psychophysics and SNR effects. The metric that best related to target recognition was Resolution. The resolution results are consistent with the position that recognition performance improves for suprathreshold targets as resolving power increases.

94-146

An Image Quality Analysis of ANVIS-6 Night Vision Goggles

By

Derek H. Abel

Thesis submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment for the degree of

Masters of Science

in

Industrial and Systems Engineering

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December 1994
Blacksburg Va.

ACKNOWLEDGMENTS

This research was made possible through the cooperation of ITT and their Roanoke Division. I also wish to thank the Displays and Controls Lab at Virginia Tech. Drs. R.J. Beaton and Harry L. Snyder for all their direction and advice. Mr. Mike Snow and Mr. Chuck Green who helped me throughout this project. I especially wish to thank Mr. Woody Farley, without whom I would still be in the measurements laboratory trying to figure out how to turn on the AEROTECH positioning system. I also wish to thank Tony Pesante for his advice on statistical analysis and being a good friend.

Last, but not least, I wish to thank my wife, Diane, and my sons, Michael and Anthony, for putting up with me and supporting me throughout my days at Virginia Tech.

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INTRODUCTION

Since the early 1970s, the frequency of use of Night Vision Goggles has increased dramatically in military aviation. Once the purview of Special Operations and Special Forces units, the use of ANVIS-6 Night Vision Goggles (NVGs) (Figure 1) has spread to conventional tactical aircraft. Along with the increased use of NVGs, there has been an increase in aviation accidents involving NVGs (Boyd, 1991).

In a study by Verona (1988), several aviation accidents were attributed to NVGs. Some accident causes cited by Verona were a lack of visual cues and contrast, flying too fast for the visual conditions present, an inability to determine distances to obstructions, and the nonvisibility of power lines and radio tower guide wires. Similarly, Boyd (1991) conducted a review of Army rotary-wing aircraft accidents ranging in severity from Class-A, (i.e., a total loss of aircraft or a loss of life) to Class-C, (i.e., repairable damage to equipment exceeding $10,000 or loss of work time) between fiscal years 1984 and 1989. During this time, there were 626 accidents, of which 23 percent occurred at night; 82 percent of these night accidents were attributed to crew error with 70 percent occurring while NVGs were in use. One hundred ninety-nine of all the accidents resulted in fatalities. Forty-one percent of the fatal accidents occurred at night, with 85% of this number attributed to crew error. Seventy-one percent of the fatal crew error accidents occurred while NVGs were in use. The high percentage of crew error accidents during NVG use appears to point to a breakdown in

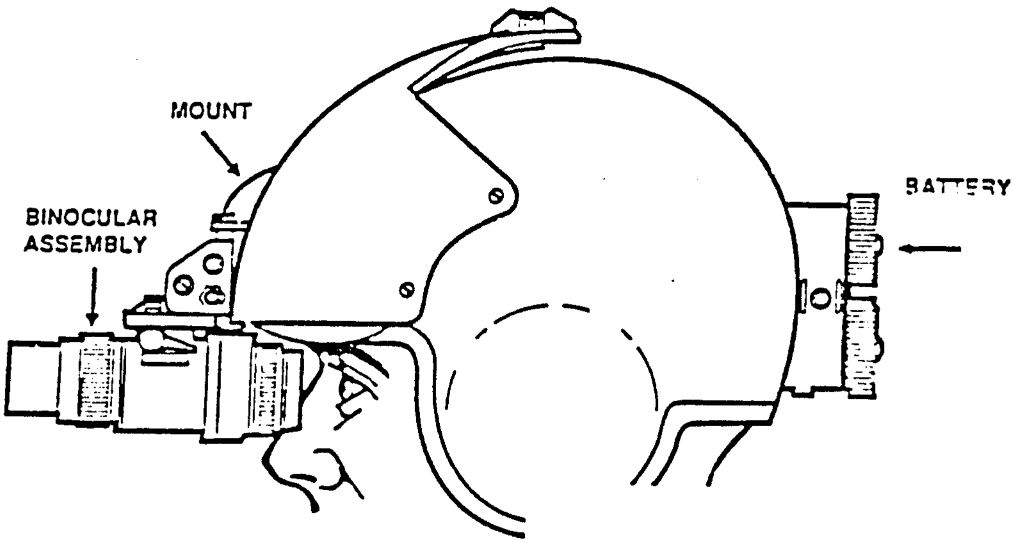


Figure 1. ANVIS-6 NVGs.
(Source: Biberman and Alluisi, 1992)

the safe use of NVGs or a deficiency of the NVG system itself (Smith and Fedor, 1984). It should be noted that one must be cautious when accepting the term "crew error," because it is used often by investigators as a catch-all phrase to explain accidents when exact causes are unclear or unknown.

In an attempt to reduce the number of NVG related accidents, one would have to look at two possible avenues. The first approach is an improvement of the system, while the second is training in the safe use of the NVGs. System improvement and safe employment of the devices depend on a better understanding of the processes that occur when looking through NVGs. It also is important to note that while NVGs can enhance night flying capabilities, they do not turn night into day (Armentrout, 1993).

According to Biberman and Alluisi (1992), NVGs can be broken down into four basic components:

1. The mounting frame which holds all the components,
2. An objective lens to focus the image onto the photocathode image intensifier,
3. A photocathode image intensifier, and
4. A unity magnification eyepiece that can be focused by the observer.

The photocathode image intensifier section consists of four distinct parts: a photocathode, a microchannel plate (MCP), a phosphor screen, and a power supply (Figure 2). The photocathode receives photons either directly from a source or reflected from an object, whether the object is natural or man-made, through the

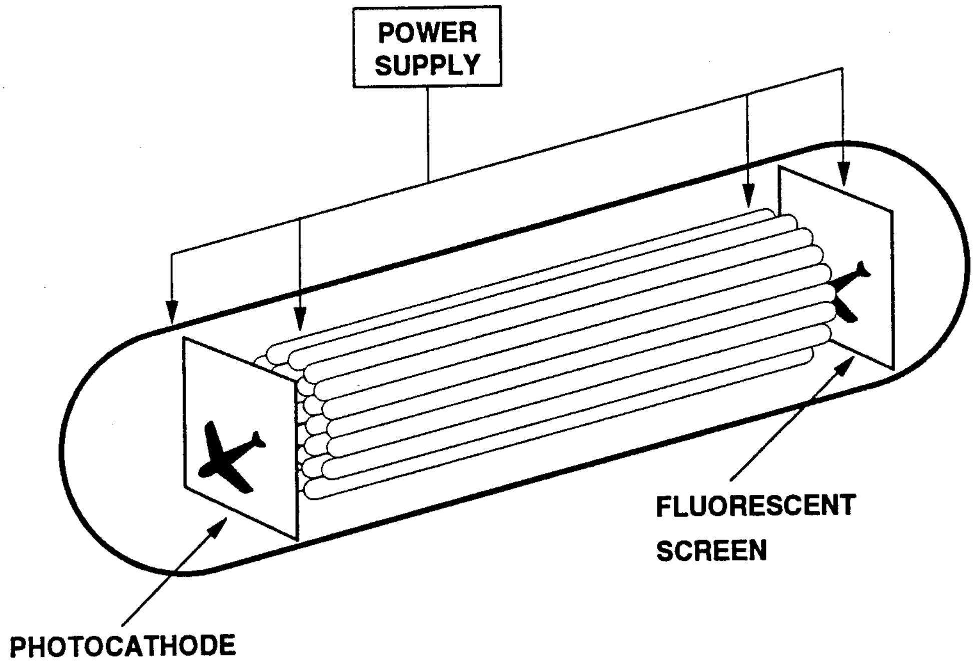


Figure 2. Image intensifier tube.

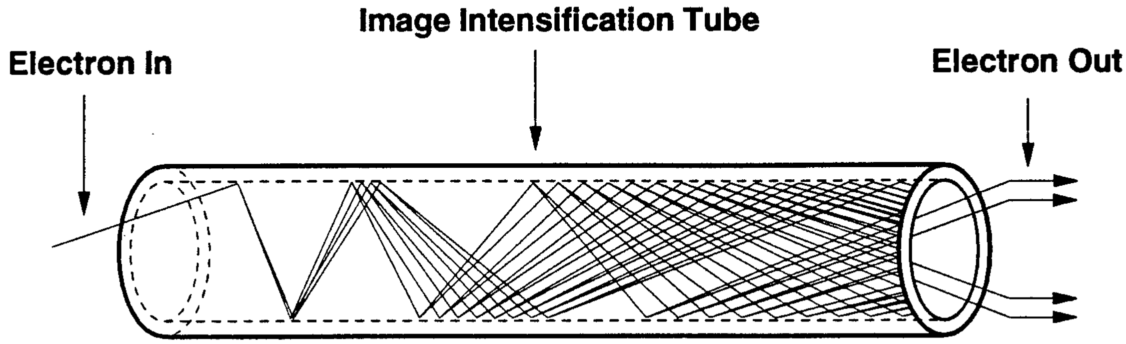
(Source: Biberman and Alluisi, 1992)

objective lens. Each photon striking the front of the photocathode releases a corresponding electron on the reverse side. The photoelectrons then strike the MCP where intensification occurs. The MCP is composed of millions of channel multipliers formed by stretching and fusing optical fibers. Each optical fiber is a hollow glass tube with lead coating on the inside surface. Whenever a photoelectron strikes the side of the fiber optic tube, it releases electrons from the lead coating. By running an electrical current through the coating, making electrons available, the channel achieves the function of multiplying each photoelectron via a chain reaction (Figure 3). Within the MCP, each photoelectron produces on the order of 10^2 to 10^8 secondary electrons. The stream of electrons emitted from the back of the MCP is projected onto a phosphor screen, creating the monochrome image that is viewed through an eye piece. The eye piece and the objective lenses are conventional unity magnification optics.

NVGs have a number of limitations that must be recognized before being used safely. The four most serious limitations are discussed below.

The first limitation is that NVGs permit at best a visual acuity of 20/40 on the Snellen scale (Price and McLean, 1985). This acuity can only be reached if the goggles are focused correctly. Biberman and Alluisi (1992) showed that the 20/40 acuity was achieved rarely by air crew members.

The second and third limitations are physical in nature. The second limitation is the field of view of the goggles, which is 40 degrees. The field of view severely limits



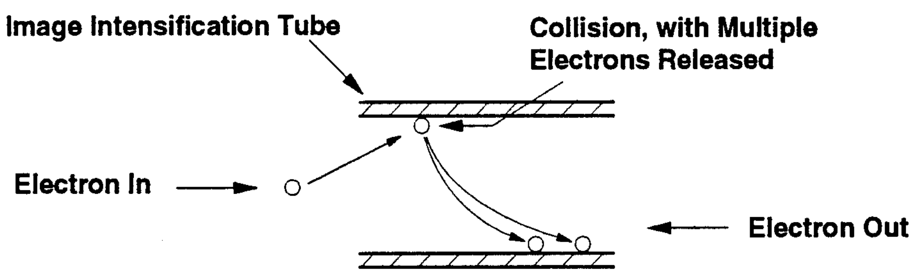


Figure 3. Multiplier tube and typical trajectories.

(Source: Biberman and Alluisi, 1992)

the aviator's peripheral vision. This limitation has been likened by many aviators to flying while looking through two toilet paper rolls.

The third limitation is visual noise. Noise appears in two forms: image noise and goggle-induced noise. Goggle induced noise consists of three effects: "sparkle," "blooming," and "halo." Sparkle is caused by random photoelectrons striking the photocathode, it also is referred to as "snow" since it resembles snow falling in front of your car while your headlights are on. Blooming and halo are related noise effects; both occur when bright lights are viewed through the goggles. Blooming, also referred to as "washing out," is caused by the spread of intensified light around the edge of the image on the screen, resulting in a blurred image. Halo is a brighter ring around an image that could cause a less bright image to go unnoticed.

The fourth limitation is degraded depth perception while wearing NVGs. This limitation was studied by Armentrout (1993). Armentrout (1993) found that depth perception performance decreases after ambient light is raised above 50% moon illumination. This also is borne out when speaking to aviators that use the NVGs on a daily basis; however, the preferred illumination levels vary from 50% to 70% moon illumination (Personal communication with U.S. Air Force and U.S. Army aircrew members from 1989 through 1993).

