EFFECTS OF TARGET SIZE, LUMINANCE CONTRAST, AND ILLUMINATION ON VISUAL TARGET DETECTION AND RECOGNITION WITH AN/AVS-6 GOGGLES

by

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(ABSTRACT)

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The military has invested in the development of low light level and night imaging technologies to gain tactical advantages on the battlefield. Moreover, certain military activities such as night aviation maneuvers demand the most sophisticated night imaging devices. Unfortunately, as the frequency of use of night imaging devices increases, so has the number of accidents (Boyd, 1991). Many of these accidents have been attributed to the novel usage as well as the intrinsic limitations of night imaging devices.

The present research examined the effects of target size, luminance contrast, and illumination level on visual target detection and recognition while using AN/AVS-6 night vision goggles. Vehicle silhouette targets were rear-projected on random screen positions under various levels of illumination, contrast, and size. The observer's task was to detect and recognize each target while viewing through night vision goggles.

The results indicate that visual detection and recognition performance degrade with decreasing levels of illumination, contrast, and target size. The

findings of this work can be used to optimize the usage of AN/AVS-6 devices.

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INTRODUCTION

People often have sought ways to improve their vision at night. Historically, natural illumination from the moon and stars was supplemented with artificial lights to allow tasks such as surveillance to be performed at night. This was a relatively inexpensive and simple means of enhancing night vision. In the past two decades, however, technologists have worked at enhancing night vision for situations where artificial lights are not cost effective (e.g., lighting inland water ways) or viable (e.g., covert surveillance). For example, law enforcement and military agencies have begun to use night vision-aided systems extensively. In particular, the military is the main sponsor for development and use of night vision systems. In military applications, night flight operations pose severe visual requirements and mandate the use of sophisticated night vision-aided systems.

Unfortunately, as the use of night vision systems increases, so has the number of accidents (Boyd, 1991). While some investigators argue that the increase in accidents is due solely to the increased usage of night vision systems, others argue that intrinsic limitations of systems have caused the accidents. Regardless of the night vision technology used, fidelity of the external scene is lost in the imaging process. Compared to unaided vision, modern night vision systems enhance some aspects of visual information, but degrade other aspects. Users of night vision systems operate with fewer visual cues than are available during daylight viewing conditions, a disadvantage that is not obvious to all inexperienced users (Verona, 1991).

Background

In a study by Rash (1990), a matched sample evaluation was made of U.S. Army Class A-C accidents under daylight, night-unaided, and Night Vision Goggle (NVG) conditions. (Class A is most severe, involving over $1 million property loss and/or a fatality; Class C involves > $10K damage and/or loss of worktime.) All NVG accidents between 1971 and 1989 for which complete data were available were included in the study (n=102). An approximately equal number of cases, matched by year of accident, were drawn from the unaided night (n=564) and daylight (n=4153) samples.

Rash's analysis focused on the comparisons of underlying accident "mechanisms" in the three conditions. Mechanisms were divided into perceptual: Sudden Loss of Outside Visual Cues (e.g., brown/white-outs), Faulty Flight Path Control (e.g., flew into water or ground, hard landing), and Faulty Object Detection (e.g., wire strike, midair accident) and non-perceptual: mechanical failures (other than NVGs), over-torques, sling load problems, and loss of tail-rotor effectiveness.

Rash's results indicated that perceptual mechanisms were responsible most often in NVG and unaided-night missions, while non-perceptual mechanisms caused most daylight accidents. Of the two night modes, NVG-aided missions had a higher incidence of perceptually caused accidents than did unaided-night missions.

Purpose

The success of any night operation depends on a full understanding of limitations and requirements of the crew and equipment. As indicated above, possible perceptual limitations associated with NVG's could have contributed to performance problems and, in the severe instances, to aircraft accidents.

The purpose of this experiment was to examine the perceptual limitations caused by AN/AVS-6 NVGs. Specifically, this study examined how well NVG users detected and recognized targets under various illumination, contrast, and target size conditions. The findings of this experiment help to define optimal conditions for NVG usage, thus assisting aviators in NVG operations.

LITERATURE REVIEW

Military aviation has fielded two night vision systems based on image intensifier tubes. The earliest version is known as the AN/Pilot Vision System-5 (PVS), and is based on second-generation image intensifier tubes. The other system uses third-generation tubes, and it is known as the AN/Aviator's Night Vision Imaging System-6 (ANVIS). The PVS and ANVIS systems amplify low level ambient light reflected from objects and present an image on a phosphor screen. Both systems use two image intensifier tubes to form a binocular device that is attached to an aviator's helmet. While both systems currently are in use, the PVS goggles are being replaced systematically in aviation by the newer

ANVIS goggles (Rash, 1990).

The light intensifying tubes used in the ANVIS goggles consist of six primary components. The **objective lens** is an optical element that focuses incoming photons (inverting the image) on a **photocathode**. The photocathode converts incoming light energy (photons) into electrical energy (electrons). Next, a thin (1 mm) wafer with about 3 million hollow fiber optic tubes (Figure 1), the **microchannel plate (MCP)**, serves to increase both the number and velocity of electrons. The inside passages of these tubes are coated with a material and tilted 8 degrees so as to cause a secondary electronic emission. Electrons bounce off the inside of the tilted tubes and collide with one another, causing the electrons to multiply (Figure 2).

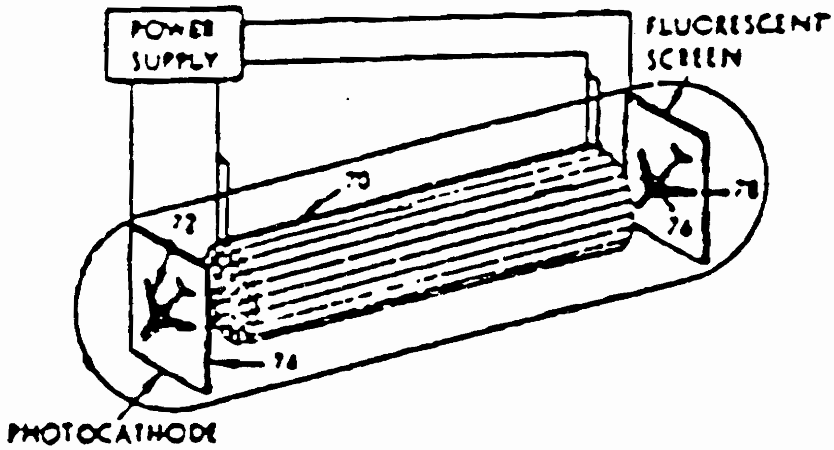


Figure 1. NVG intensifier tube schematic (Biberman and Alluisi, 1992).

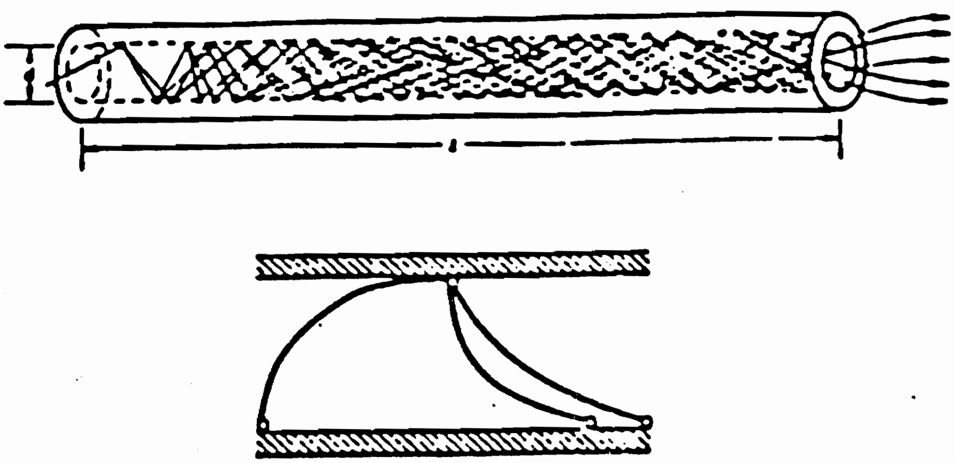


Figure 2. Channel multiplier and electron trajectories (Biberman and Allusi,1992)

For every electron entering the PVS MCP, about 10,000 exit; whereas, the more advanced ANVIS MCP is capable of producing about 25,000 electrons. The electrons are converted back into light energy (photons) as they strike a thin layer of phosphor (the **phosphor screen**) applied to the output fiber optic system. These photons pass through the **fiber optic inverter**, which is a bundle of about three million optical fibers twisted 180 degrees. As the photons exit the fiber bundle, the image is presented right-side-up. The image then is focused onto the user's eye by the **eyepiece lens**.

General characteristics

NVGs are passive light amplification/intensification systems. NVGs do not magnify images; rather they intensify light 750-1500 times (AN/AVS-5s) and 2000-3500 times (ANVIS). They are considered passive devices since they intensify existing light rather than generate light, as in the case of a flashlight. An Automatic Brightness Control (ABC) adjusts MCP voltage to hold eyepiece brightness levels to a preset level by controlling the number of electrons that exit the MCP. The best visual acuity attainable with ANVIS (20/40) is less than daytime (20/10 or 20/20), but a great improvement over night unaided (20/200 or less). 20/40 Snellen acuity is the best attainable under optimal viewing conditions with well functioning NVGs, properly fitted and focused to the user.

Depth perception and distance estimation through NVGs are reduced from daytime capabilities. These perceptual capabilities are affected by ambient light, type and condition of NVGs, degree of contrast, and viewers experience utilizing monocular cues. The Field-of-View (FOV) of NVGs is 40 degrees as compared to about 200 degrees for unaided vision. This limitation can be improved by utilizing a proper scan technique. A 40 degree FOV is best case and can only be obtained when eye relief distance of the NVG eyepiece lenses is within 18mm (11/16"). The focal range of NVGs is from 10 inches (254mm/25cm) to infinity. Normally, tubes are focused to infinity.

All objects viewed through the NVGs appear as green (AN/AVS-5's) or bluish-green (ANVIS) and, thus, NVGs do not provide color discrimination. Blue-green was chosen since the dark adapted human vision system is most sensitive to light in this wavelength range. ANVIS radiance sensitivity range is 390-1000 nm, minus blue filtered light at 525 nm. ANVIS sensitivity extends well into the near-IR range. The minus blue filter makes the ANVIS insensitive to the blue-green cockpit lights.

Dark adaptation is recommended before use of NVGs. Initially, it requires 30-45 minutes to dark adapt. This time period may increase if individuals are affected by poor diet, hypoxia, or exposure to bright light (NVG Operations, 1991).

Luminance contrast

As mentioned above, luminance contrast has been demonstrated to affect goggle performance. In an experiment performed by Wiley (1989), the effects of contrast and luminance on visual acuity were measured under six viewing conditions. Luminance of the apparatus was set at 0.012 footlamberts for all aided viewing conditions. The target was a Snellen optotype "E" presented for 500 msec in one of four possible orientations. The observer was required to indicate the orientation of the "E" in each trial. The "E" varied in sizes corresponding to the Snellen notations of 20/10 to 20/400, and contrast of the target was set at 94, 35, or 5 percent. Wiley's results showed an acuity of around 20/50 through binocular AN/PVS-5s,-7As, and -7Bs (ANVIS was not tested) under full moon, 94 percent contrast condition. As luminance and contrast were reduced, visual acuity decreased. At the quarter moon, 5 percent contrast condition, observers were unable to resolve the largest target (20/400 Snellen acuity). These results indicate that the luminance and contrast of the night scene have a significant impact on aided visual acuity.

Luminance adaptation

Prior research in psychophysics indicates that visual performance is affected by luminance adaptation levels. For example, target detection performance improves as average luminance increases. As luminance increases from very dark (i.e., scotopic) to bright (i.e., photopic) levels, the amount of luminance contrast required to detect a circular spot of light decreases (Barlow, 1958, Blackwell, 1946). In other words, as the level of luminance is increased, less luminance contrast is required to detect a target. Presumably this is with all other conditions being equal. The visual threshold levels have been found to vary rapidly with adaptation luminance in the scotopic (i.e., less than 0.01 cd/m^2) and mesopic (i.e., 0.01 to 0.1 cd/m^2) range. That is, a log unit increase in adaptation luminance from 0.01 to 0.1 cd/m^2 reduces the minimum detectable target size by 60% (20 to 8 arc min), whereas a log unit increase from 1.0 to 10.0 cd/m^2 reduces the detectable target size by only 30% from (20 to 14 arc min).

Additionally, a study by Shlaer (1937) indicates that visual acuity measured in terms of minimum resolvable bar widths or minimum resolvable Landolt-C sizes improves with increasing luminance levels. Acuity approaches an asymptote at luminance levels of 40-1000 cd/m^2, depending on the type of target used. It also was indicated that at a given luminance level, acuity increases as target contrast or target exposure duration increases.

These data indicate that visual detection and acuity capabilities improve with increasing light adaptation levels and, specifically, the visual performance peaks in the photopic range. This information has significant consequences for NVG designers and users, because it indicates that night scene light levels should be amplified to the photopic range. Typical NVG goggles provide an average luminance of about 14 cd/m^2; a light level within the photopic range (Glick, 1974).

Target size

Target size is important for determining levels of visibility (i.e., how well someone sees something). In an experiment conducted by Hecht, Haig, and Wald (1935), it was demonstrated that after five min of dark adaptation, for a given number of minutes in the dark, the threshold for light decreases (sensitivity increases) as the size of the test target increases.

Johnson (1958) indicated that the acuity with which an object is seen depends on range (the interaction of range and target size determine arc minutes of visual angle). Range, in this instance, indicates the threshold at which an object can barely be discerned with the needed acuity. The needed acuity depends upon the level of discrimination desired, whether mere detection of an object, its recognition, or its positive identification. The process is typically, as follows. At very long range a seen object appears first as a blob. Moving closer (as the arc minutes increase) it begins to take some shape such as a rectangle. Closer yet, the observer becomes able to classify the object as to type and finally to identify the object positively. Johnson divided these levels of object discrimination into four categories two of which are the primary focus of the present experiment: detection (the point at which an object is perceived to be present) and recognition (the point at which the class of the object, such as truck, house, etc. may be discerned). To better quantify the degree of visual acuity needed to identify an object as opposed to just detecting it, Johnson performed a series of experiments correlating the detectability of a bar pattern of a given spatial frequency with the level of object discrimination. The procedure was to increase the object range until it was just barely detected (or recognized, etc.). Then a bar pattern was placed in the field of view and its spatial frequency was increased until it could barely be resolved at the same range. The spatial frequency of the pattern was specified in terms of the number of lines in the pattern subtended by the object's minimum dimension. Johnson found that with higher acuity a bar pattern of higher spatial frequency could be discerned and the level of object discrimination increased.

Blackwell (Blackwell, 1946, 1959, 1961, 1964, 1967; Blackwell & Blackwell 1968, 1971) sought to determine the threshold of visibility, which he defined as the point at which observers detect a target 50 percent of the time. The results of his research clearly indicate that as adaptation luminance increases from very dim to very bright levels, the amount of luminance contrast required to detect a circular spot of light decreases. Also, within an adaptation luminance level, the amount of luminance contrast required to detect the circular spot decreases with increasing target size.

Data obtained by Beaton and Farley (1993) were used to compute visual threshold functions similar to Blackwell's data. Although no statistical comparison was made between the data sets, it was apparent that the 50 percent detection thresholds were affected similarly by target contrast and target size. Based on these psychophysical findings, it was expected that target sizes in the range used by Beaton and Farley (1.25-10.0 min of arc) would represent threshold detectable objects when seen through NVGs. A pilot study was conducted which started with Beaton and Farley's target sizes and increased them until actual NVG 50 percent detection levels were determined. These results determined what levels were used in the present experiment.

Objective of Work

The objective of this work was to examine the perceptual limitations of the AN/AVS-6 night vision goggles. Based on the studies above, the effects of adaptation luminance, luminance contrast, and target size affect visual performance. The present experiment examined the effects of these three variables on visual performance while using the AN/AVS-6 NVGs. Specifically tested was how these variables affected target detection and recognition.

METHOD

Participants

Twelve individuals (six males), ranging in age from 19 to 25 years were recruited from Blacksburg, Virginia to participate in this experiment. The 50/50 male/female participant disposition was intentional so that the study would not be biased toward either sex. All participants were screened for normal visual acuity (i.e., minimum 20/20 Snellen acuity; Bausch & Lomb Master Ortho-Rater, Model: 71-21-40-65) and normal contrast sensitivity (VISTECH Eye Chart, Model: Near Field Vision). Corrected vision was acceptable.

Equipment

The experiment was conducted in a dimly lit (i.e., <1 lux) room consisting of an experimenter's station, observer's station, and a rear projection display system. The experimenter's station consisted of a chair and a low-intensity light-source equipped with aqua-blue filter. This was located adjacent to the projectors. The experimenter operated the projection display system and recorded participant responses from the station.

The observer's station included an adjustable swivel chair, allowing each participant to assume a comfortable viewing position. Due to the duration of each session, participants were allowed to alternate between a seated and standing position to ensure comfort and limit distractions during each set of observations. Viewing height and distance was held constant. Observations were made using a set of ANVIS NVGs hard mounted six feet from the rear projection display screen. The goggles were equipped with ITT's F-4921A training filters, which allowed accurate manipulation of the light levels stimulating the goggles (Figure 3). A shield was constructed around the goggles along with curtains to prevent excess light from reaching the participants (Figure 4). The only visual stimuli came from the goggle image.

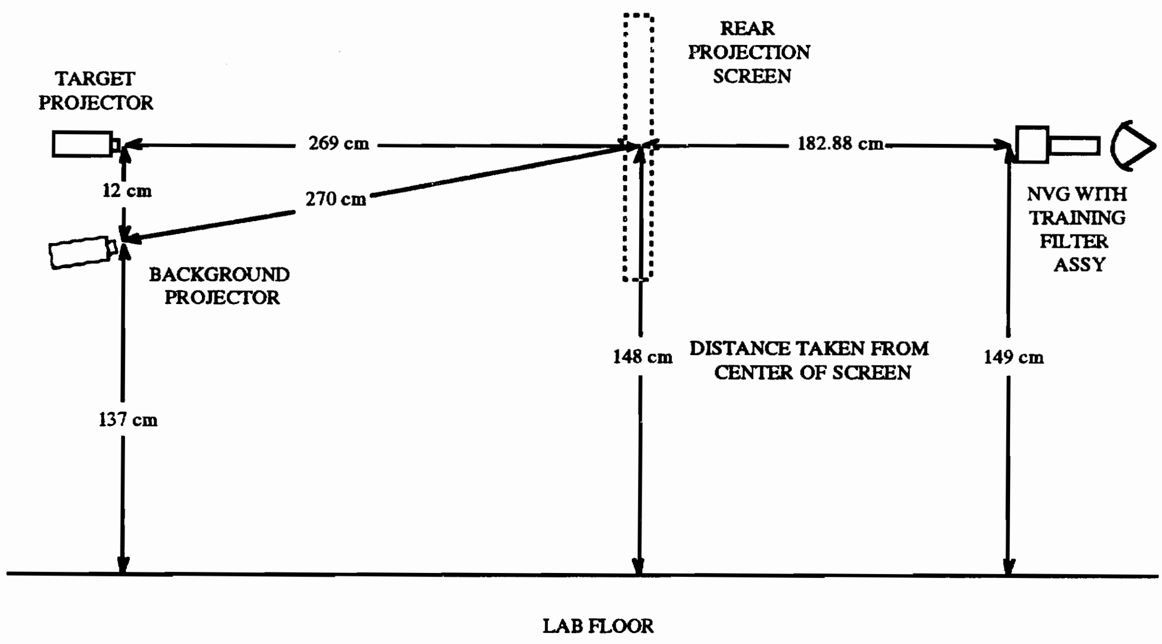


Figure 3. Illustration of lab layout.

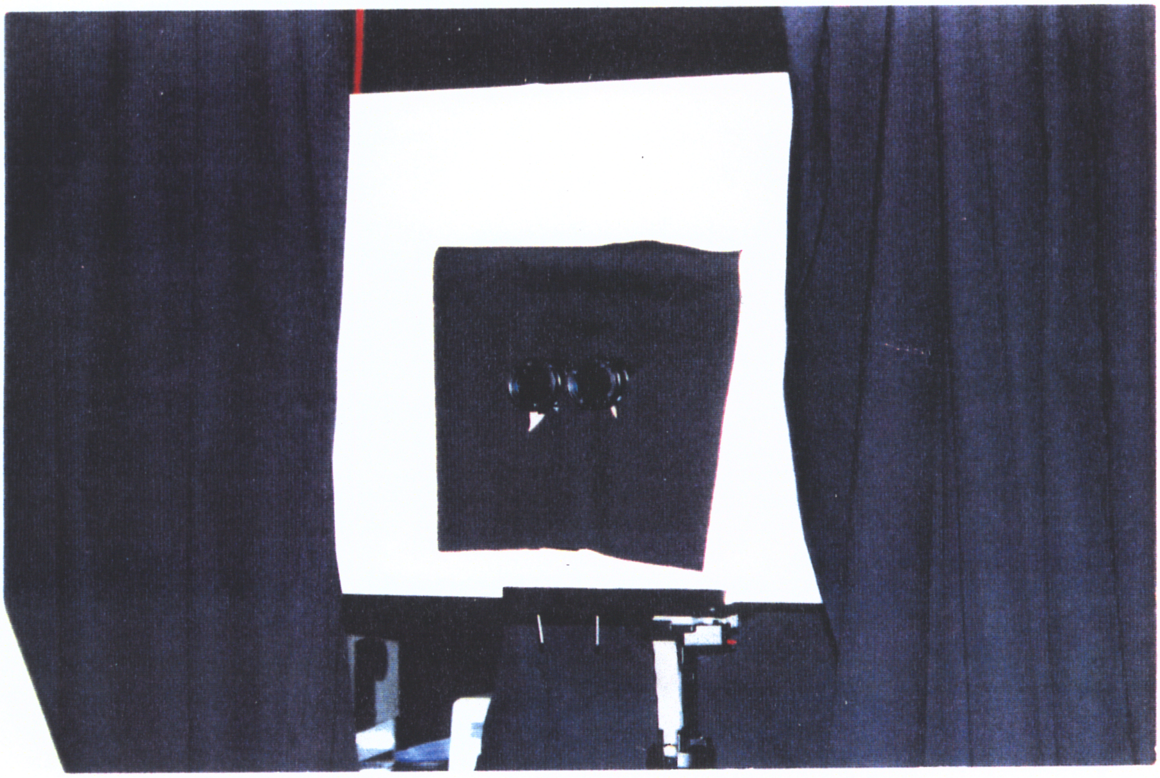


Figure 4. Photo of curtains and shield.

The dual channel, rear projection display system consists of two 35-mm slide projectors (Model: Kodak 4400, f4 lens, GE EYX 250 W bulbs) powered by an uninterruptable, constant-voltage power supply (Model: Clarx OnGuard PC), one per projector. The top projector was used for target presentation and was equipped with a remote slide changer switch and an image presentation timer set for ten seconds. The bottom projector was used to project a background field necessary for the experiment's manipulation of contrast. Neutral density filter holders were mounted on each projector, and combinations of neutral density filters were used to achieve desired contrast levels.

Images were rear-projected on a specially constructed screen, which was located between the projectors and the observer's station (Figure 5). The screen was constructed of a single quarter inch pane of glass tightly covered with a sheet of mylar. Black construction paper bordered the screen creating a circular viewing area with a 65.5 cm radius. Concentric mylar circles more dense towards the center and less dense towards the outside were used to balance the luminance of the projection screen thus preventing washout from an otherwise brighter center (Figure 6). Target images were projected on the outer most circle. This gave the observers a circular shaped search area 131cm in diameter, 26cm from outer to inner edge, and 1,319.47 square centimeters in area.