These limitations highlight NVG problems that need further investigation. The first is that a great number of aviators are very comfortable when flying on high illumination nights (Personal communication with U.S. Air Force and U.S. Army aircrew members from 1989 through 1993). Studies by Armentrout (1993) and Riegler, Whitely, Task, and Schueren (1991) suggest that as illumination levels increase above 50% moon illumination, there is a decrease in the resolving power and signal-to-noise ratio of the NVGs that degrades performance. This performance degradation at the higher illuminations could be leading to an unwarranted sense of comfort and complacency while flying. The current thinking in the U.S. Air Force and the U.S. Army is that higher illumination levels lead to better pilot performance.

In this paper, five image quality metrics will be considered to see how they relate to performance of persons using ANVIS-6 NVGs. The metrics considered are: Signal-to-Noise Ratio (SNR), Resolution, Modulation Transfer Function Area (MTFA), Integrated Contrast Sensitivity (ICS), and SQuare Root Integral (SQRI). There are more image quality metrics available for analyzing system performance, many of which are beyond the scope of this paper (Beaton, 1984).

Studies on SNR effects in visual psychophysics can be traced back to the work of Fechner (1860 cited by Gescheider, 1985: Hecht, Shlaer, and Pirenne, 1942; Rose 1942; and de Vries, 1943, cited by Schnitzler, 1973). Since this early work, SNR effects have been studied in the context of imaging devices with varying degrees of success (Task, 1979, Beaton, 1984).

Resolution is a system parameter that is related directly to the edge sharpness on a display. It also is related to display quality in that the smaller the discernible details on the display, the higher the quality of the display. Because resolution is a system parameter, one would expect it to be constant for a given device. Armentrout (1993) found that for ANVIS-6 NVGs, resolution was not constant across different moon illumination levels.

The concept of Modulation Transfer Function Area (MTFA) was proposed first by Charman and Olin (1965, as reported by Snyder, 1973) as Threshold Quality Factor (TQF). TQF was renamed MTFA by Borough, H.C., Fallis, R.F., Warnock, R.H., and Britt, J.H. (1967, cited by Snyder, 1973). Charman and Olin (1965, as reported by Snyder, 1973), characterized MTFA as a measure of photographic image quality that contains the cumulative effect of the various stages of the observation process, the "noise" introduced into the perceived image, and the limitations imposed by the physiological and psychological characteristics of the observer. In two photointerpretation studies cited by Snyder (1973), Klingberg (1970) and Borough et al., (1967), MTFA was found to have correlation coefficients of 0.92 and -0.93, respectively (the negative value was due to the use of number of errors as a human performance measure, which was inversely related to MTFA).

Integrated Contrast Sensitivity (ICS) was introduced by Van Meeteren (1973) as an improvement over MTFA. Since multiplication, rather than subtraction, is the integrand operator involved in the ICS equation, it is more responsive to small changes in either the system Modulation Transfer Function (MTF) or the visual Contrast

Threshold Function (CTF) than the MTFA metric. Task (1979) found that ICS had a higher correlation with performance than did the MTFA.

The SQRI metric, proposed by Barten (1987), is another MTF-based metric. The SQRI metric uses non-linear scaling of modulation across spatial frequencies. This non-linear scaling matches observed patterns in human suprathreshold contrast discriminations. It does so by giving greater weight to the contributions of lower modulation levels at lower spatial frequencies through a square root operator and logarithmic integration.

While a number of studies have examined individual image quality effects in relation to NVGs (Armentrout, 1993; Riegler et al., 1991), none have examined several image quality metrics in the same study. Since improved image quality should allow the pilot to see obstacles better, it is important to ascertain which metric best relates to performance so engineers can design safer NVGs.

PURPOSE

The purpose of this project was to evaluate image quality metrics for NVGs. This work assessed the relationships between MTFA, SNR, Resolution, ICS, and SQRI image quality metrics with two human visual performance measures.

LITERATURE REVIEW

A study conducted by Riegler, Whitely, Task, and Schueren (1991) examined the effect of SNR on visual acuity. Visual acuity was measured by determining the minimum angular subtense of a test character (e.g., Landolt "C," tumbling "E," or Snellen letter). The observers in this study were asked to determine the orientation of the Landolt "C" or the tumbling "E" or to read characters on a Snellen chart. Visual acuity was measured at two contrast levels (20% and 95%), two illumination levels (25% and 1% lunar disk), and four SNRs (17.92, 15.28, 13.71, and 11.37). At the beginning of each trial, observers were seated in a golf cart 12.2 m from the acuity chart. The cart then was moved toward the chart and stopped by the subject when he was "virtually certain" that he could determine the orientation of all the "C"s on the Landolt chart. If the response was incorrect, the cart was restarted and it proceeded down the track until the subject could identify the orientation or until the end of the track. Visual acuity was measured as the minimum angle of resolution computed using the distance from the visual acuity targets when the subjects correctly identified the orientation of all Landolt "C"s.

The results of this experiment showed that the SNR does affect visual acuity through the NVGs at low levels of moon illumination. Specifically, increases in intensifier SNR resulted in better visual acuity at both quarter moon and starlight (1% moon) illumination levels and at high and low target contrasts.

Armentrout (1993) examined depth perception while looking through NVGs. A modified Howard-Dolman apparatus was used under the levels of illumination and contrast described earlier. The participants (i.e., 10 male and 2 female volunteers) were screened for far distance visual acuity and stereoacuity using a Bausch and Lomb Ortho-Rater. The volunteers were required to meet a minimum criterion of 20/25 Snellen acuity and at least marginal stereoacuity (top two lines on the test screen).

The bars of the Howard-Dolman apparatus were replaced by flat targets made of exposed photographic paper. The target bars were cut from paper with differing exposures to provide three distinct contrasts. The contrasts were 83%, 53%, and 25%, using positive target-to-background calculations. The contrast conditions were measured with a Minolta CS-100 chromometer.

The targets were illuminated from a single calibrated light source, and neutral density filters were used to manipulate the illumination levels. The levels of illumination used by Armentrout were full moon, half moon, 10 percent moon and 1 percent moon (star light) illumination. These equated to 0.2152, 0.1076, 0.02152, and 0.002152 lux, respectively (RCA, 1974). The illumination measures were performed using a Minolta T-1 illuminance meter.

The participant's task was to align the right target rod until it appeared to be in the same plane as the fixed, left target rod. The starting position for the right target fell randomly into 1 of 10 locations fore or aft of the stationary left target (+/- 1 through +/- 10 centimeters). When the participant was sure the targets were aligned, the linear displacement of the right target was measured. The mean displacement error (performance variable) for each treatment combination (Table 1) was the dependent variable.

The results of the study indicated that stereoacuity was worse at 50% and 100% moon illumination; in other words, performance increased to a point with increased illumination and then decreased as illumination increased further. Armentrout related this performance decrement to a decrease in resolution at the higher illuminations (Figure 4), suggesting that the resolution decrement comes about due to halo and blooming display effects at the higher levels.

The two performance measures used in the present work came from an experiment conducted by Pierce (1994). In Pierce's study, participants were asked to detect and recognize targets under various illumination levels, target sizes, and target contrasts. Specifically, there were four levels of illumination: full moon (0.2152 lux), three-quarter moon (0.1614 lux), half moon (0.1076 lux), and one-quarter moon (0.0538 lux). The three levels of positive target-to-background contrast used were 86.86%, 53.63%, and 17.58%. The third independent variable in Pierce's study was target size, which had four levels: 8.75, 17.5, 35.0, and 70.0 minutes of visual angle. For the experiment, the participants were placed in a darkened room, 1.8 meters away from a rear projection screen, and asked to look through a pair of ANVIS-6 NVGs at the screen. Using one of two slide projectors, targets were shown on the screen.

TABLE 1. Mean Displacement Error, in Centimeters, from Armentrout (1993)

Means for Viewing Condition.

Condition	*Mean*	*Std. Dev.*
Day	3.592	2.572
Night	7.477	3.863

Means for Viewing Condition vs. Illumination

Condition	*Mean*	*Std. Dev.*
Day, 100	3.183	2.459
Day, 50	3.773	2.827
Day, 10	3.454	2.722
Day, 1	3.959	2.282
Night, 100% Moon	8.064	4.897
Night 50% Moon	8.326	4.388
Night 10% Moon	6.442	2.275
Night 1% Moon	7.074	3.057

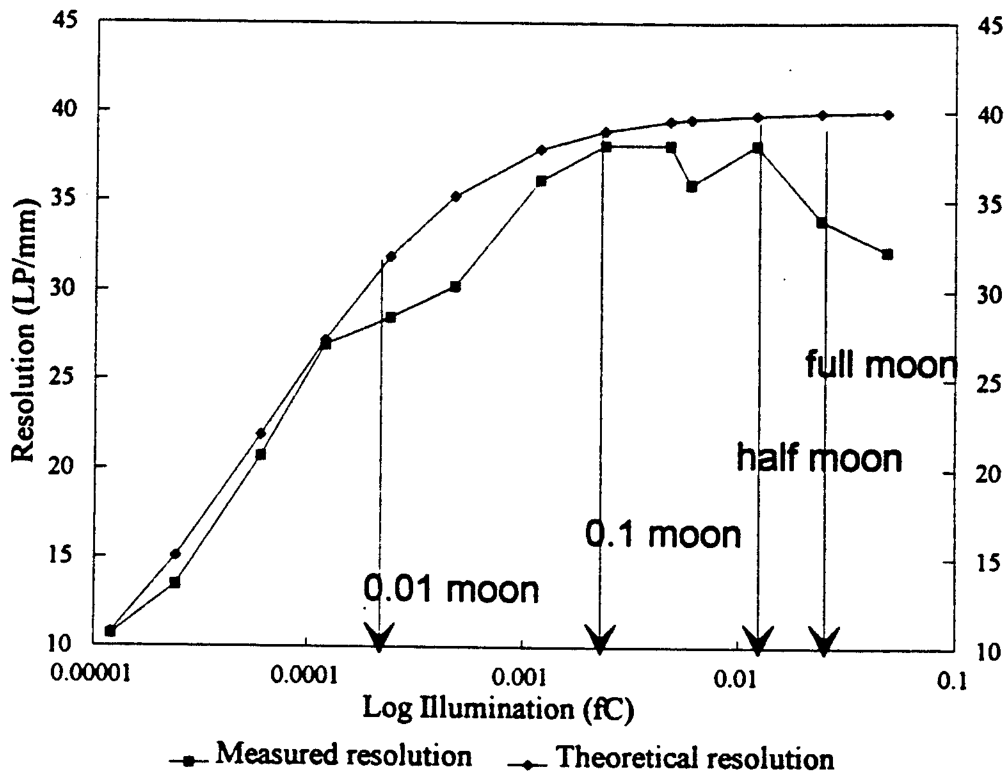


Figure 4. Measured resolution of NVGs.

(Source: Armentrout, 1993)

The targets were silhouettes of a tank, armored personnel carrier (APC), and a civilian car (see Figure 5). The targets also were shown individually at random locations on the screen. In relation to a clock, the target positions were 12:00, 1:30, 3:00, 4:30, 6:00, 7:30, 9:00, and 10:30. On each trial, the participant was asked to say the location of the target and then to state the type of target.

The two dependent variables were: 50% target detection probability and 50% target recognition probability. Data analysis consisted of reducing the data into the probabilities of target detection and then target recognition for each viewing condition. The probability of correct target detection was calculated by taking the number of correct responses given (i.e., the target was said to be at 12:00 when it actually was at 12:00) in each treatment combination divided by the total number of trials for each treatment combination. The probability of correct target recognition under each viewing condition was calculated in almost the same way, the difference being correct recognition was only counted if the target had been successfully detected. The percentages of correct responses for target detection and target recognition for Pierce's four illuminations are shown in Table 2. After the initial data reduction, the average probabilities, collapsed across replications and target type for each observer, were subjected to Analysis of Variance (ANOVA) procedures. Pierce (1994) found the effects of illumination, contrast, and target size to be significant.

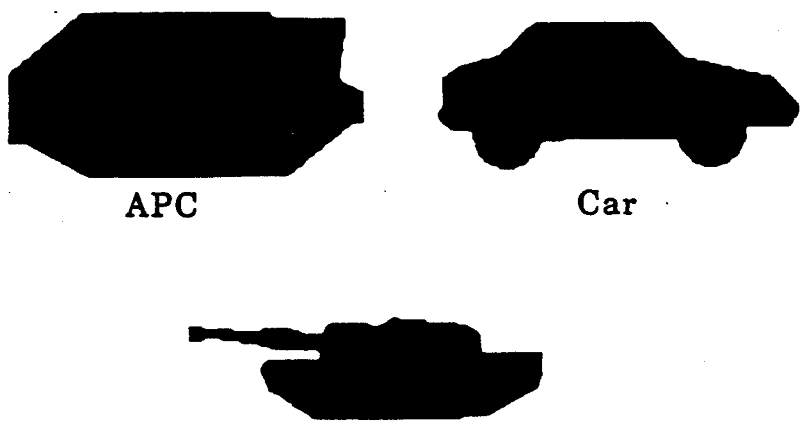


Illustration of target types

Figure 5. Target silhouettes.