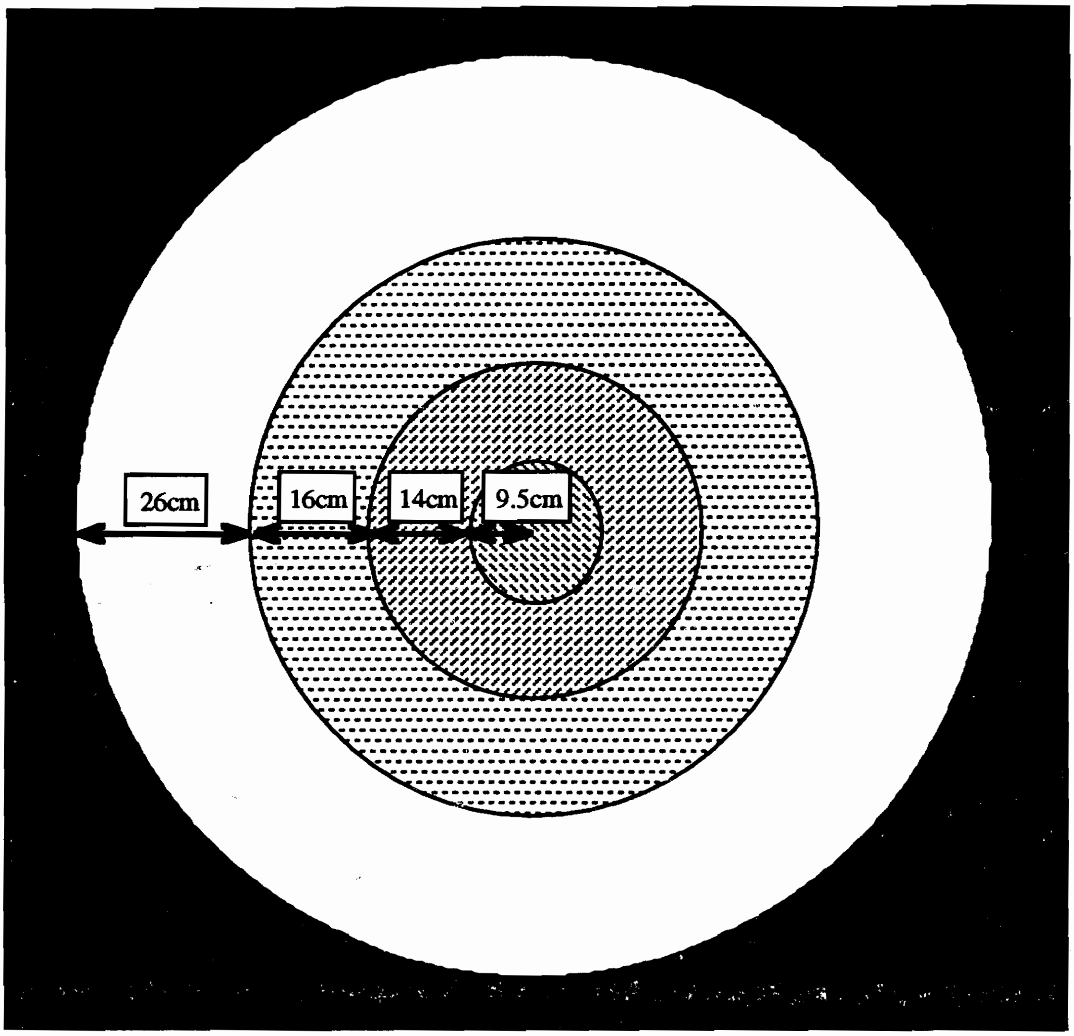
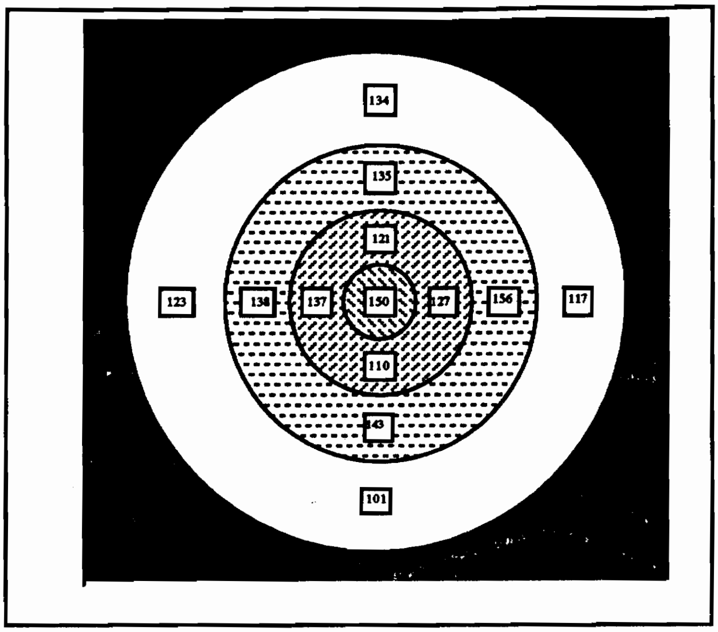


Figure 5. Illustration of rear projection screen dimensions.

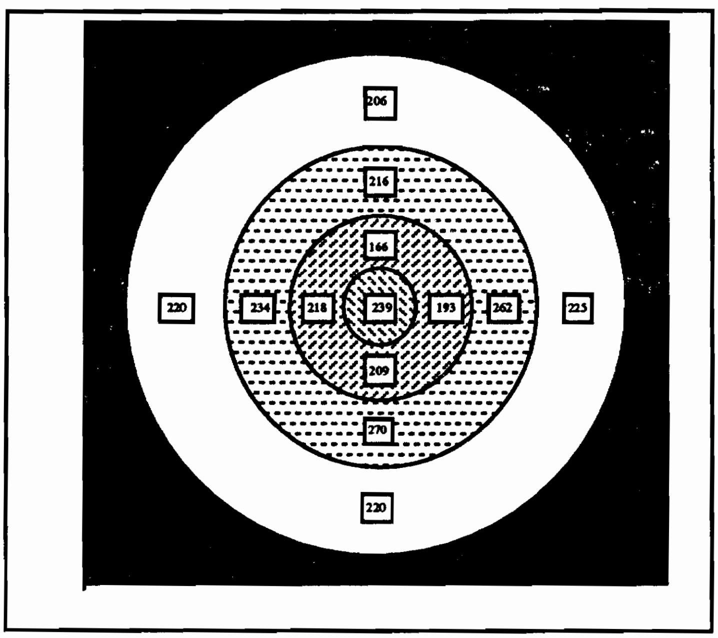


TARGET PROJECTOR LUMINANCE

The following measurements were taken of the rear projection screen from the night vision goggle mount using the Minolta CS-100 Luminance Meter. All measurements are given in candelas per square meter.

Average luminance from rear projection screen was 125.8573.

Post experiment measurement of screen center yielded 147.



BACKGROUND PROJECTOR LUMINANCE

Average luminance from rear projection screen was 219.7276.

Post experiment measurement of screen center yielded 245.

Figure 6. Illustration of screen luminance measurements.

The apparatus setup was similar to that used by Beaton and Farley (1993), in which the effects of target size, luminance contrast, color contrast, and adaptation level on unaided visual target detection and recognition performance were tested. Color contrast was not included in the present experiment since the goggles provide only a monochrome image.

Experimental design

Data collection was structured by a 4 x 3 x 4 within-subjects factorial design. The three *independent variables* are described below.

1) Target Size (4 levels): defined as the angular extent of a target subtended on the observer's retina, expressed in units of visual angle, as given by

$$Size_{degree} = \frac{180}{\pi} \arctan\left[\frac{Size_{lin}}{D}\right] \qquad \text{(Eq. 1)}$$

in which **arctan[.]** denotes the transcendental arc tangent function (i.e., **tan-1[.]**) computed in radians, D denotes the observer-to-screen viewing distance in linear distance units (i.e., six feet), and $Size_{lin}$ denotes the target extent in linear distance units (i.e., foot units). The four levels of target size were: 8.75, 17.5, 35.0, and 70.0 arc minutes of visual angle. These angular units correspond to 0.4655, 0.9310, 1.8620, and 3.7239 centimeters, respectively. These target sizes were derived by starting with those used by Beaton and

Farley (1993) and then gradually increasing their size under "middle" lighting and contrast levels (0.1614 lux and 53.63 percent level of contrast) until a Threshold of Visibility (Blackwell and Blackwell, 1968; 1971) was determined for the 0.9310 cm target.

2) Luminance Contrast (3 levels): defined as

$$Luminance Contrast = \frac{[L_b - L_t]}{[L_b + L_t]} \qquad \text{(Eq. 2)}$$

in which L_b and L_t denote the luminance of the background and target fields, respectively. Targets were darker than their background field. Levels were set at 86.86, 53.63, and 17.58 percent luminance contrast as used by Wiley (1989).

3) Illumination (4 levels): defined using ITT's F-4921A training filters. These levels were based on the following moonlight illumination levels: 100 percent or full moon (0.2152 lux), 75 percent moon (0.1614 lux), 50 percent moon (0.1076 lux), and 25 percent moon (0.0538 lux) (RCA, 1974).

The two *dependent variables* were as follows:

1) Target Detection Probability: Participants were required to detect a target in one of eight screen positions on each trial. The observer's detection responses were correct or incorrect; thus, the proportion of correct detection responses across all trials under each viewing condition defined a 50% detection probability. The random probability of correct detection is

indeterminate. It is less than one out of eight possible target positions per trial ($p < 0.1250$) due to a ninth choice the participants had to state they did not detect a target. Non detection was recorded as an incorrect response.

2) Target Recognition Probability: Participants were required to recognize a target out of three possible choices on each trial. The participants' recognition responses were correct or incorrect; thus, the proportion of correct recognition responses across all trials under each viewing condition defined a 50% recognition probability. The random probability of correct recognition is indeterminate. It is less than one out of three possible target types per trial ($p < 0.3334$) due to a fourth choice the participants had to state they did not recognize a target. Non recognition was recorded as an incorrect response.

Procedure

After screening for normal contrast sensitivity and 20/20 acuity, each participant read a set of instructions for the experimental task (see Appendix). The instructions detailed the method and type of target presentations, the stimulus response protocol, and the procedures for trial and rest-break initiation. Familiarization with stimulus-response protocol was achieved by viewing example targets presented in the instruction packet. Following a review of the instructions with the experimenter to assure an accurate understanding of the task, each participant was familiarized with the ANVIS NVGs and taught how to focus them according to his or her vision needs. Familiarization took place in the actual test lab under reduced lighting. After familiarization was achieved, the participants were prompted by the experimenter to focus the goggles according to their individual needs. With this accomplished, the experiment began.

During each trial, the method of constant stimuli was used to determine the detectability and recognizability of the targets presented under each viewing condition. For each trial, one of three potential targets was presented randomly in one of eight positions for a fixed viewing interval of ten seconds. During each ten second interval, the target was visible only for approximately eight seconds due to surge protection built into the ANVIS goggles. When a target was projected, power in the goggles was automatically reduced and gradually recovered to prevent overload and damage to the system. As determined during the pilot study for this experiment, this process takes approximately two seconds during which targets are indistinguishable. The pilot study also determined that eight seconds was an adequate amount of observation time to accurately locate and identify targets under conditions of high contrast, high illumination, and large target size.

During each target presentation trial , participants were asked to verbally report a target position (using the 12-hr clock values: 12:00, 1:30, 3:00, 4:30, 6:00, 7:30, 9:00, or 10:30) and a target type (car, APC, or tank; see Figure 21 in Appendix). After the experimenter recorded the detection and recognition responses, each participant was asked to initiate the next trial by stating his or her state of readiness.

Each participant completed the entire test in a single session. Target type, size, and replications were varied in a unique random order for each observer. Trials were blocked within each session by illumination level and luminance contrast to avoid shifts in the participants' visual adaptation to the test scenes. Prior to each block of trials, participants viewed an empty adaptation field for two minutes to light adapt to the illumination level being tested.

RESULTS

The initial data analyses involved the computation of probabilities for correct target detection and recognition for each viewing condition. The probabilities of correct target detection were calculated by comparing an observer's judgment of target position to the actual position used on each trial. A correct observation was coded as a 1, whereas an incorrect observation was coded 0. The probabilities of correct detection for each combination of illumination level, target contrast, and target size was computed as the sum of the coded position judgments divided by the maximum number of observations per viewing condition per subject.

The probabilities of correct target recognition under each viewing condition were calculated in a like manner, with the exception that recognition probabilities were calculated as conditional probabilities. Only recognition responses from trials producing correct detection responses were considered. This was done to remove some portion of variance due to chance recognition.

Target detection and recognition probabilities were subjected to separate Analysis of Variance (ANOVA) procedures. The data used were average probabilities, collapsed across replications and target type for each participant. All ANOVA effects were corrected for sphericity using the Greenhouse-Geiser adjustment to F-test degrees of freedom (see Tables 1 and 2).

Post hoc analyses were performed on all significant main effects and interactions using the Student-Newman-Keuls procedure. The post hoc results are presented for each significant ANOVA effect.

Target Detection

As shown in Table 1, all main effects and all but the Illumination x Contrast interaction effect from the target detection data were statistically significant ($p < 0.05$).

Table 1. ANOVA Summary Table for Target Detection

SOURCE	DF	SS	MS	F	ε	$p_{G\text{-}G}$
ILLUM (I)	3	1.4212	0.4737	36.72	0.8331	**0.0001**
Error(I)	33	0.4258	0.0129			
CONTRAST (C)	2	6.0047	3.0024	162.14	0.9230	**0.0001**
Error(C)	22	0.4074	0.0185			
SIZE (S)	3	76.8496	25.6165	1027.92	0.7325	**0.0001**
Error(S)	33	0.8224	0.0249			
I*C	6	0.0692	0.0115	1.00	0.6888	0.4206
Error(I*C)	66	0.7636	0.0116			
I*S	9	0.8447	0.0939	7.73	0.3926	**0.0003**
Error(I*S)	99	1.2024	0.01215			
C*S	6	4.6297	0.7716	49.81	0.3926	**0.0001**
Error(C*S)	66	1.0223	0.0155			
I*C*S	18	0.8469	0.0470	4.87	0.3474	**0.0003**
Error(I*C*S)	198	1.9111	0.0097			

Illumination.

Figure 7 shows the main effect of illumination on target detection. A post hoc

Newman-Keuls test shows that target detection performance improves when illumination increases from 0.0538 lux to 0.1076 lux and again from 0.1614 lux to 0.2152 lux ($p < 0.05$).