(Source: Pierce, 1994)

TABLE 2. Percent Correct Responses vs. Illumination from Pierce (1994)

Illumination	*Detection*	*Recognition*
100% Moon	58.18%	45.21%
75% Moon	54.32%	41.43%
50% Moon	51.18%	34.58%
25% Moon	44.36%	34.01%

Another study investigating the relationship of visual acuity and NVG use was conducted by Wiley (1989). In this study, the effects of contrast and luminance on visual acuity were considered under six viewing conditions. Size and contrast were manipulated in this study. The size of the target, a Snellen "E," varied from 20/10 to 20/400, in Snellen notation, and contrast was set at 5, 35, and 94 percent. The targets were presented in one of four orientations and the observers were asked to determine the orientation of the "E" on each trial. Wiley found that as luminance and contrast were reduced, visual acuity decreased. This leads one to believe that luminance and contrast impact visual acuity with NVGs. The findings of Barlow (1958) and Blackwell (1946), among others, lead to the same conclusion. Barlow (1958) and Blackwell (1946) stated that as luminance levels increase, the contrast required to detect a target decreases.

IMAGE QUALITY METRICS

Modulation Transfer Function Area

This metric takes into account the MTF of an imaging system as well as the CTF of the visual system (Snyder, 1985) when assessing image quality (Figure 6). To adequately define MTFA we need to first describe its components, namely MTF and CTF. The MTF is the plot of Modulation Transfer Factors across the spatial frequency passband of an imaging system. By knowing the modulation of a sine wave going into

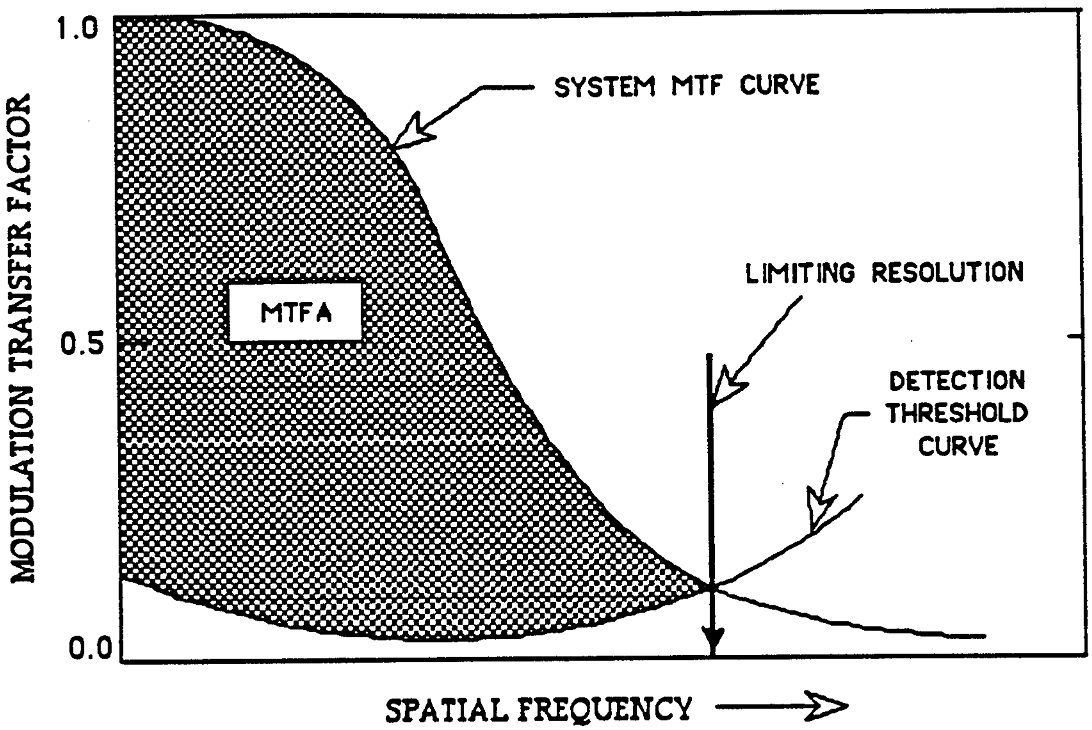


Figure 6. The MTFA concept.

(Source: Snyder, 1985)

a system, and by measuring the modulation of the sine wave coming out if the system, one calculates the Modulation Transfer Factor using the equation:

$$\text{Modulation Transfer Factor} = M_{out} / M_{In} , \tag{1}$$

where modulation (M) is defined as:

$$M = (L_{Max} - L_{Min}) / (L_{Max} + L_{Min}), \tag{2}$$

and L_{Max} = maximum luminance of the lighter grating half-cycle, and

L_{Min} = minimum luminance of the darker grating half-cycle.

Linear systems analysis makes it possible for one to determine the transmission capacity of a given system across its spatial frequency passband. The Fourier Theorem states that any waveform can be broken down into a series of sine waves, each having a unique amplitude and phase relationship to each other.

The CTF is the modulation that must be received by the human eye to detect a sine wave pattern at a given frequency. The CTF can be determined by psychophysical experiments or calculated using an equation proposed by Barten (1990).

The equation proposed by Barten (1990) is:

$$CTF = 1/au^{(-bu)} [1 + c^{(bu)}]^{1/2} , \tag{3}$$

where $a = \dfrac{540 \left(1 + \frac{0.7}{L}\right)^{-0.2}}{\dfrac{12}{DW\left(1 + \frac{u}{3}\right)^{2}} + 1}$,

$b = 0.3 (1 + 100/L)^{.15}$,

c = 0.06,

u = spatial frequency in cycles per degree,

DW = the angular display size in degrees calculated from the square root of the picture area, and

L = the effective adaptive display luminance in candelas per square meter.

In psychophysical CTF experiments, an observer adjusts the luminance contrast (modulation) of the grating to a point where the sine wave pattern can just be detected. The modulation needed to reach a threshold response is an indication of the sensitivity of the observer to that spatial frequency pattern.

When plotting the threshold contrast as a function of the spatial frequency, the result is the CTF. The inverse of the CTF is known as the Contrast Sensitivity Function (CSF).

MTFA is related to both MTF and CTF by the equation:

$$MTFA = \int_{0}^{fc} MTF(f) - CTF(f)\,df \qquad (4)$$

or

$$MTFA = \int_{0}^{fc} MTF(f) - CSF^{-1}(f)\,df \qquad (5)$$

where f_c , where f is the spatial frequency at the eye of the observer in cycles/degree and the subscript, c, denotes the spatial frequency point at which the MTF curve crosses the CTF curve.

Thus, the MTFA is a measure of a system's capacity to present detectable modulation across the observer's spatial frequency passband.

Task (1979) evaluated the MTFA, along with other image quality metrics, and found high correlations between visual task performance and the MTFA. Similar results were found by Beaton (1984), Jorna (1989), Snyder (1973), and Snyder and Maddox (1980).

Integrated Contrast Sensitivity (ICS)

This metric also is related to the MTF and CTF. As stated earlier, it was introduced by Van Meeteren (1973) as an improvement over MTFA. Since multiplication, rather than subtraction, is the operator involved in the ICS equation, it is more responsive to small changes in either the system's MTF or the visual CTF than is the MTFA metric (Jorna, 1993). The equation for calculating ICS is:

$$ICS = \int_{0}^{f_{ny}} MTF(f) / CTF(f) df , \qquad (6)$$

where f is the spatial frequency at the eye of the observer in cycles/degree, MTF(f) is the MTF of the display, CTF(f) is the CTF at the spatial frequency, and f_{ny} is the Nyquist frequency. The Nyquist frequency is the maximum spatial frequency transmitted by the imaging system (Dainty and Shaw, 1974). Beaton (1984) and Task (1979), found a slightly higher numerical correlation between performance measures and ICS than with the MTFA metric.

Square Root Integral (SQRI)

A third variant of the MTF-based metrics was proposed by Barten (1987). It was called SQRI and it resembled the ICS metric. The difference between SQRI and ICS is that the perceptually weighted MTF area in SQRI is transformed with a power function, followed by a logarithmic integration. The non-linear behavior of the human visual system is accounted for by taking the square root of the ratio between the display MTF and the CTF. The most recent SQRI metric equation (Barten, 1990) is:

$$SQRI = \frac{1}{\ln 2} \int_{f1}^{f2} \left[MTF(f) / CTF(f) \right]^{1/2} df / f \, , \qquad (7)$$

where f is the angular spatial frequency at the eye of the observer in c/deg; MTF(f) is the MTF of the display, and CTF(f) is the Contrast Threshold Function. The lower integration limit, f_1, is either zero spatial frequency or the lowest frequency that can be determined by the size of the displayed image. The upper integration limit f_2 , is the highest spatial frequency that can be determined by the size of the displayed image. The units for SQRI are expressed in terms of Just Noticeable Differences (jnd), with one jnd defined as a detection probability of 75% in a two-alternative forced-choice experiment.

Resolution

According to the ANSI/HFS 100-1988 Standard, resolution is the ability of a visual device to display the smallest discernible details. This measure is strictly a system parameter, referring to the size of the picture elements on the screen. In the case of ANVIS-6 NVGs, the best available resolution is 40 line pairs per millimeter (LP/mm). If one doesn't take static noise such as halo and blooming into account, then resolution theoretically remains at 40 LP/mm. This is not how the NVGs work, however. As illumination decreases, the gain in the goggles automatically increases, resulting in more goggle-induced noise. The increase in noise results in a decrease in resolution. Resolution is measured by looking at Air Force standard three-bar chart to determine the smallest spatial frequency that can be viewed as separate lines through an imaging system. Theoretical resolutions for different illuminations are shown in Figure 7. The limiting resolution of a system is the spatial frequency at which an observer can no longer discriminate the light and dark bars of a square-wave image (Snyder, 1985 p. 87).

Signal-To-Noise Ratio (SNR)

Beaton (1984) found that the SNR metric correlates well with performance tasks in both hard- and soft-copy displays. In fact, Beaton found that the SNR metric had the highest average R^2 (86.8%) across four different experiments of the 16 metrics considered. SNR is calculated by relating the amount of signal energy to be detected

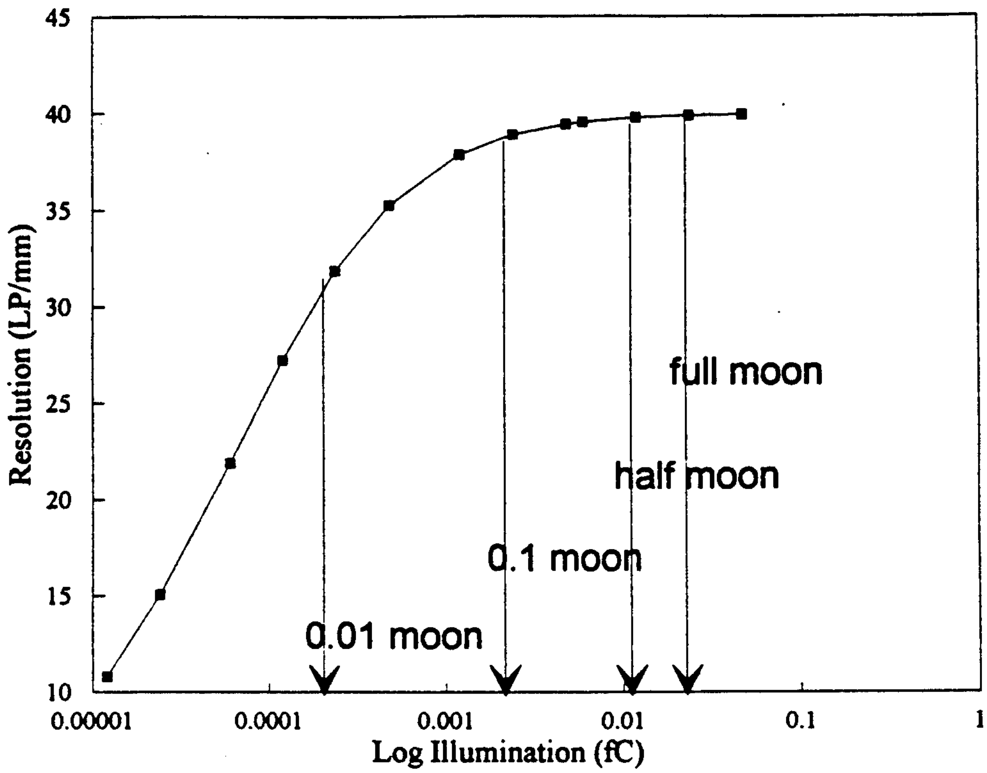


Figure 7. Theoretical NVG resolution.