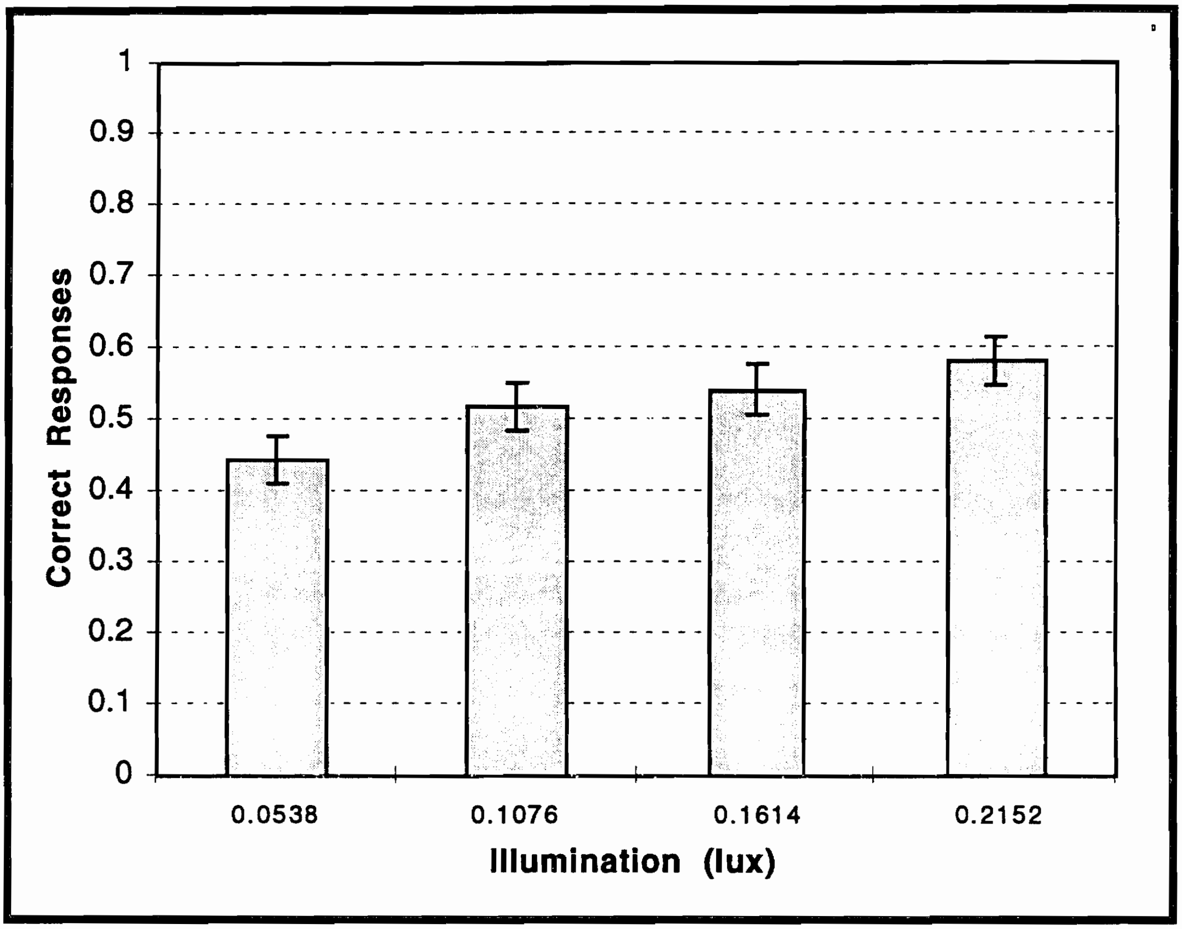


Figure 7. Main effect of illumination on target detection performance.

Contrast.

Figure 8 shows the main effect of luminance contrast on target detection. A Newman-Keuls test reveals that at low (17.58 percent) contrast, target detection performance is worse than at medium (53.63 percent) and high (86.86 percent) contrasts. Target detection performance at the medium contrast condition is significantly worse than at the high contrast condition ($p < 0.05$).

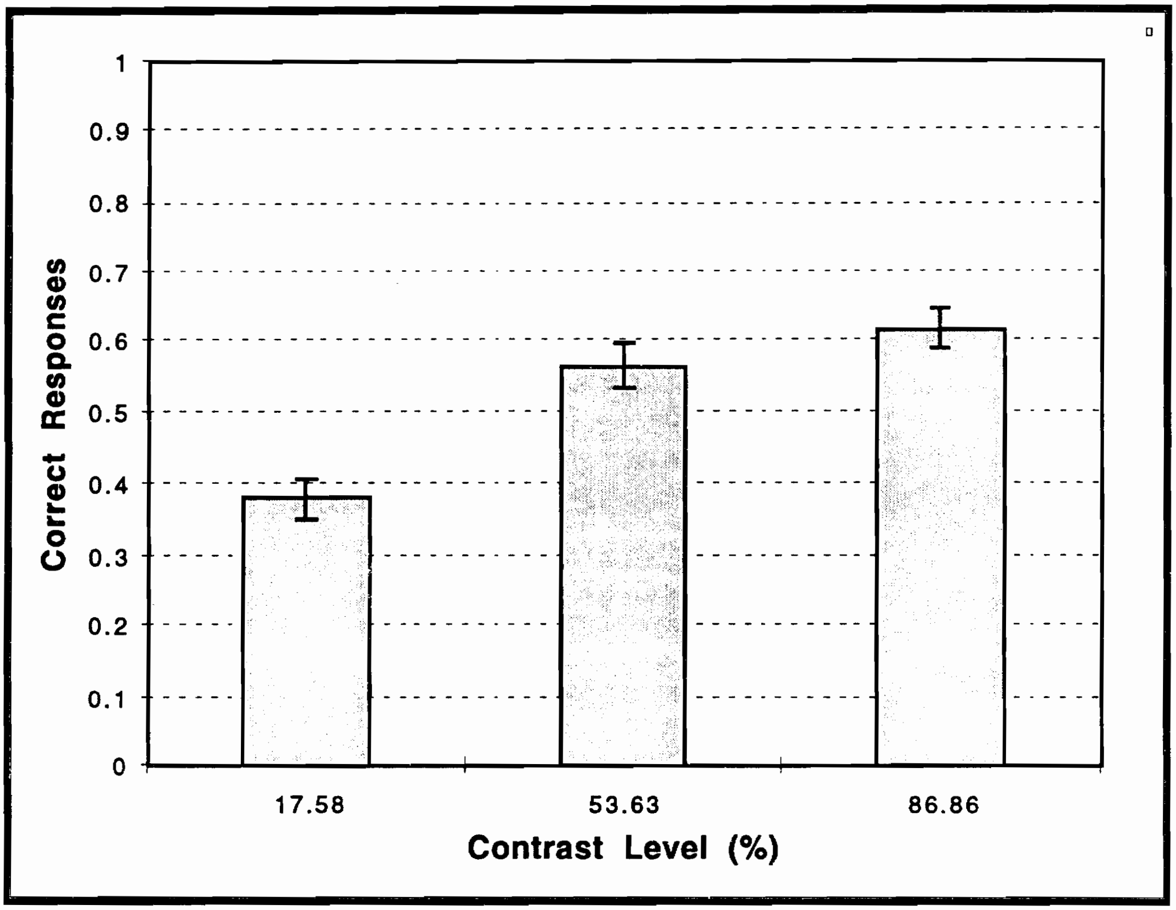


Figure 8. Main effect of luminance contrast on target detection performance.

Size.

Figure 9 shows the main effect of target size on detection performance. A Newman-Keuls test indicates that detection performance differed across all levels of target size. Specifically, target detection improves with each increasing level of target size ($p < 0.05$).

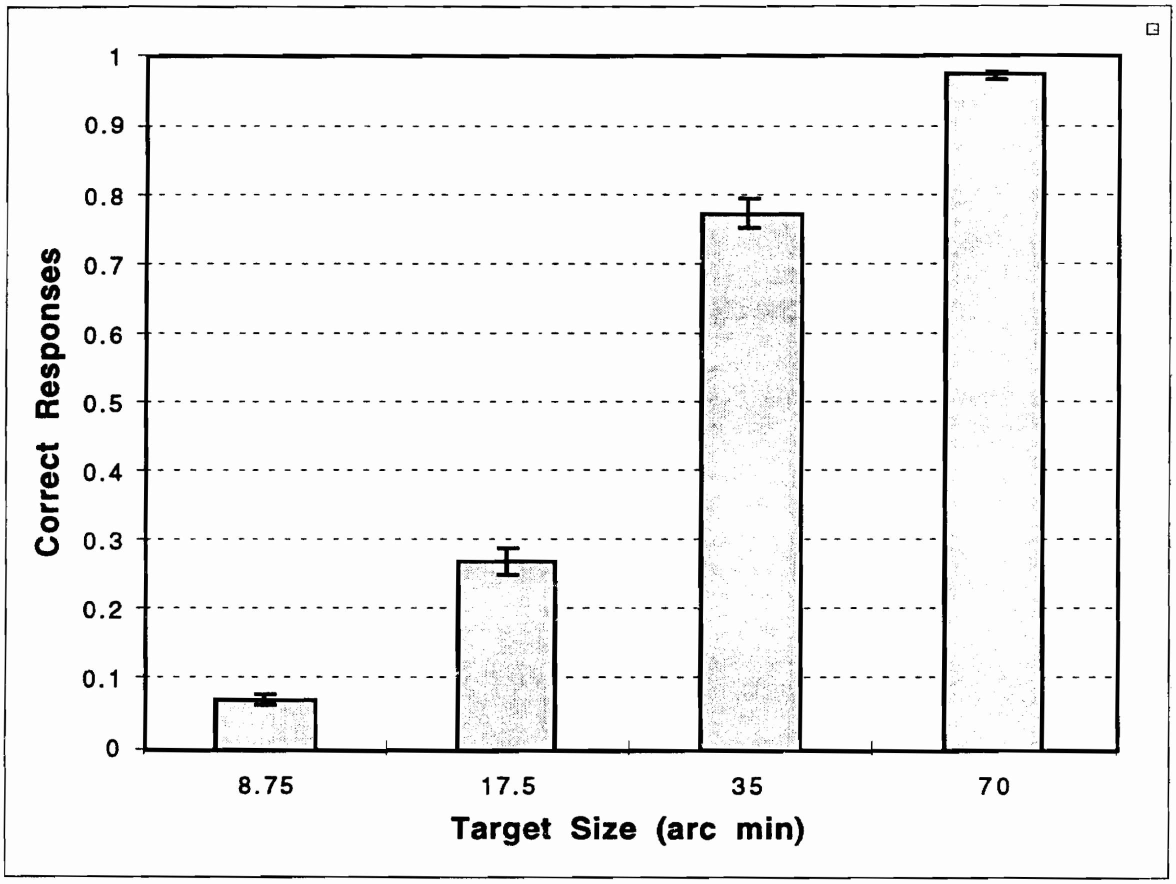


Figure 9. Main effect of target size on target detection performance.

Illumination x Size.

Figure 10 shows the interaction effect of illumination and target size on detection performance. A Newman-Keuls test shows that detection performance significantly improves as illumination and target size increase ($p < 0.05$). No significant difference in detection performance exists among illumination levels at the smallest and largest target sizes (i.e., 8.75 and 70 arc min). At these extreme levels, the detection results appear to reflect psychophysical floor and ceiling response effects. That is, performance levels have achieved both their minimum and maximum possible outcomes respectively. No further increase or decrease in illumination or target size levels would significantly add or detract from the range of performance levels already witnessed.

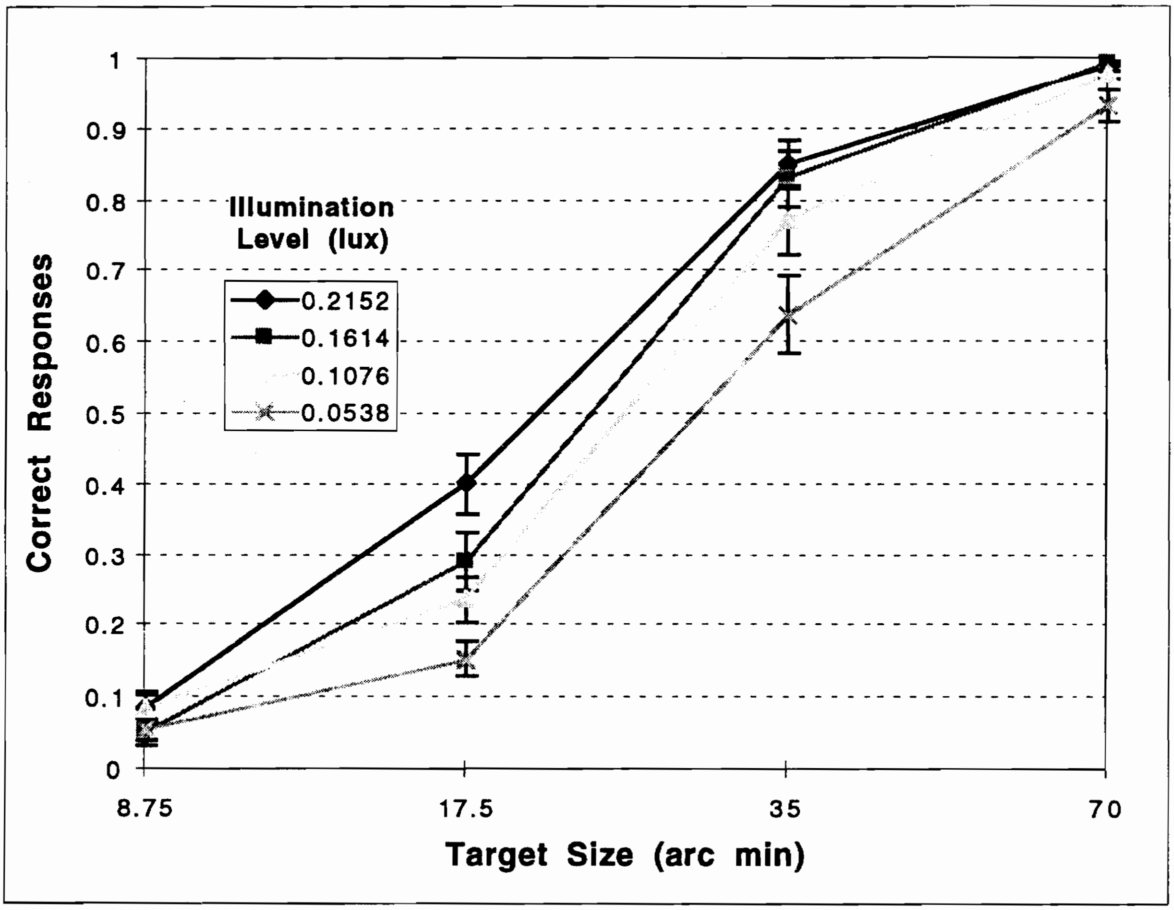


Figure 10. Interaction of illumination and target size on detection performance.