(Source: Armentrout, 1993)

by the participant against a background energy (noise). The relationship is the amount of signal energy divided by the noise energy. In this case the signal was the measured DC current coming from a Gamma Scientific GS-2110 Telemicroscope that was pointed at the NVGs. The noise was the AC current coming from a Gamma Scientific GS-2110 Telemicroscope that was pointed at the NVGs.

METHOD

Task (1979) said that there are two approaches to determining functional image quality: subjective and objective. The subjective approach involves the comparison of an analytically derived image quality measure and a subjective human quality assessment of the same image. The objective approach takes an analytically derived measure of image quality, but it compares it to a performance variable associated with a specific task. In this study, the objective approach was taken.

Participants

The participants for the performance database used in this work (Pierce, 1994) were males and females between the ages of 22 and 34 years. There were 12 participants in the study, 6 male and 6 female. The participants were screened for visual acuity of 20/20 (corrected) using the Ortho-Rater. Since current Department of Defense policy allows for women in combat, and aviators are typically between the ages of 22 (graduation from flight training) and 42 (retirement or senior, mission ready only fliers), participants in the study provide a close match with the military aviation population currently using NVGs.

Equipment

The NVGs used were ANVIS-6 goggles produced by ITT. The tubes used were numbers 34425 (left tube) and 37270 (right tube); these were the same tubes used by Armentrout (1993) and Pierce (1994).

The target was illuminated using a Hoffman Energy Corp. Spectral Radiance Standard. Power for the Spectral Radiance Standard was provided by a KEPCO Power Supply (model ATE 15-6m). Neutral density filters were used to simulate the different moon illumination levels.

The observation target was a black-on-white (85%contrast) three-bar chart, made from matte board. The size of the white matte board was 76.2 cm x 101.6 cm. The black target bars were cut to produce 1, 2.5, 5, 10, and 15 cycles per degree observation targets.

The MTFs of the NVGs were calculated using the Questar 2000 OMI 10151 Mk III SZ, which was run by PMIS 201 software on an IBM 486/33 MHz computer. The AEROTECH Unidex 11 positioning system was used to place the goggles in front of the Questar for measurement. Equations for the Modulation Transfer Functions (Appendix A) were found using *DELTA GRAPH* software on a Macintosh computer. *MATHEMATICA* (version 2.2.2.) was used to calculate the MTFA, ICS, and SQRI.

The SNR level was found using a Gamma Scientific GS-2110 Telemicroscope, a Singer 323-01True RMS Voltmeter, Fluke 8000A Digital Multimeter, and a Photo Research DR-2 Digital Radiometer with a 1mm aperture and a 1x magnification lens. The telemicroscope was aimed at the MCP on the NVGs. The signal from the Gamma Scientific GS- 2110 Telemicroscope then was passed to the digital multimeter and the RMS voltmeter through a single cable with a T-connection at the digital multimeter. The AC current was measured on both the multimeter and the voltmeter yielding the same value on both instruments.

Resolution measurements were performed at ITT Roanoke using a Hoffman Test Bench. The Hoffman Test Bench also was used to check the signal-to-noise measurements.

The statistical calculations and regression plots, were done on *STATGRAPHICS* (version 5).

Testing Method

First, the MTFs were calculated. This was done by placing a three-bar chart three meters from the NVGs. The Questar then was focused on the MCP of the NVGs. Each of five spatial frequencies (i.e., 1, 2.5, 5, 10, and 15 cycles per degree) on the target board were illuminated at each of six moon illumination levels (i.e., 100%, 75%, 50%, 25%, 10%, and 1% lunar disk). The PMIS 201 software was used to plot the maximum and minimum luminance for each spatial frequency at each illumination level. The plots were converted into *Microsoft* EXCEL (version 5.0) spreadsheets so the average maximum and minimum luminance, hence each M_{Out} (Eqn. 1), could be calculated for the spatial frequencies at each illumination level. To compute M_{In} (Eqn. 1) to the NVGs, the maximum and minimum luminance values of the three bar target were determined using the same procedure with one difference; the Questar was focused directly at the chart instead of looking through the NVGs.

DELTA GRAPH was used to determine the equations for the MTFs. The MTF data were fit using a Gaussian MTF model and the Levinson-Marquardt method (Delta Point Inc., 1993). With the MTF determined using the Questar, and the CTF found using Barten's Equation, the MTFAs, ICSs, and SQRIs were calculated *MATHEMATICA* (version 2.2.2).

SNRs were calculated from the NVGs viewing a white matte board under the six different illumination conditions. The Gamma Scientific 2110 telemicroscope was set up to look at the MCP of the NVGs. The signal coming out of the telemicroscope was routed through the RMS voltmeter and the Digitizing Multimeter. The value of DC divided by RMS volts was taken as the SNR. It was assumed that DC current was the intensity of illumination because the power source for the illuminator was constant DC. It was also assumed that AC readings from the True RMS Voltmeter were noise.

Resolution was measured at ITT Roanoke using an Air Force standard three-bar chart and a Hoffman Test Bench. The resolution of each tube was taken and the two resolutions were averaged to get an estimate of system resolution.

In this study, it was decided to concentrate on the center of the NVG operating range and avoid the extreme illuminations (1%, 10%, and 100% Moon), because of the system's automatic gain control responses at the lower and upper levels. The MTF equations and plots for all six illuminations were retained for informational purposes (see Appendix A). The above metrics were computed only for the three illuminations used and for both image intensifier tubes. The metrics for both tubes were averaged to get an estimate of the system metrics. The results of the metric calculations can be found in Table 3.

Once the metric values were determined for each illumination level, they were regressed on the performance measures described below using *STATGRAPHICS* (version 5). The performance measures for this study were taken from Pierce (1994).

RESULTS

Once the data were collected, the MTFA, ICS, SQRI, Resolution, and SNR metrics were calculated. The metrics were compared to the two visual detection and recognition performance measures from Pierce (1994) using statistical regression techniques. The basic regression equation for each metric is of the form:

$$\text{PERFORMANCE} = b_0 + b_1 M, \qquad (8)$$

where M denotes the metric of interest (MTFA, SQRI, ICS, Resolution, or SNR), b_0 denotes the intercept of the regression equation, and b_1 denotes the slope of the regression equation.

TABLE 3. Results of Metric Calculations

	MTFA	*ICS*	*SQRI*	*RES*	*SNR*
75% MOON	4.6370	1821.33	85.0094	35.9	72.40
50%MOON	4.6204	1821.88	85.1181	38.1	70.95
25%MOON	4.6572	1840.84	85.5793	38.1	66.60

In the following subsections, each metric is compared to the performance measures and evaluated to determine the metric best related to operator performance. The statistical measures of R^2 , the p value associated with R^2 , and Mallow's C_p statistic were used to assess the best fit models. For a summary of the evaluation tool results see Appendix B.

MTFA vs. Target Detection Performance

The R^2 value for the regression of MTFA on target detection is 0.5065 ($p = 0.495$). The regression equation is:

$$\text{Performance} = 9.621 - (196.6)(\text{MTFA}) \qquad (8)$$

Figure 8 shows a plot of Equation 8.

ICS vs. Target Detection Performance

The R^2 value for the regression of ICS on target detection is 0.9188 ($p = 0.1839$). The regression equation is:

$$\text{Performance} = 853.1 - (0.439)(\text{ICS}) \qquad (9)$$

Figure 9 shows a plot of Equation 9.

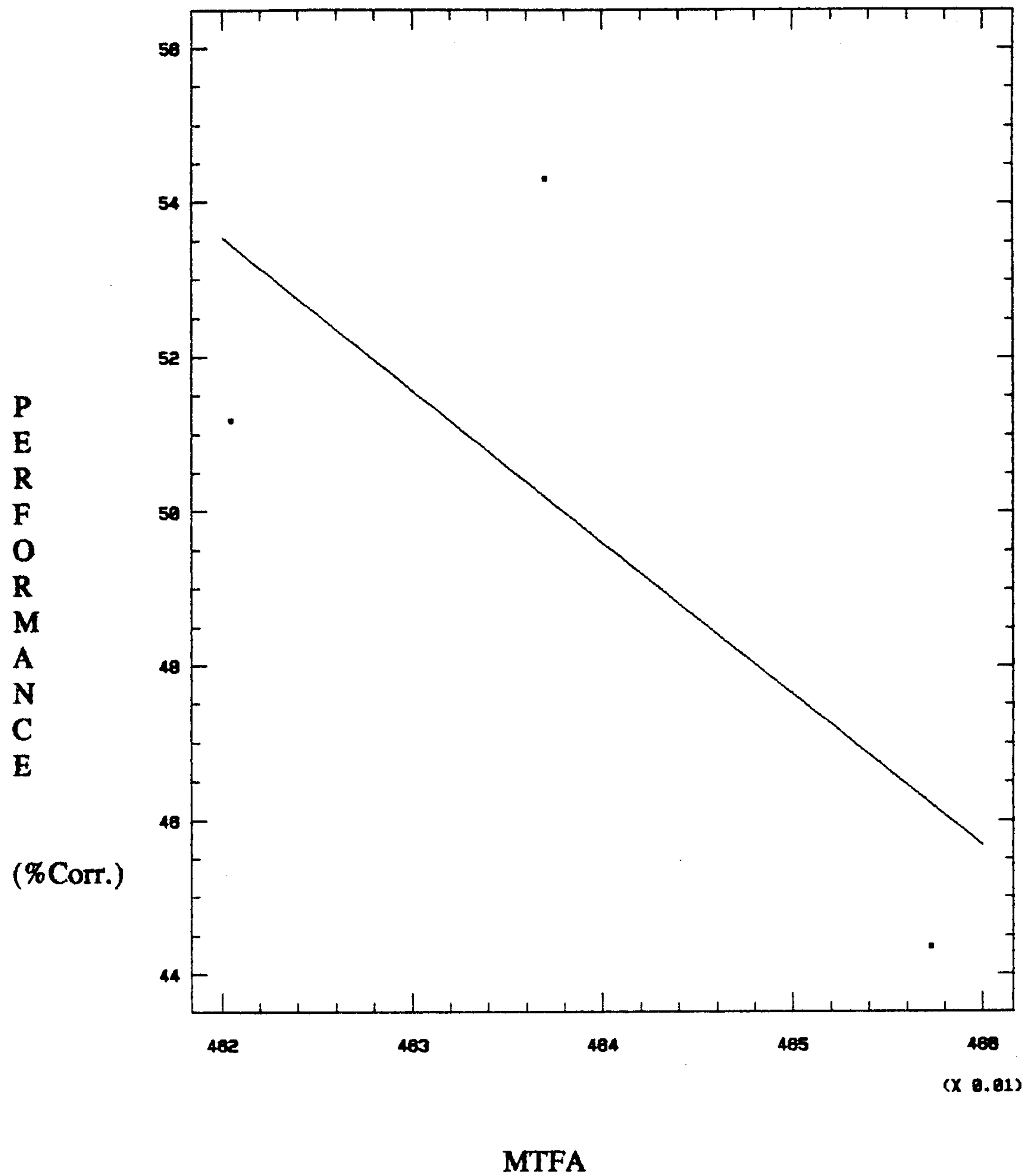


Figure 8. MTFA detection regression plot.