Contrast x Size.

Figure 11 shows the interaction of contrast and target size on detection performance. A Newman-Keuls test shows that detection performance improves as luminance contrast and target size increase ($p < 0.05$). No significant difference in detection performance exists across contrast levels at the largest and smallest target sizes examined. Again, at these extreme levels, the response trends appear to reflects psychophysical floor and ceiling effects.

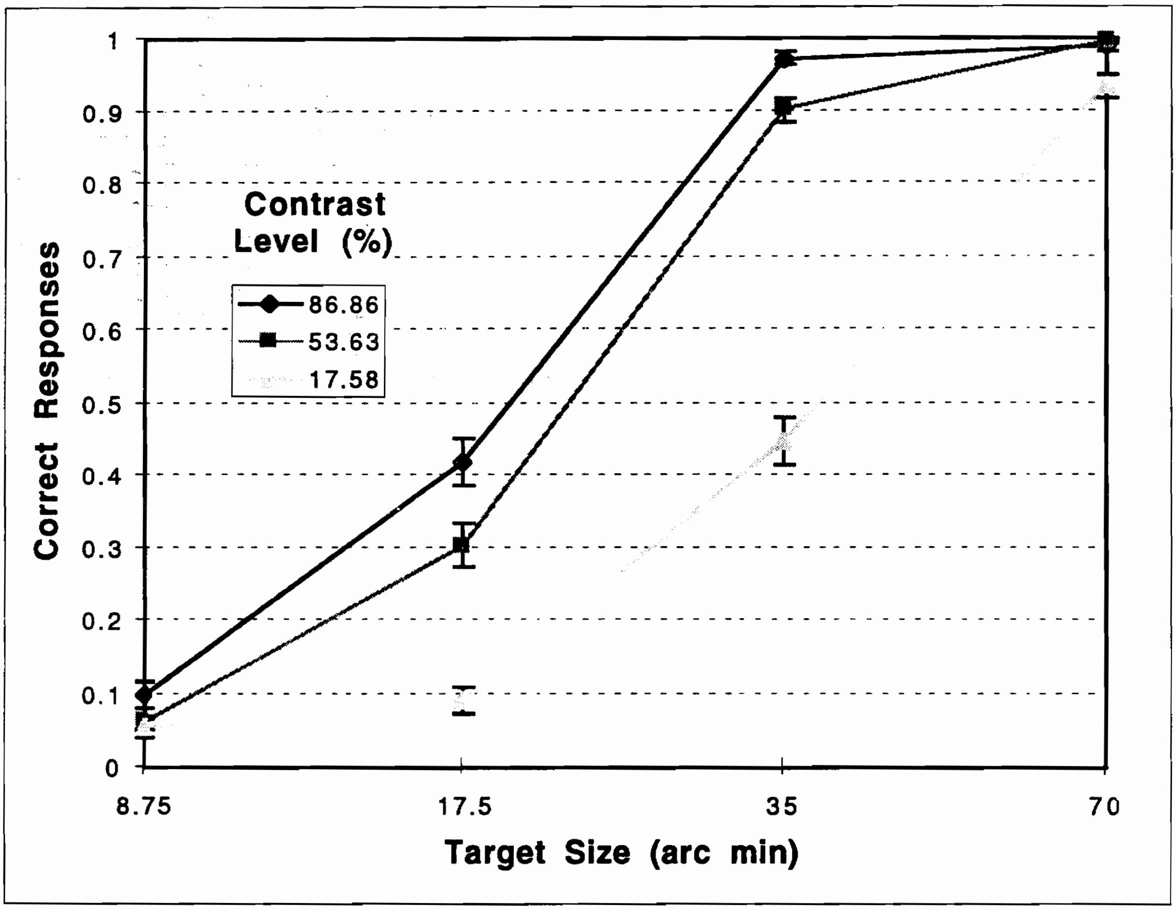


Figure 11. Interaction of luminance contrast and target size on detection performance.

Illumination x Contrast x Size.

Figure 12 shows the three-factor interaction of illumination, luminance contrast, and target size on detection performance.

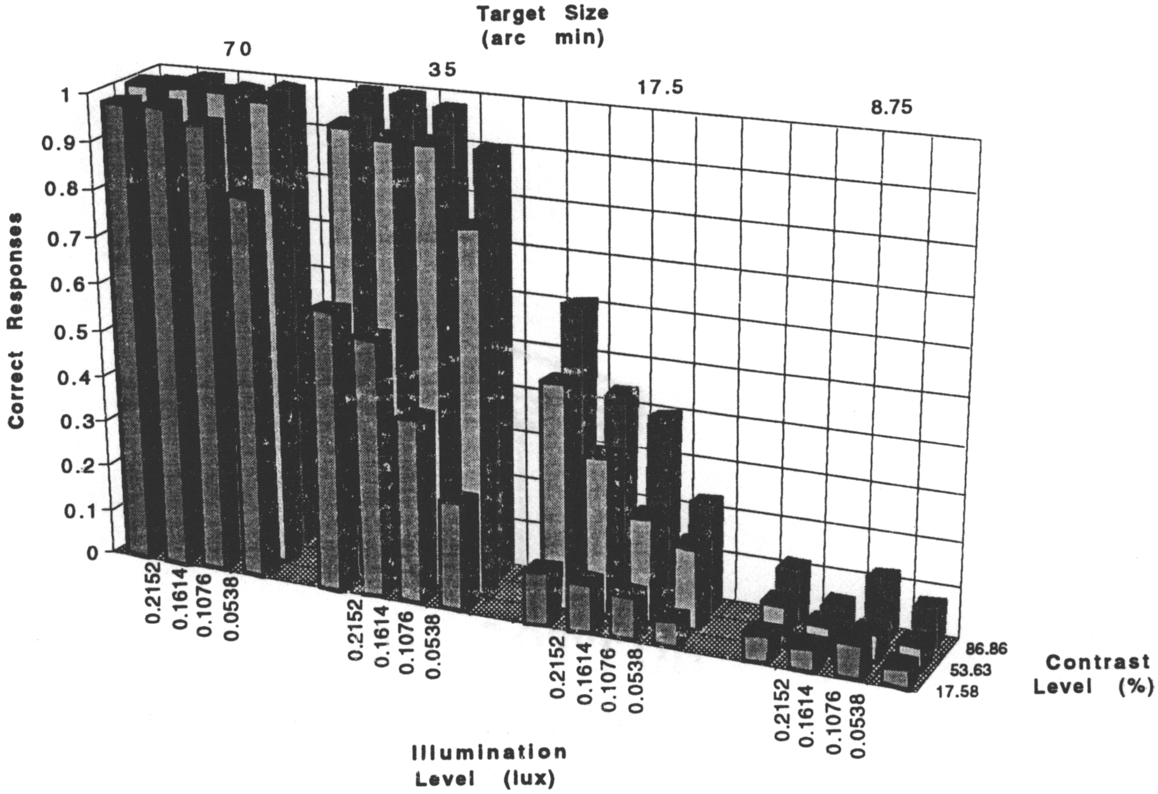


Figure 12. Interaction of the illumination, contrast, and target size on detection performance.

The three-factor interaction was evaluated by examining the simple-effect, two-factor interactions between illumination and contrast target across the four levels of target size. The simple-effect interactions were subjected to separate Analysis of Variance procedures. The simple-effect interactions of illumination and contrast for 17.5, 35.0, and 70 arc min targets were significant (p < 0.05), as shown in Figures 13, 14, and 15, respectively.

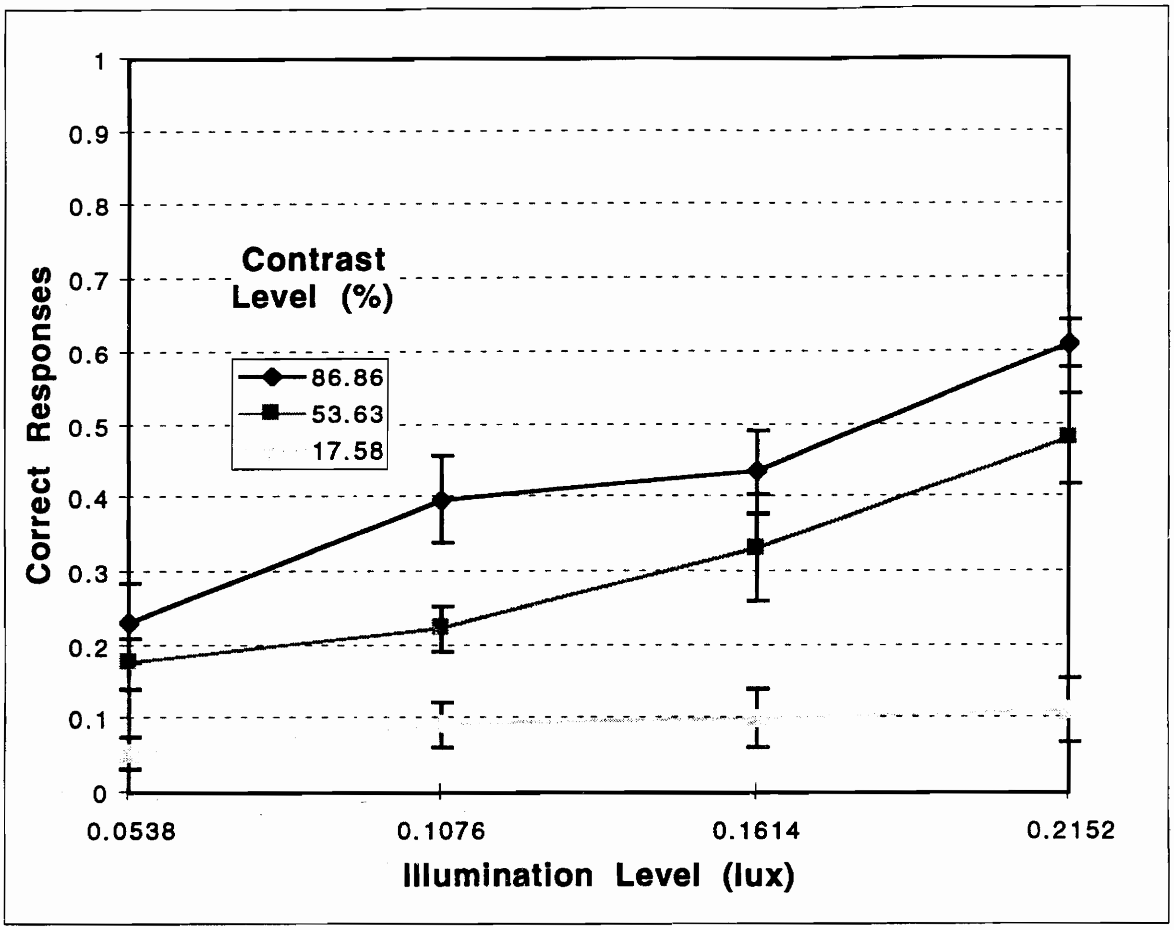


Figure 13. Simple two-factor interaction of illumination and contrast on detection performance for 17.5 arc min targets.

For the 17.5 arc min targets, a Student-Newman-Keuls test shows that detection performance improves with increasing illumination at the two highest contrast examined. However, illumination had no affect on detection performance at the lowest contrast level examined.

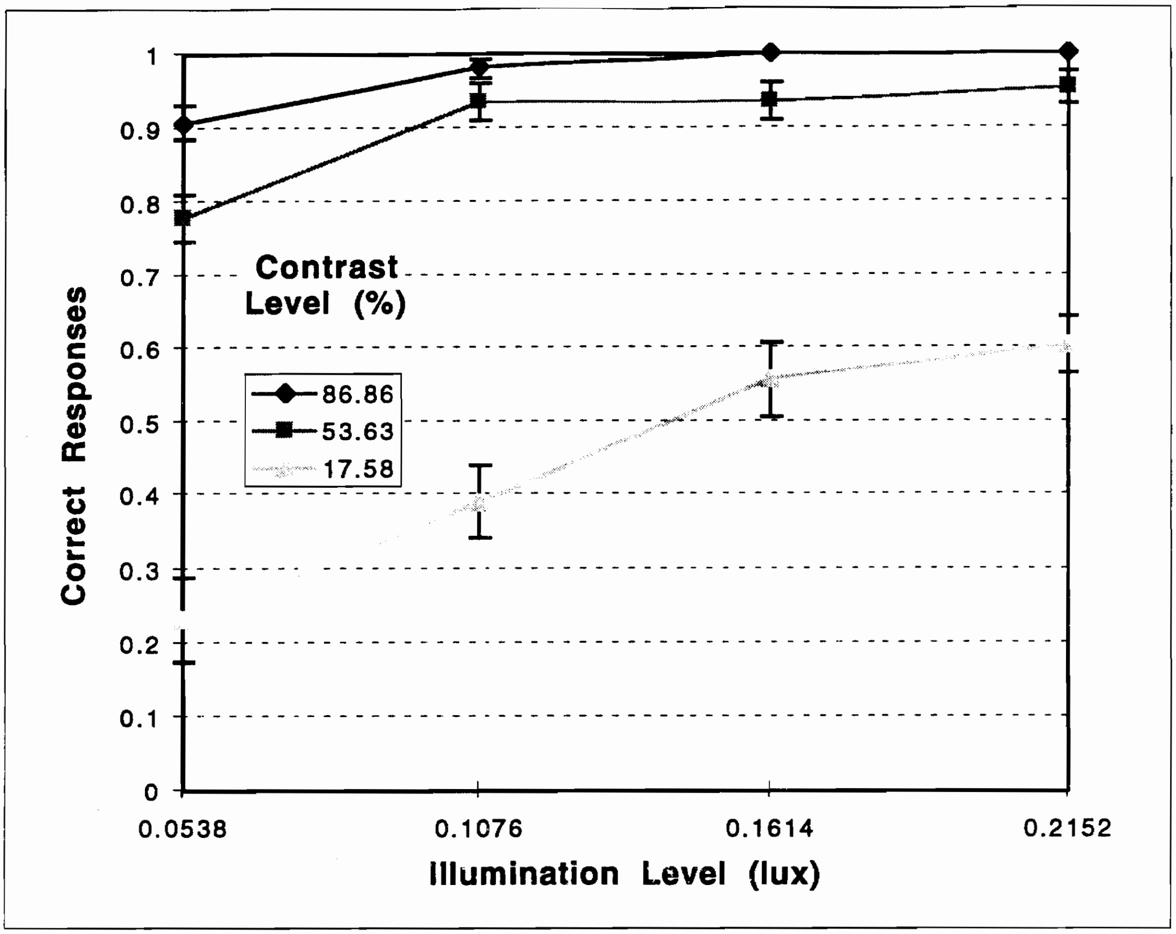


Figure 14. Simple two-factor interaction of illumination and contrast on detection performance for 35 arc min targets.

For the 35 arc min targets, a Student-Newman-Keuls test shows that detection performance improves with increasing illumination from 0.0538 lux to 0.1076 lux across all contrast levels examined. At higher illumination levels, no further increases in detection performance are seen due to apparent ceiling effects.

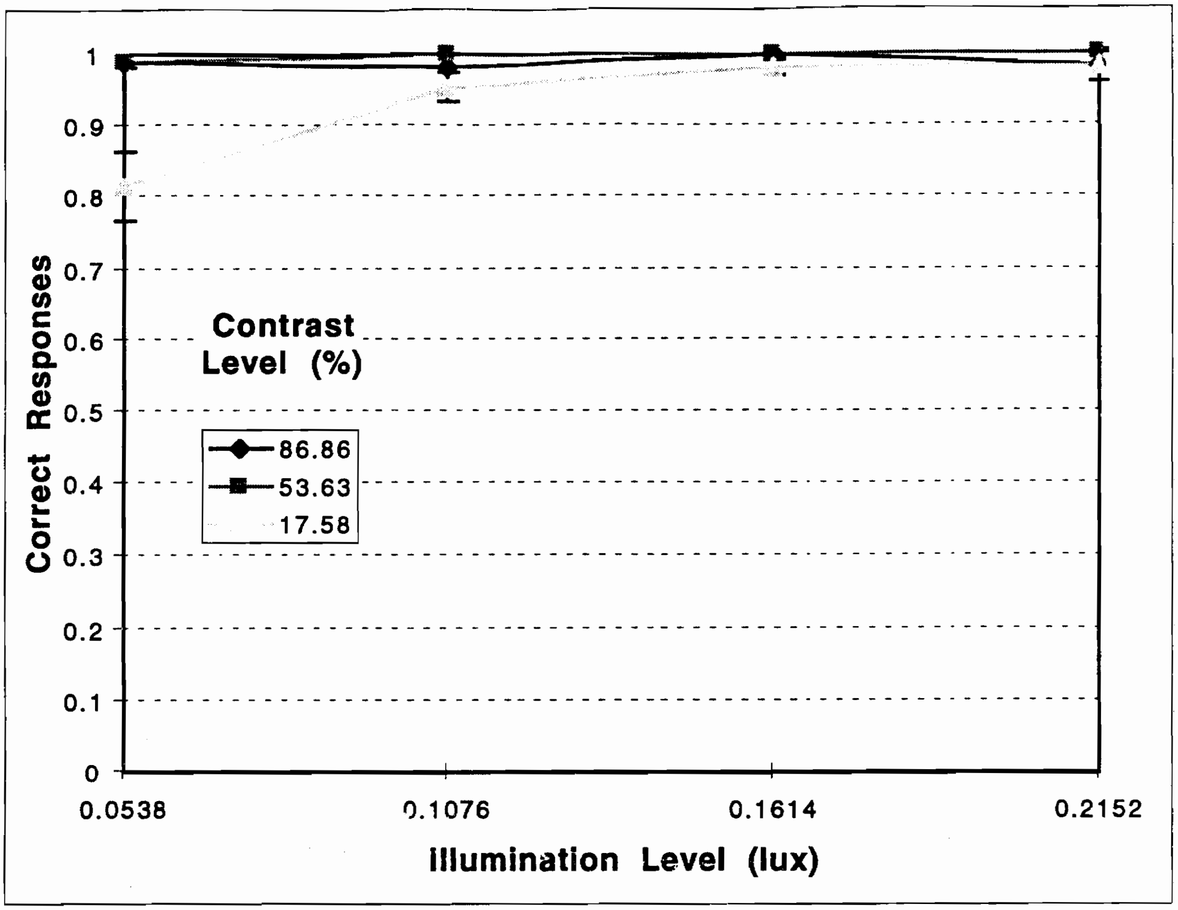


Figure 15. Simple two-factor interaction of illumination and contrast on detection performance for 70 arc min targets.

For the 70 arc min targets, a Student-Newman-Keuls test shows that detection performance improves with increasing illumination from 0.0538 lux to 0.1076 lux for the 17.58 percent contrast level. No further increases in detection performance are seen due to an apparent ceiling effect.

Target Recognition

Table 2 shows the ANOVA findings for the target recognition data. All main effects and two interaction effects were statistically significant ($p < 0.05$).

Table 2. ANOVA Summary Table for Target Recognition

SOURCE	DF	SS	MS	F	ε	$p_{G\text{-}G}$
ILLUM(I)	3	1.2798	0.4266	10.25	0.8363	**0.0002**
Error(I)	33	1.3739	0.0416			
CONTRAST(C)	2	4.4836	2.2418	80.30	0.9424	**0.0001**
Error(C)	22	0.6142	0.0279			
SIZE(S)	3	54.8514	18.2838	312.13	0.5714	**0.0001**
Error(S)	33	1.9331	0.0586			
I*C	6	0.4206	0.07011	2.20	0.5496	0.0989
Error(I*C)	66	2.0987	0.03180			
I*S	9	1.2528	0.13920	3.06	0.4400	**0.0266**
Error(I*S)	99	4.5004	0.04546			
C*S	6	1.3066	0.21777	7.47	0.5100	**0.0005**
Error(C*S)	66	1.9230	0.02914			
I*C*S	18	1.0123	0.05624	1.89	0.2865	0.1092
Error(I*C*S)	198	5.9068	0.02983			

Illumination.

Figure 16 shows the main effect of illumination on target recognition. A Newman-Keuls test indicates that target recognition performance significantly improves as illumination increases from 0.1076 lux to 0.1614 lux ($p < 0.05$). The overall trend of increasing recognition performance with increasing illumination is similar to that observed for target detection performance (see Figure 7).

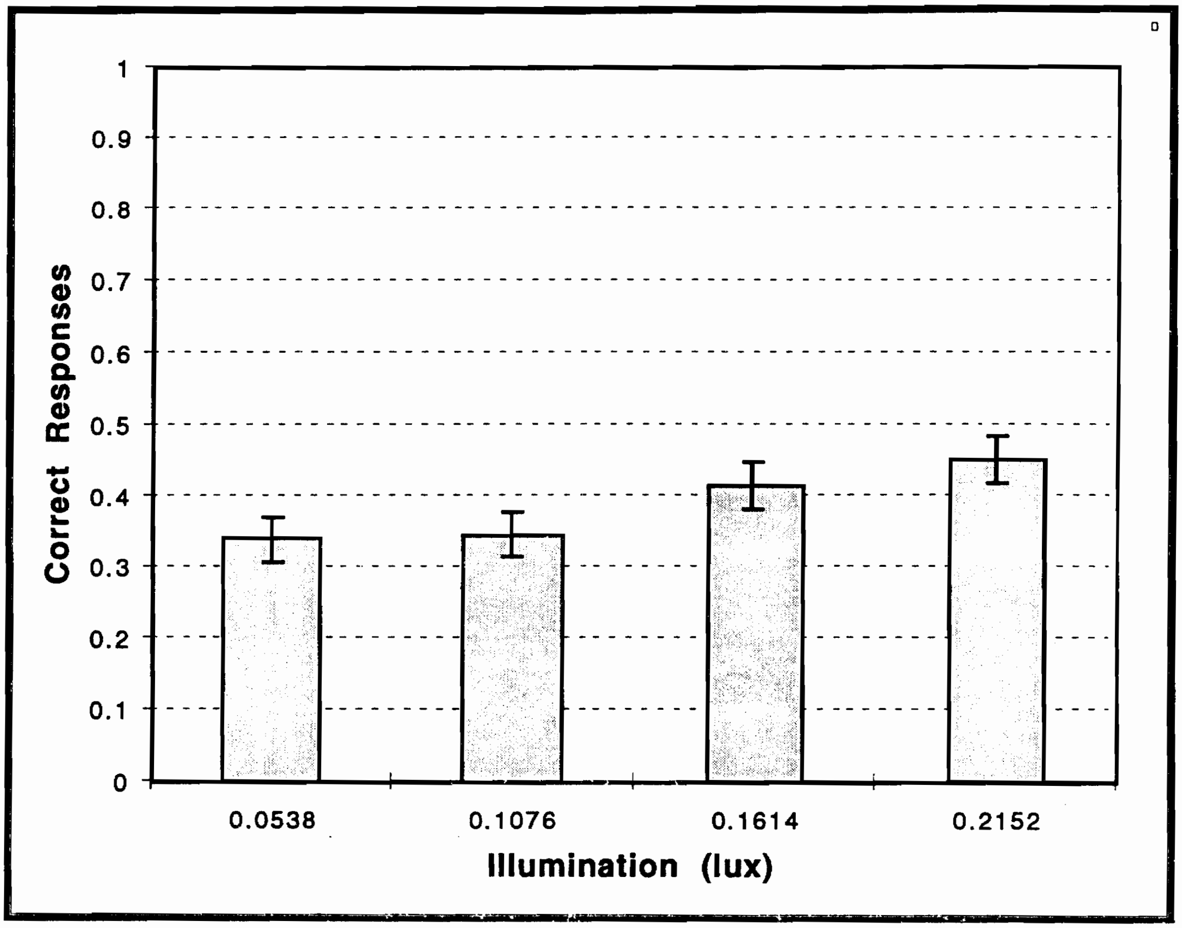


Figure 16. Main effect of illumination on target recognition performance.

Contrast.

Figure 17 shows the main effect of luminance contrast on target recognition. A Newman-Keuls test indicates that target recognition performance significantly increases with increasing contrast levels ($p < 0.05$). This data trend is similar to the effect of contrast on target detection performance (see Figure 8).