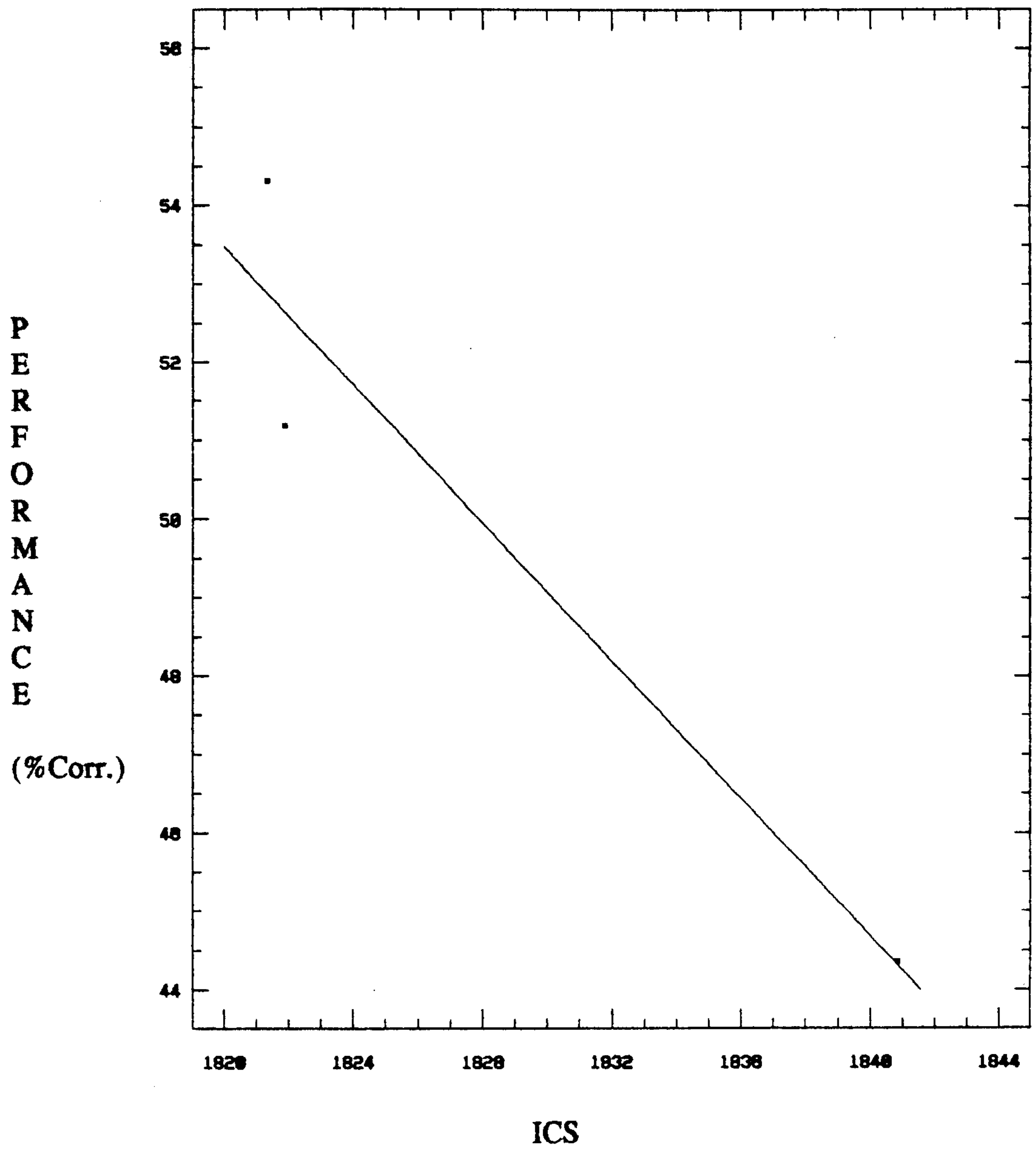


Figure 9. ICS detection regression plot.

SQRI vs. Target Detection Performance

The R^2 value for the regression of SQRI on target detection is 0.9829 ($p = 0.0835$). The regression equation is:

$$\text{Performance} = 1486.5 - (16.854)(\text{SQRI}) \qquad (10)$$

Figure 10 shows a plot of Equation 10.

Resolution vs. Target Detection Performance

The R^2 value for the regression of Resolution on target detection is 0.5519 ($p = 0.4669$). The regression equation is:

$$\text{Performance} = 161.229 - (2.977)(\text{Resolution}) \qquad (11)$$

Figure 11 shows a plot of Equation 11.

SNR vs. Target Detection Performance

The R^2 value for the regression of SNR on target detection is 0.9949 ($p = 0.0453$). The regression equation is:

$$\text{Performance} = -67.802 + (1.682)(\text{SNR}) \qquad (12)$$

Figure 12 shows a plot of Equation 12.

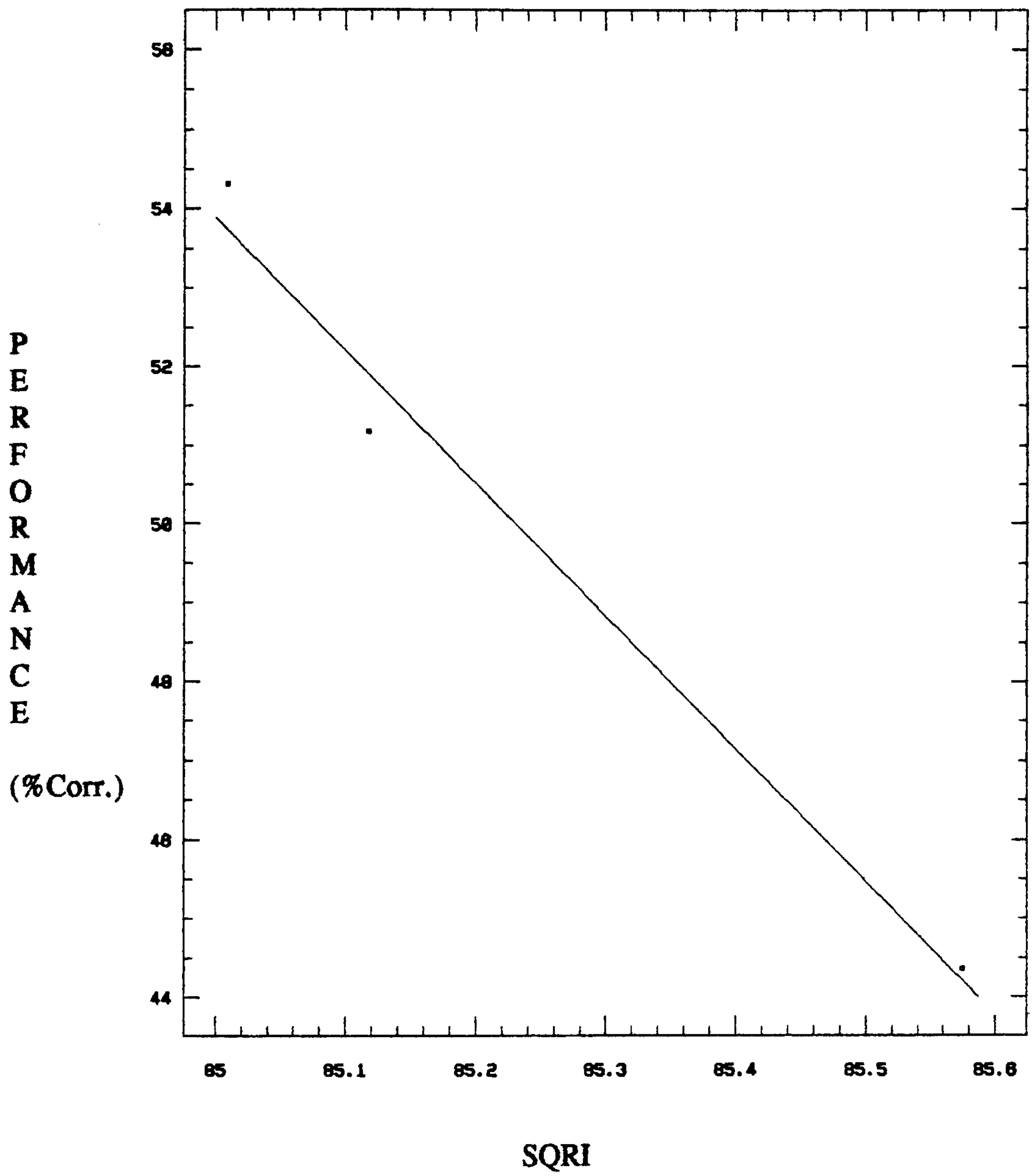


Figure 10. SQRI detection regression plot.

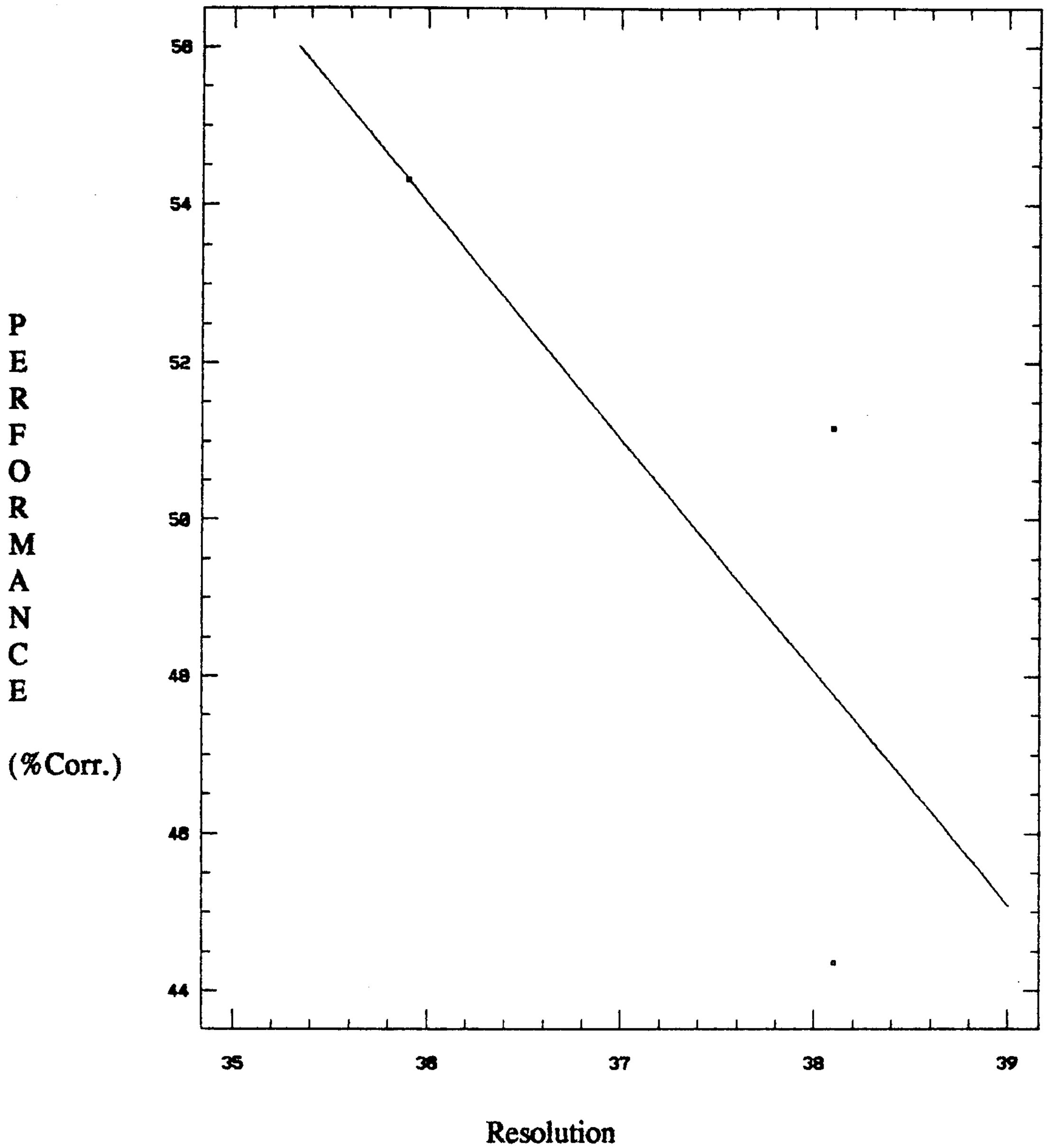


Figure 11. Resolution detection regression plot.