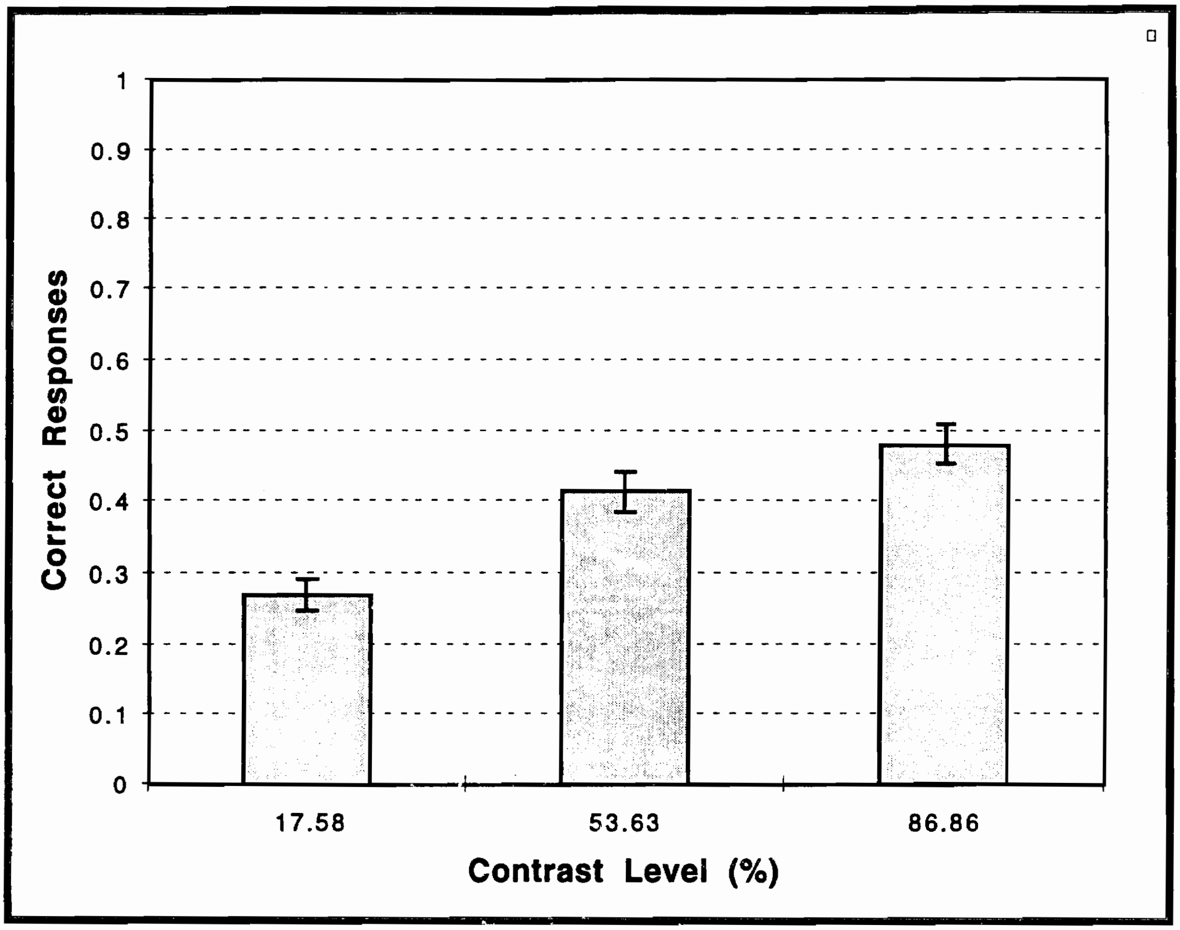


Figure 17. Main effect of luminance contrast on target recognition performance.

Size.

Figure 18 shows the main effect of target size on target recognition performance. A Newman-Keuls test reveals that target recognition performance significantly improves with increasing target size ($p < 0.05$). This data trend is similar to the effect of target size on detection performance (see Figure 9).

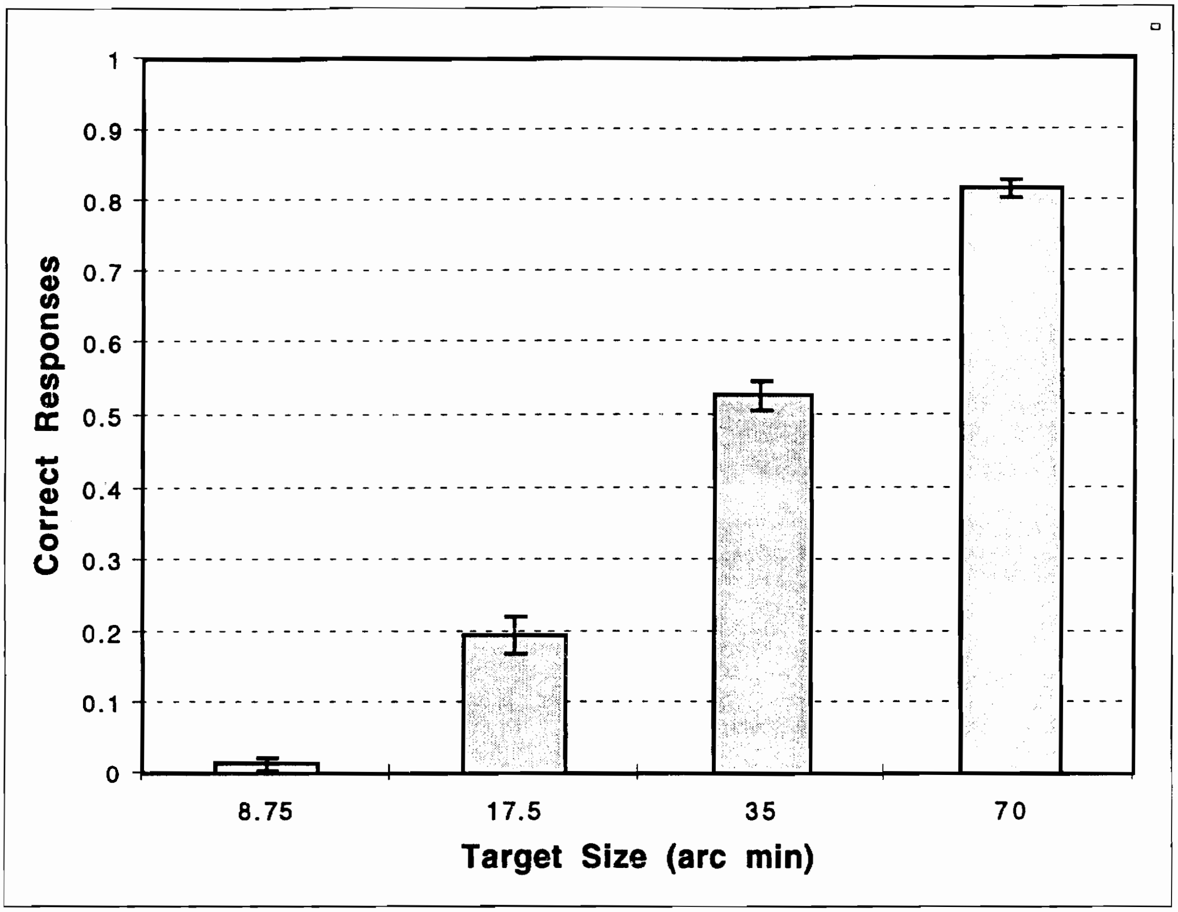


Figure 18. Main effect of target size on recognition performance.

Illumination x Size.

Figure 19 shows the interaction effect of illumination and target size on recognition performance. A Newman-Keuls test shows that recognition performance significantly improves as illumination and target size increase ($p < 0.05$). No significant differences in performance were found between illumination levels at the largest or smallest target size tested (i.e., 8.75 and 70 arc min). As discussed with the detection data, the response , at these extreme levels, appears to reflect psychophysical floor and ceiling effects.

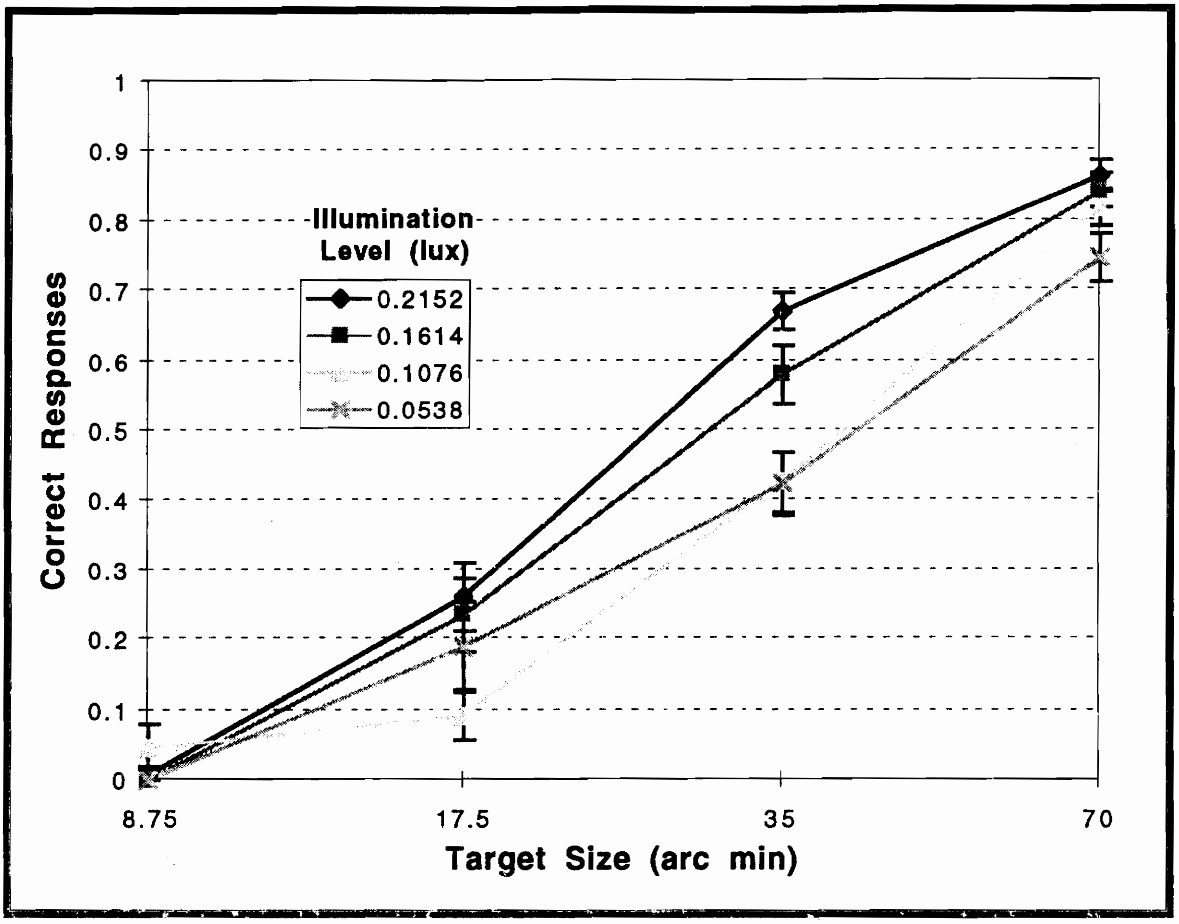


Figure 19. The effect of the interaction of illumination x size on recognition performance.

Contrast x Size.

Figure 20 shows the interaction effect of luminance contrast and target size on recognition performance. A Newman-Keuls test shows that recognition performance improves as luminance contrast and target size increase. No significant differences in recognition performance were found across contrast levels at the smallest target size tested as well as between 53.63 and 86.86 percent contrasts for the largest target size tested (p>.05). This effect is similar to the interaction effect of illuminance and target size on detection performance (see Figure 11).