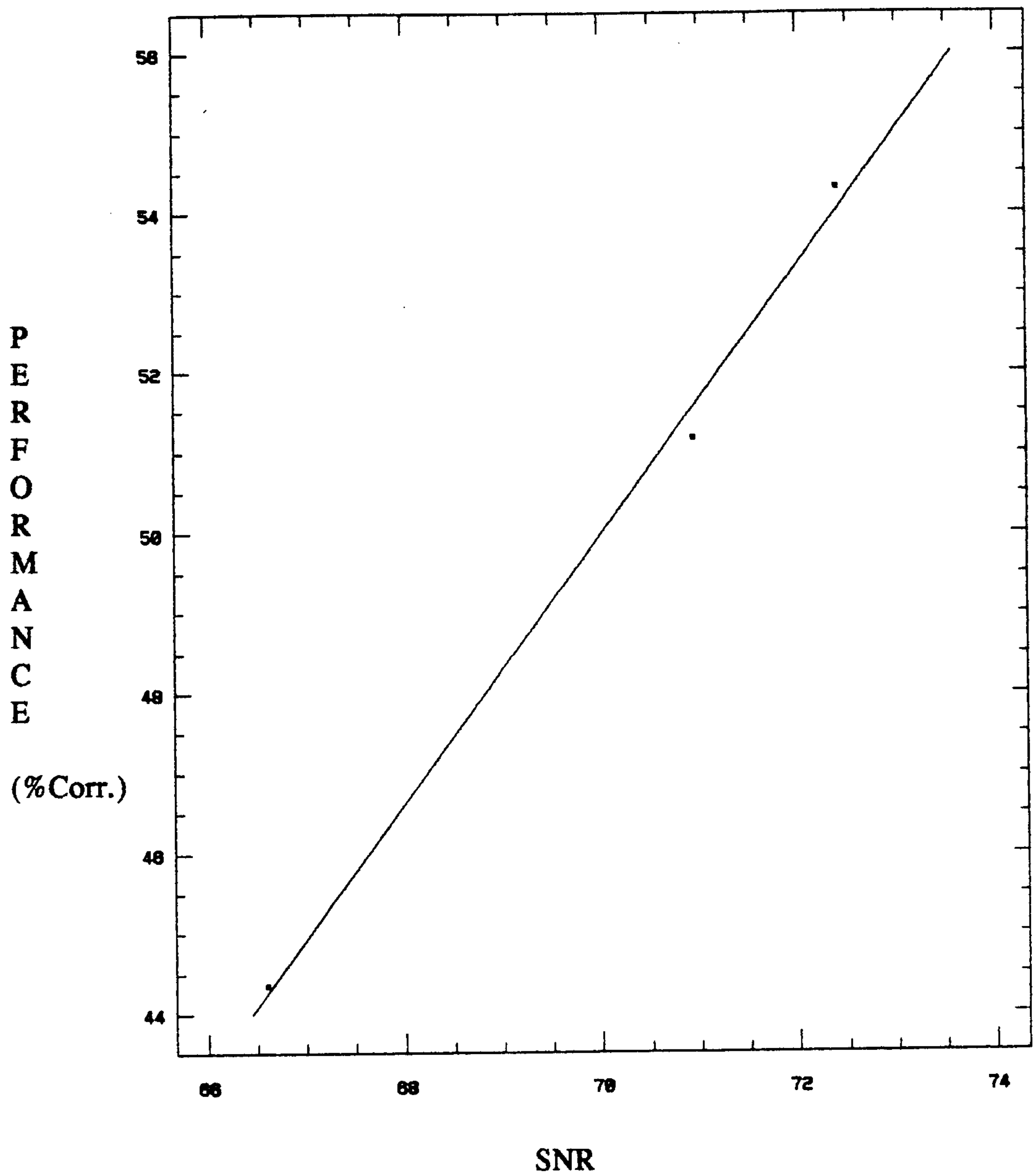


Figure 12. SNR detection regression plot.

MTFA vs. Target Recognition Performance

The R^2 value for the regression of MTFA on target recognition is 0.0165 (p =0.9181). The regression equation is:

$$\text{Performance} = 170.178 - (28.784)(\text{MTFA}) \tag{13}$$

Figure 13 shows a plot of Equation 13.

ICS vs. Target Recognition Performance

The R^2 value for the regression of ICS vs. target recognition is 0.3363 (p =0.6062). The regression equation is:

$$\text{Performance} = 431.008 - (.2157)(\text{ICS}) \tag{14}$$

Figure 14 shows a plot of Equation 14.

SQRI vs. Target Recognition Performance

The R^2 value for the regression of SQRI on target recognition is 0.4909 (p =0.5058). The regression equation is:

$$\text{Performance} = 860.646 - (9.667)(\text{SQRI}) \tag{15}$$

Figure 15 shows a plot of Equation 15.

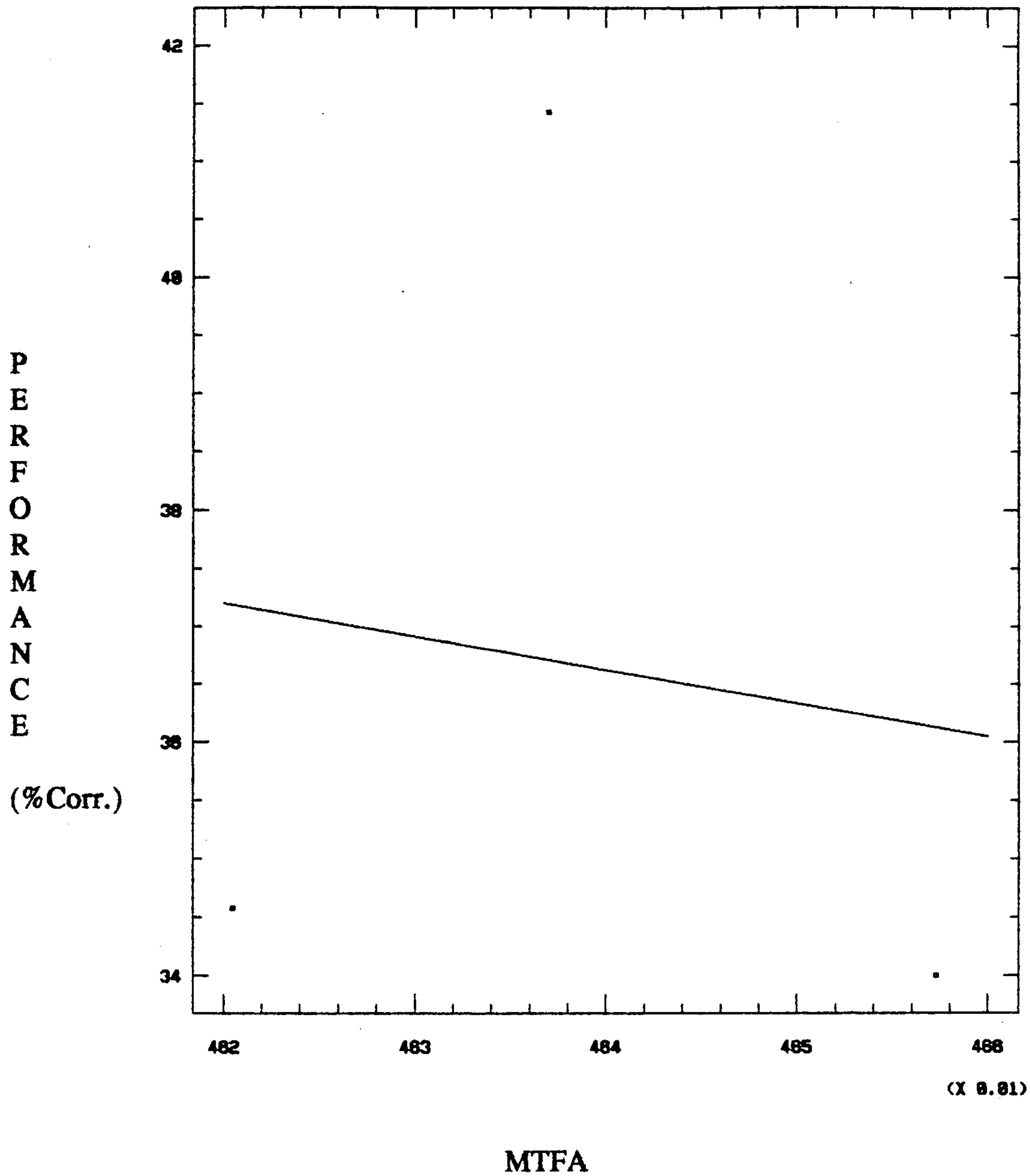


Figure 13. MTFA recognition regression plot.

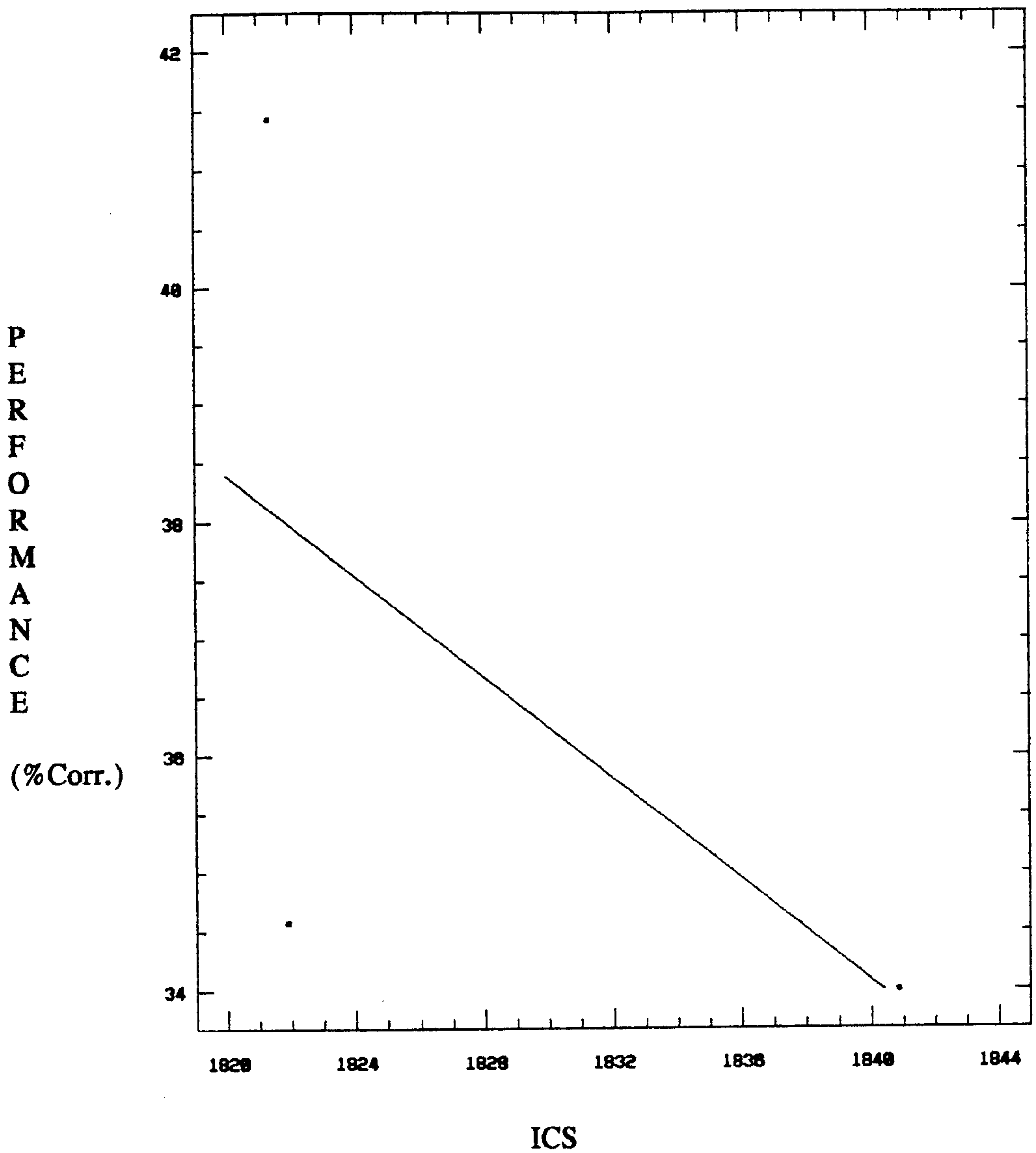


Figure 14. ICS recognition regression plot.

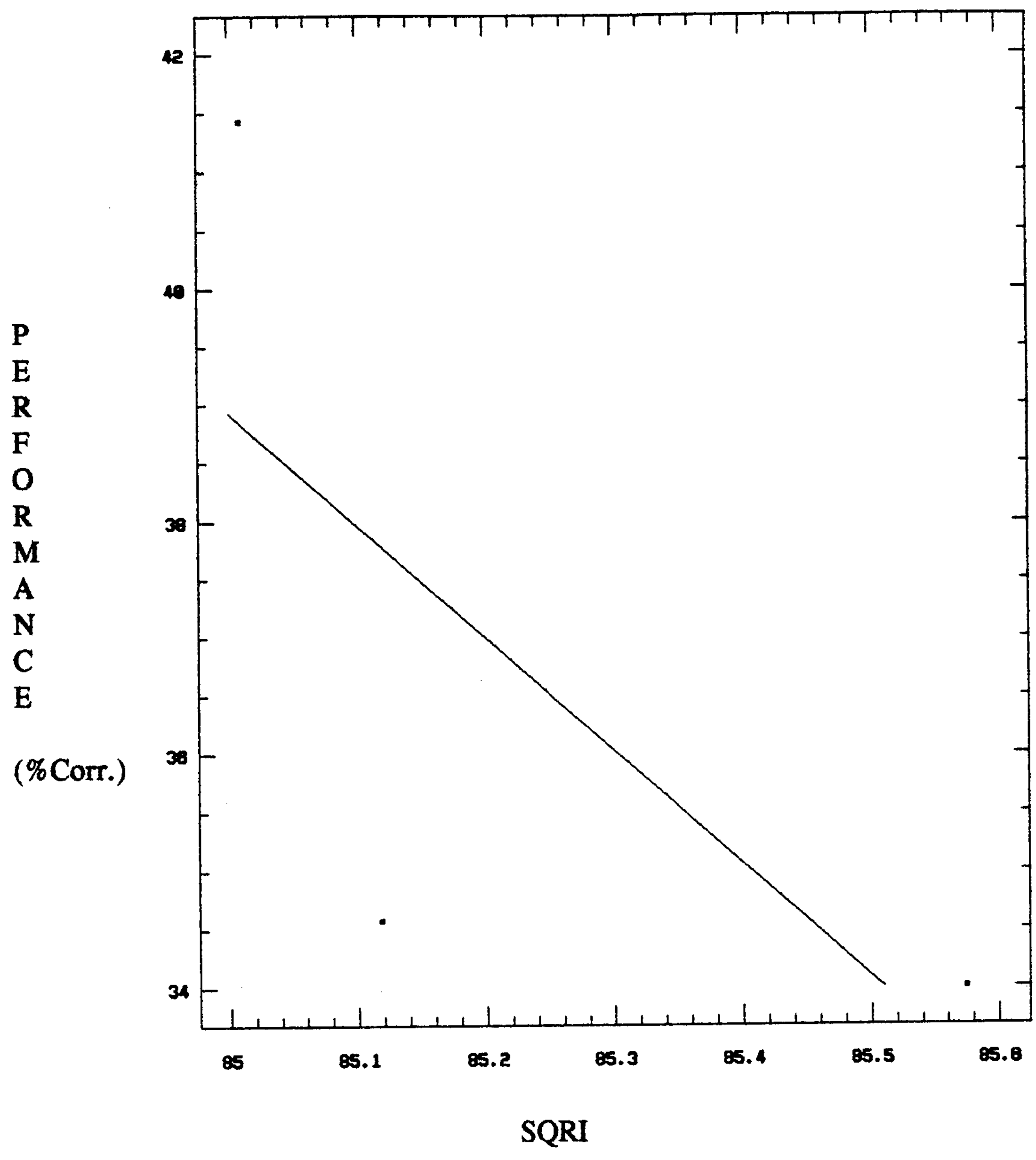


Figure 15. SQRI recognition regression plot.

Resolution vs. Target Recognition Performance

The R^2 value for the regression of Resolution on target recognition is 0.9951 ($p = 0.0447$). The regression equation is:

$$\text{Performance} = 157.942 - (3.245)(\text{Resolution}) \qquad (16)$$

Figure 16 shows a plot of Equation 16.

SNR vs. Target Recognition Performance

The R^2 value for the regression of SNR on target recognition is 0.5509 ($p = 0.4675$). The regression equation is:

$$\text{Performance} = -34.445 + (1.016)(\text{SNR}) \qquad (17)$$

Figure 17 shows a plot of Equation 17.

The Mallow's Cp statistic was calculated for each of regression equations. The results of the Cp statistic confirmed the results of the other evaluation tools, namely that for target detection the SNR regression equation has the least bias and for target recognition the Resolution regression equation has the least bias.

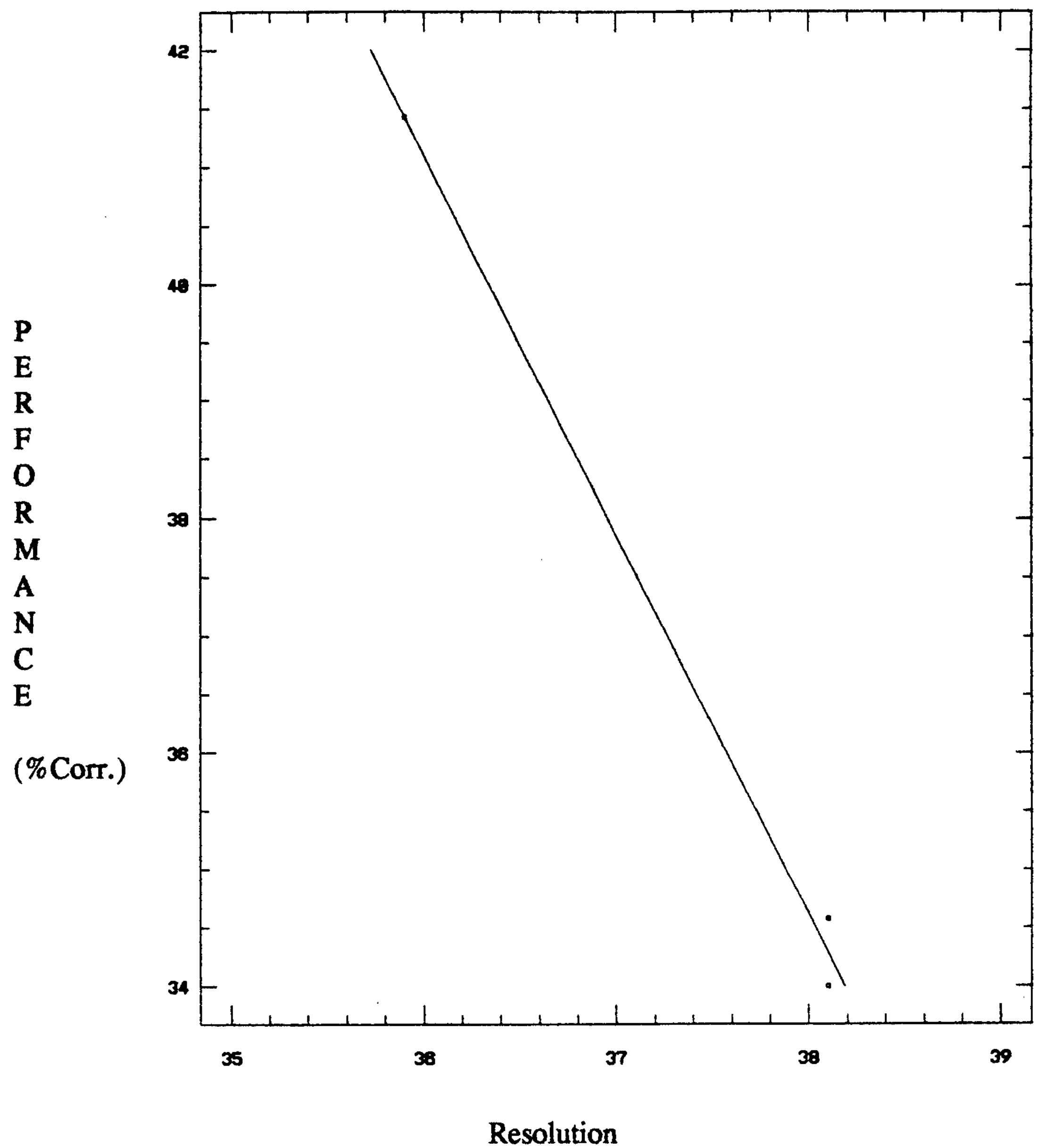


Figure 16. Resolution recognition regression plot.

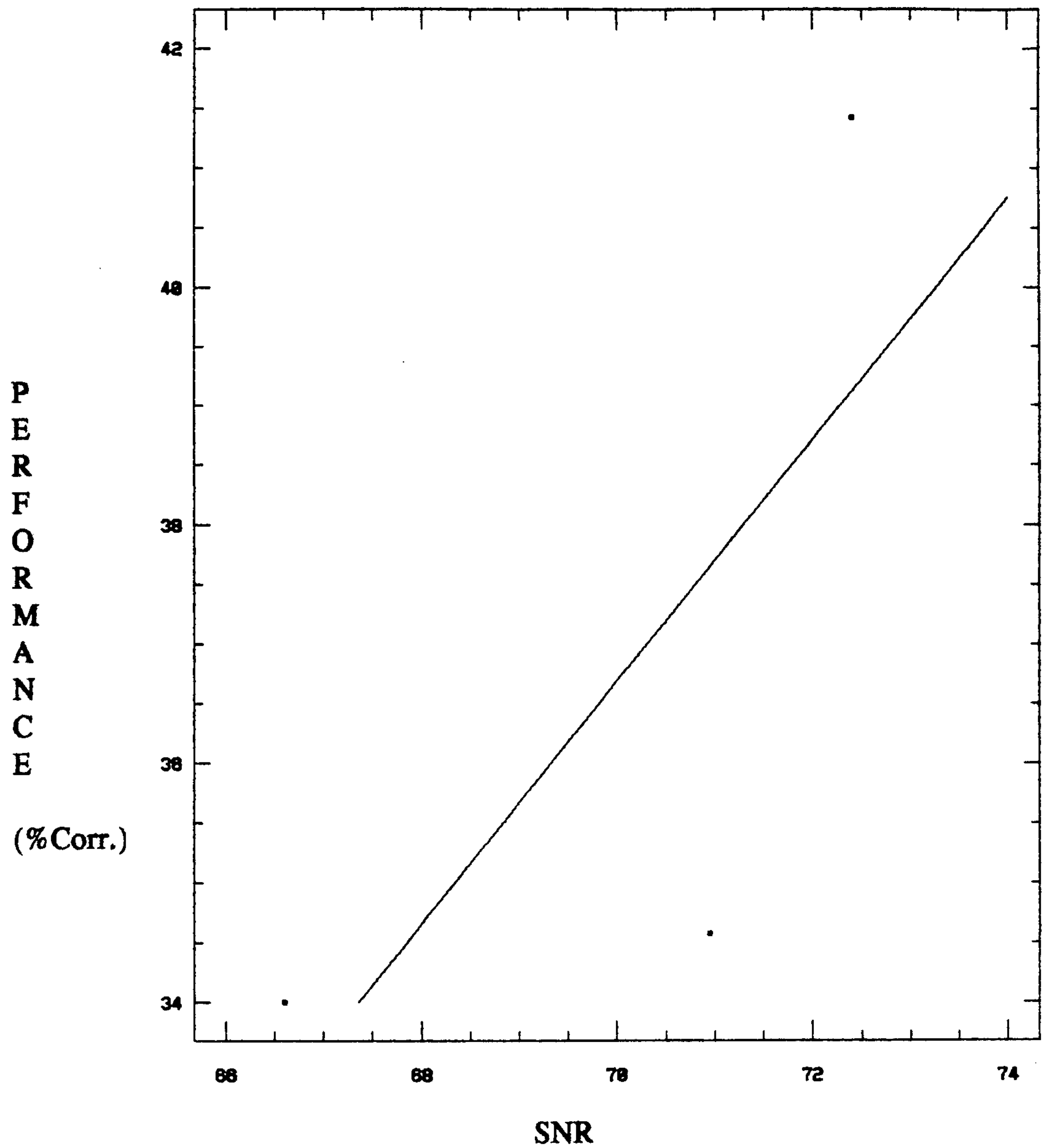


Figure 17. SNR recognition regression plot.

In addition to the regression equations and Mallow's Cp statistics, t-tests on the differences between R^2 values and on observed metric correlations were computed. The t-tests found that there were no significant differences among the metrics for the target detection and target recognition tasks (Table 4). The only metric correlations that were significantly different from zero were: SNR for target detection and Resolution for target recognition (Table 5).

DISCUSSION

The only metric that correlated significantly with target detection performance was SNR. This suggests that noise levels in the NVGs actually drive operator target detection performance. This finding is consistent with those of Riegler, Whitely, Task, and Schueren (1991), who found that as the SNR of NVGs improves so does performance. Also, Beaton (1984) found SNR to be the best performance predictor when noise in a system was a consideration. This also makes sense from a psychophysical, signal-to-noise ratio perspective, as the signal strength increases it is easier to pick it out from a noisy background.

For target recognition, Resolution has the only significant R^2 value, 0.9951. One would, however, expect recognition performance to improve as system resolving power improved, so the large R^2 value does not come as a surprise.

TABLE 4. T-test Results for R^2 Differences [1]

R^2 PAIR	*Detection* *t observed*	*Recognition* *t observed*
MTFA-ICS	0.027	0.050
MTFA-SQRI	0.032	0.004
MTFA-Resolution	0.002	0.014
MTFA-SNR	0.033	0.025
ICS-SQRI	0.026	0.050
ICS-Resolution	0.027	0.050
ICS-SNR	0.031	0.050
SQRI-Resolution	0.032	0.010
SQRI-SNR	0.022	0.022
Resolution-SNR	0.033	0.014

1. The critical t-test value was 2.132 (df =4, α =0.05)

TABLE 5. T-test Results for Correlation Equal to Zero [1]

	r	*t observed*
Detection		
MTFA	0.7116	1.01
ICS	0.9585	3.36
SQRI	0.9914	7.58
Resolution	0.7429	1.11
SNR	0.9974	13.96
Recognition		
MTFA	0.1283	0.1294
ICS	0.5798	0.7116
SQRI	0.7006	0.9818
Resolution	0.9975	19.950
SNR	0.7422	1.1075

1. The critical t-test value was 12.71 (df = 1, α = 0.05)

Another consideration in regard to the values of the MTFA, ICS, and SQRI metrics is that system noise was not accounted for when making the measurements. Beaton (1984) and Barten (1991) found that system noise elevated the CTF. The implication here is, the metric values calculated in this paper are actually higher than they would be if noise were taken into account. Also, the MTFs did not vary much with changes in illumination levels, so changes in performance effects were not captured by the MTFA, ICS, and SQRI metrics. These findings suggest that the ANVIS-6 NVGs are noise-limited systems and the that MTF-based metrics should be corrected for noise for effective use in modeling NVGs.

Also, when one looks at the plots of the MTFs on the same graph (Figure 18), it can be noted that on the 25% moon illumination curve there appears an abnormal bump at 2.5 cycles per degree. This bump causes the MTFA, ICS, and SQRI values to be slightly greater for 25% illumination than for 50% and 75% illuminations. Since the bump occurs at a low spatial frequency SQRI is more effected than MTFA and ICS.

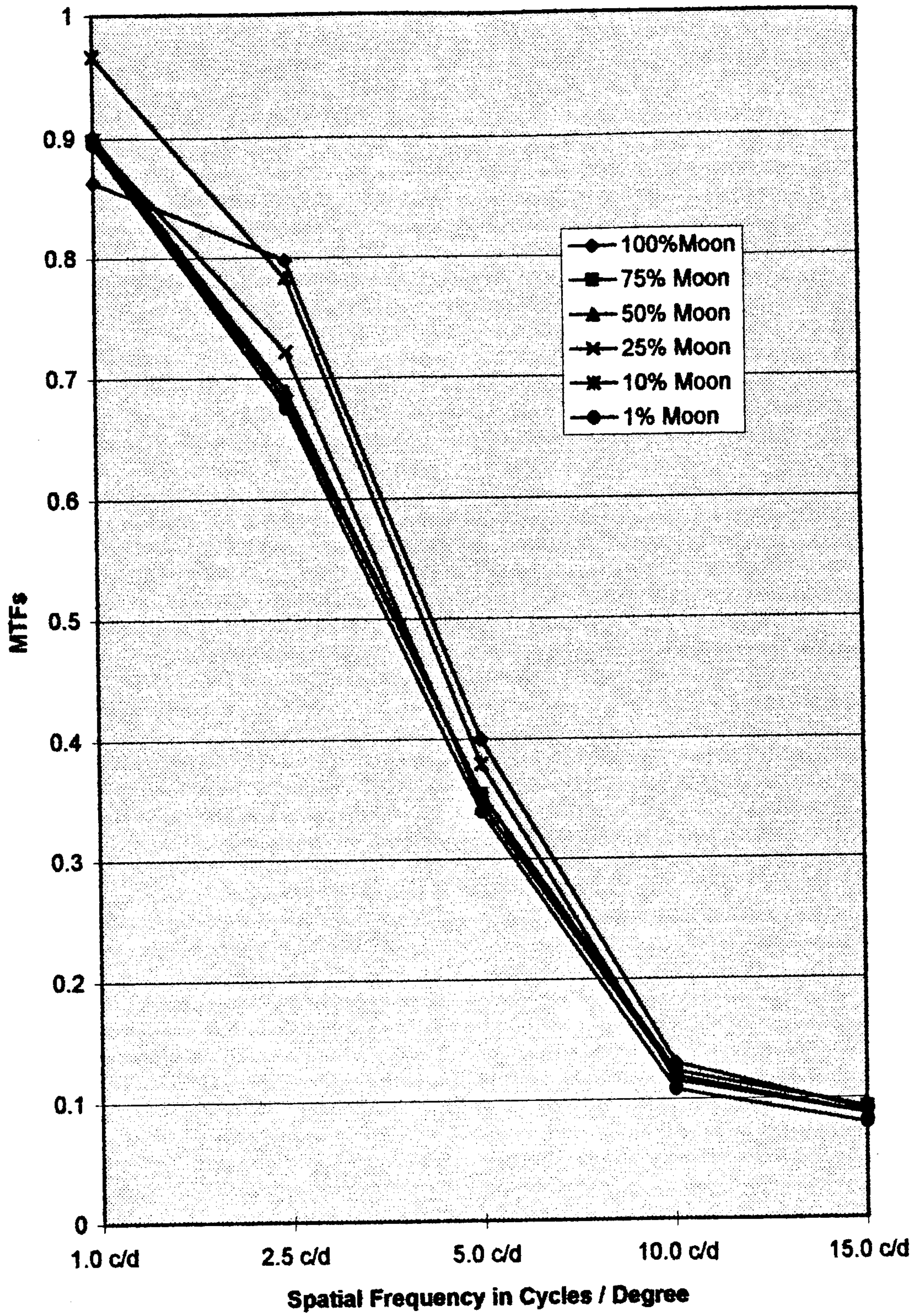


Figure 18. MTF Plots.

CONCLUSION

The main conclusions reached in this study are: that the SNR image quality metric serves as the best predictor of performance in target detection tasks and resolution serves as the best performance predictor in target recognition.

The purpose of this study was to provide an objective assessment of the image quality of ANVIS-6 NVGs using five image quality metrics. This purpose was fulfilled; although only one metric was found to predict each performance task. It is suggested by the present findings that the MTFA, ICS, and SQRI metrics need to be reformulated to account for the effects of noise on visual target detection and recognition performance. The trends shown by the metrics were as expected. To fully explore the metric trends, a more extensive or follow on study should be conducted. The next study should include additional illumination levels to effectively cover the operating range of the goggles. Also, the study should take noise into account when calculating MTFA, ICS, and SQRI. The increase in illumination levels should also result in more statistical power when analyzing regression equations and R^2 values, perhaps resulting in higher confidence levels for the metrics.

The trends observed in the present finding can be used as engineering criteria to guide and evaluate NVG system improvements and to predict the usability of these devices. Future improvements in SNR and Resolution will lead to increased operator performance. Also, if unit level tests are to be developed to rate NVGs already in the field, the tests should involve SNR and Resolution measures.

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Appendix A

MTF Equations

$k = \pi$ ^2 / 4 ln2; x = spatial frequency in cycles per degree.

MTF at 100% moon illumination

y =9.671E-2 + 8.252 E-1* Exp(k* 1.021E-1^2*x^2)

$R^2 = .9928$

MTF at 75% moon illumination

y =1.061E-1 + 8.1814 E-1* Exp(k* 1.184E-1^2*x^2)

$R^2 = .9975$

MTF at 50% moon illumination

y =1.1011E-1 + 8.284 E-1* Exp(k* 1.177E-1^2*x^2)

$R^2 = .9978$

MTF at 25% moon illumination

y =9.900E-2 + 8.409 E-1* Exp(k* 1.170E-1^2*x^2)

$R^2 = .9993$

MTF at 10% moon illumination

y =9.589E-2 + 9.143 E-1* Exp(k* 1.144E-1^2*x^2)

$R^2 = .9996$

MTF at 1% moon illumination

y =9.229E-2 + 8.298 E-1* Exp(k* 1.192E-1^2*x^2)

$R^2 = .9978$

Appendix B

METRIC EVALUATION RESULTS

DETECTION	R^2	*P*	*Mallow Cp*
MTFA	0.5065	0.4958	1.9870
ICS	0.9188	0.1839	1.1624
SQRI	0.9829	0.0835	1.0343
RESOLUTION	0.5519	0.4669	1.8963
SNR	0.9949	0.0453	1.0101

RECOGNITION	R^2	*P*	*Mallow Cp*
MTFA	0.0165	0.9181	2.9670
ICS	0.3363	0.6062	2.3275
SQRI	0.4909	0.5058	2.0182
RESOLUTION	0.9951	0.0447	1.0098
SNR	0.5509	0.4675	1.8982

Appendix C

Modulation Transfer Factors

MTFs	*100% Moon*	*75% Moon*	*50% Moon*	*25% Moon*	*10% Moon*	*1% Moon*
1.0 cy/deg	0.863	0.899	0.903	0.899	0.967	0.895
2.5 cy/deg	0.798	0.682	0.689	0.722	0.783	0.675
5.0cy/deg	0.400	0.354	0.354	0.346	0.379	0.339
10 cy/deg	0.130	0.123	0.119	0.119	0.115	0.108
15cy/deg	0.090	0.092	0.087	0.087	0.087	0.079

Appendix D

Signal-to-Noise Ratio Data

	100% Moon	*75% Moon*	*50% Moon*	*25% Moon*	*10% Moon*	*1% Moon*
Left Tube Signal (mV)	702	699	697	688	628	460
Left Tube Noise (mV)	10.1	9.9	10.1	10.6	12.4	11.2
Left Tube SNR	69.5	70.6	69.0	64.9	50.6	41.1
Right Tube Signal (mV)	724	720	715	710	690	610
Right Tube Noise (mV)	10.3	9.7	9.8	10.4	10.7	10.9
Right Tube SNR	70.3	74.2	72.9	68.3	64.5	55.9
AVG. SNR	69.9	72.4	70.95	66.6	57.57	48.5

VITA

Derek H. Abel, was born in Englewood, N.J., in 1962. He grew up in Toms River, N.J., and graduated from Toms River High School North in 1980. He next attended the United States Air Force Academy from 1980 until graduating with a B.S. in psychology in 1984. From the USAF Academy he went on to navigator training and was assigned to C-130s at Dyess AFB, TX. In 1989, Captain Abel was assigned to the 9th Special Operations Squadron at Eglin AFB, FL, where he served until his current assignment at Virginia Polytechnic Institute and State University.

In 1987, Derek married the former Diane DeCarlo, also of Toms River, N.J., and they have two sons, Michael, born 1989, and Anthony, born 1992.

Derek H. Abel

An Image Quality Analysis of ANVIS-6 Night Vision Goggles

By

Captain Derek H. Abel, United States Air Force

1994

Committee Chairman: Robert J. Beaton

Industrial and Systems Engineering Department, Master of Science Degree

Virginia Polytechnic Institute and State University

(ABSTRACT)

This study was undertaken in an effort to relate ANVIS-6 Night Vision Goggle image quality to user performance. The purpose was to determine which of five image quality metrics best related to performance tasks. The image quality metrics examined Modulation Transfer Function Area (MTFA), Integrated Contrast Sensitivity (ICS), Square Root Integral (SQRI), Resolution, and Signal-to-Noise Ratio (SNR). The performance tasks were detection and recognition of targets under various levels of moon illumination. The metric that best related to target detection was SNR. The SNR results are consistent with visual psychophysics and SNR effects. The metric that best related to target recognition was resolution. The resolution results are consistent with the position that recognition performance improves for suprathreshold targets as resolving power increases (62 pgs).

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An Image Quality Analysis of ANVIS-6 Night Vision Goggles

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(ABSTRACT)

This study was undertaken in an effort to relate ANVIS-6 Night Vision Goggle image quality to user performance. The purpose was to determine which of five image quality metrics best related to performance tasks. The image quality metrics examined Modulation Transfer Function Area (MTFA), Integrated Contrast Sensitivity (ICS), Square Root Integral (SQRI), Resolution, and Signal-to-Noise Ratio (SNR). The performance tasks were detection and recognition of targets under various levels of moon illumination. The metric that best related to target detection was SNR. The SNR results are consistent with visual psychophysics and SNR effects. The metric that best related to target recognition was resolution. The resolution results are consistent with the position that recognition performance improves for suprathreshold targets as resolving power increases (62 pgs).

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