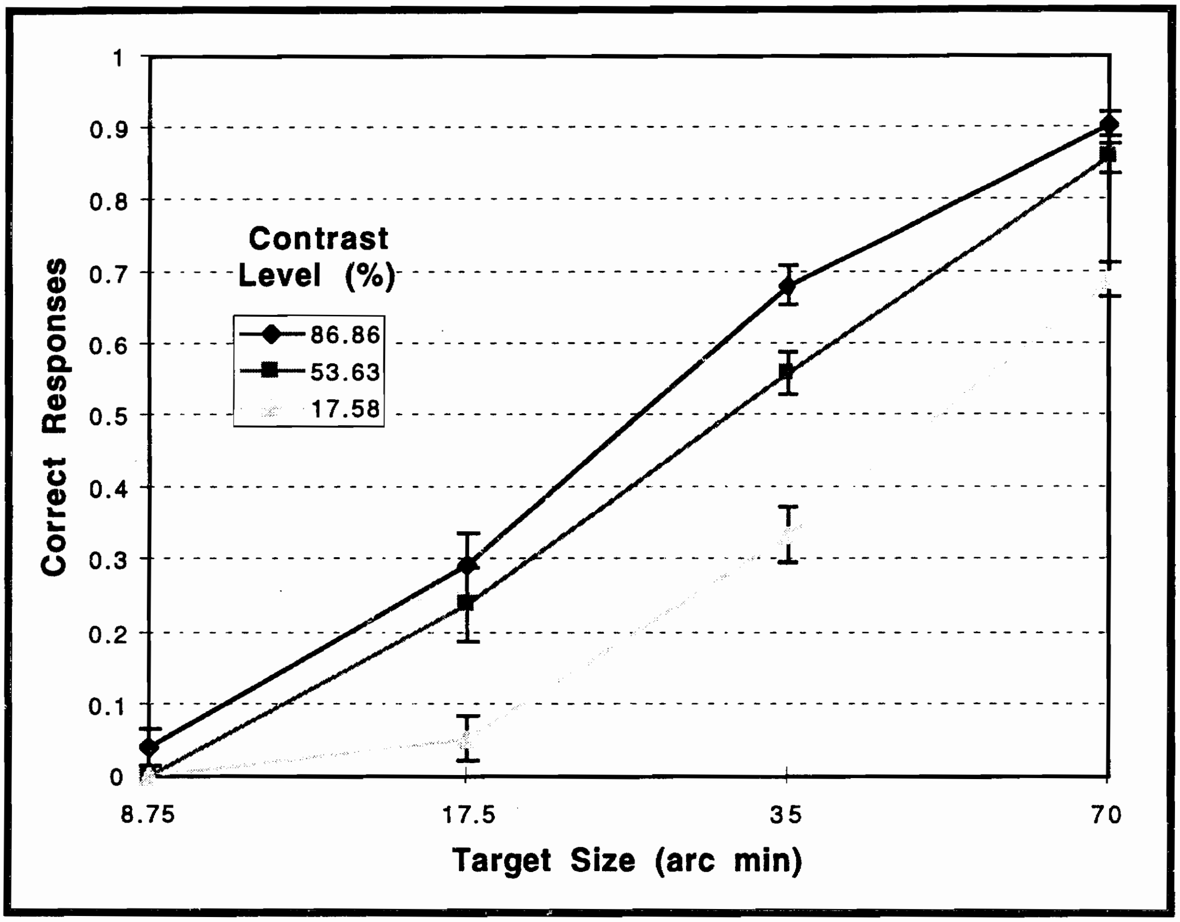


Figure 20. Interaction of luminance contrast and target size on recognition performance.

DISCUSSION

The findings of this experiment show that while using the AN/AVS-6 NVGs, visual psychophysical judgment is affected by illumination level, luminance contrast level, and target size similarly to the way they affect unaided visual psychophysical judgment. At the levels tested, target detection and recognition performance levels improved as illumination, luminance contrast, and target size increased. This was best illustrated in Figure 12.

Most vision research indicates that higher illumination levels have a beneficial effect on visual performance. For target detection and recognition tasks, NVG performance levels improved as illumination levels increased. Although performance never decreased as a result of increased illumination, increased illumination levels affected detection and recognition in dissimilar ways. Target detection performance significantly improved only when illumination was increased from 0.0538 lux to 0.1076 lux and when increased from 0.1614 lux to 0.2152 lux. Target recognition performance was significantly improved only when illumination was increased from 0.1076 lux to 0.1614 lux. This information coincides with past research denoting a relationship between illumination level and performance, greatly dependent on the specific task being performed (Bennett, Chitlanga, & Pangrekar, 1977; Hughs & McNelis, 1978). This indicates that while using NVGs under less than full moon light (0.2152 lux), illumination advantageous to one task type may not be advantageous to another. Overall, greater illumination of the night scene is consistently shown to be an advantage.

This study confirms that contrast significantly affects at least two types of visual performance tasks common to helicopter pilots. For target detection and recognition tasks, NVG performance levels improved as contrast levels increased. In the case of the recognition task, performance above chance level was not observed until a luminance contrast of 53.63 percent was achieved. Since the visual environment in which helicopters operate rarely exceeds a contrast of 50 percent (Tjernstrom, 1992), contrast becomes an important consideration for both the designers and users of NVGs.

It is well known that size is an important element and must be defined when determining a target's level of visibility. Visibility, i.e. how well someone sees something may be defined by information criteria such as detectability or recognizability. In order to consistently define visibility throughout his extensive research, Blackwell (1959, 1961, 1964, 1967; Blackwell & Blackwell 1968, 1971) found it necessary to standardize a target, which among other constraints, was standard in size. Based on this previous information, it came as no surprise that size was significant for both NVG detection and recognition tasks or, that performance tended to degenerate as target size was reduced. What made this study useful was the discovery that performance drops uniformly for recognition tasks, but not for detection tasks. As illustrated in Figure 18, recognition task performance dropped at relatively regular intervals as target size was reduced. This information is useful to NVG crews who, lacking stereoscopic depth perception, tend to rely on monocular depth cues such as relative size of an object. Consistent degeneration of an object's distinguishable features as distance increases could be critical in pilot judgment of distance.

Changes in target size had a nonuniform effect on NVG target detection. The change in performance between 70 and 35 arc minutes was similar to the decrease between 17.5 and 8.75 arc minutes of visual angle. What was unexpected was the comparably drastic drop in detection performance between 35 and 17.5 arc minutes. Based on this, it is possible that obstacles (i.e. other aircraft) subtending less than 35 arc minutes of visual angle on a pilot's retina may easily be overlooked until reaching 35 arc minutes. Depending on speed of closure, this could severely limit pilot reaction time. Reasons for this sudden decrease in detectability could be the effects of blooming or the halo effect upstaging smaller targets. Blooming occurs when light from a brighter area of a scene bleeds into a darker object and, haloing occurs when adjacent areas with different intensities appear even brighter where they meet.

The interaction results indicate a tradeoff among the variables studied. Specifically, if a variable (i.e. illuminance, contrast, or size) was reduced in level, the remaining variables had to be greater in level for a similar performance level to be maintained. These findings verify earlier research indicating that when the contrast between a visual target and its background is low, the target must be larger in size for it to be equally discriminable to a target with greater contrast (Heglin, 1973). For the current study's illumination and target size interaction, higher levels of both illumination and target size coincided with better detection and recognition performance. These findings are important to NVG assisted pilots involved with search and rescue or reconnaissance type missions. For such missions, size of the object being sought coupled with available illumination may be determining factors for a mission's success as well as degree of risk.

A linear relationship was found between contrast, size and detection/recognition performance. In each case, higher levels of both contrast and target size coincided with better detection and recognition performance. Reducing target size while maintaining contrast level reduced visual performance at similar intervals for all contrast levels in the recognition task. For the detection task (Figure 11), performance also decreased, but at slightly irregular intervals. During the detection task, while enjoying contrast levels between 53.63% and 86.86%, subject performance remained relatively high for targets 70 to 35 arc minutes of visual angle. For these two levels of contrast, detection performance drastically dropped (approximately 60%) when target size was reduced from 35 to 17.5 arc minutes. One reason for this could again be that blooming or the halo effect is upstaging the smaller targets. The two higher levels of contrast, 86.86 and 53.63, could have exaggerated these effects making it more difficult to detect smaller targets.

Throughout this study, reductions of illumination level, contrast level, or target size had a tendency to correlate with reduced subject detection performance. Newman-Keuls tests indicated that with increased target size less significant changes were made in detection performance. In other words, as target size increased, contrast illumination levels had significantly less to do with visually locating a target. As target size decreased, contrast and illumination became more critical to good performance. No statistical significance was found for the smallest target in this interaction. This indicates a threshold was reached and that illumination and contrast levels tested were not sufficient to affect detection performance when a target is 8.75 arc minutes in size.

Based on the apparent psychophysical floor and ceiling effect responses observed in the two-way interactions, it is thought that the levels tested adequately reflect lower and upper performance limits for AN/AVS-6 NVGs. Based on the results of this experiment, minimum criteria for 50 percent detection and recognition were calculated and listed in Table 3. Once again the random probability of correct detection and recognition is indeterminate due to the non-detection/recognition response choice. 50 percent criteria may be less than stated. Asterisks indicate 50 percent detection/recognition level is not possible.

Table 3. Performance Summary Table

	50% Detection		50% Recognition	
Target Size	min Illum	min Contrast	min Illum	min Contrast
70 arc min	25%	17.58%	25%	17.58%
35 arc min	25%	53.63%	75%	53.63%
17.5 arc min	*	*	*	*
8.75 arc min	*	*	*	*

CONCLUSION

This research has demonstrated that illumination, luminance contrast, and target size affect visual detection and recognition performance while using ANVIS NVGs. Target detection and recognition performance trends were similar to one another, and, in general, they increased with increasing illumination, luminance contrast, and target size.

As is clearly indicated in the three-way interaction, reduction in one of these factors greatly increases the importance of the other two. Considering the importance of these performance attributes to missions involving NVGs (i.e., accommodating and categorizing obstacles and targets), it is recommended that these findings be considered during future development of night imaging systems. Based on this study, development needs to include improving image quality at lower illumination and contrast levels.

Future studies should attempt to further define NVG performance characteristics by testing levels (i.e. illumination, etc.) within those already tested. In addition to detection and recognition performance, identification performance should be studied. Time required to detect and recognize targets should be included as another independent variable. Although in the present study, specific times were not recorded for analysis, while under visual conditions typically associated with poorer performance (i.e. lower levels of illumination, luminance contrast, and target size), observers seemed to use more of the available eight seconds before responding.

Finally, a study comparing these results to dynamic targets could be readily related to real world applications.

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APPENDIX A. INSTRUCTIONS TO PARTICIPANTS

In this experiment you will be performing a task to test your ability to recognize and correctly identify a specific type of target and determine its location on a viewing screen.

This will be done for four different levels of target size, three different levels of luminance contrast, and four different levels of illumination. The targets will be viewed in nighttime conditions while using the AV/AVS-6 night vision goggles.

At this time the experimenter will acquaint you with the night vision goggles mounted at your station. After the experimenter shows you how to switch the goggles on and off and focus them to your needs please feel free to ask about anything for which you have a question.

Six feet in front of you is a display screen. When you are comfortable and ready for the experiment to start, please indicate so to the tester. The experiment will begin with an empty adaptation field appearing on the screen for two minutes. This is so your eyes will be adjusted to that particular level of light. After adaptation the experimenter will ask you to initiate the actual trial. When you feel ready, initiate the test by saying the word "now".

At this time one of three targets will appear in one of eight positions on the screen for a fixed viewing interval of ten seconds. {It was explained that for approximately the first two seconds of each ten second interval, the target would not be visible due to a goggle safety feature.} During this interval please try to notice what the target is and its position on the screen. After each observation you will verbally report to the experimenter target type (car, APC, or tank, see Figure 21) and target position (using the 12-hr clock values: 12:00, 1:30, 3:00, 4:30, 6:00, 7:30, 9:00, or 10:30). {It was explained that in addition to the above verbal reports, participants were allowed to indicate not detecting or recognizing a target}. Please refer to the sample targets on the back of this handout.

Once an observation is complete, the experimenter will record the data and prompt you to initiate the next observation by once again saying the word "now". This process will continue for 36 observations in a set of trials, for a total of 12 sets. After each set is complete, you will be given a short rest break while the experimenter sets up the next set of trials. Please use this time to report any discomfort you may have such as eyestrain, backache, etc.. This will be addressed by the experimenter to determine if the experiment will continue. Each consecutive trial will follow the same protocol.

At this time please focus the night vision goggles to your particular needs. Adjust your chair so that you may view through the goggles comfortably. {To promote comfort and reduce distractions from the experimental tasks, participants were permitted to alternate between a seated and standing position. The goggles were mounted ensuring constant viewing height and distance to the screen throughout the experiment}. Announce to the experimenter when you are ready. We will have a short practice session prior to the actual experiment.

If at any time you have difficulty seeing through the goggles or they appear out of focus please inform the experimenter. We are now ready to begin the experiment. Do you have any questions at this time?

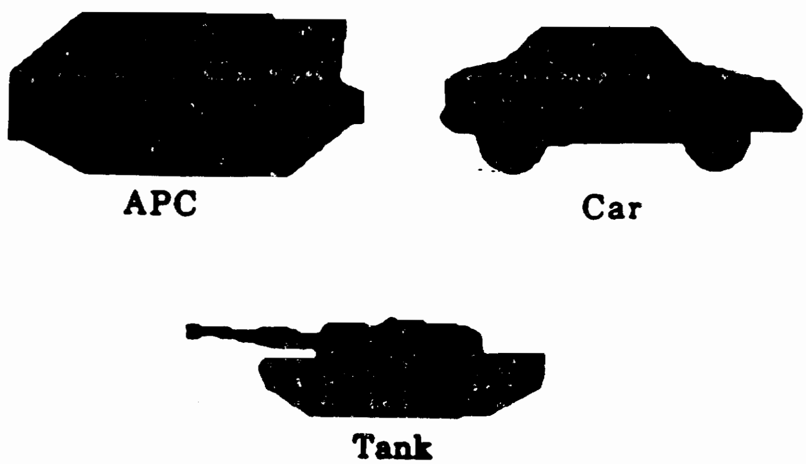

Figure 21. Illustration of target types.

VITA

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PERSONAL

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EDUCATION

Marion Military Institute Marion, Alabama	A.A., U.S. Army Commission, 1986
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Transportation Officer Basic Course Fort Eustis, Virginia	Branch Affiliation, 1990
Initial Entry Rotary Wing School Fort Rucker, Alabama	Helicopter Pilot, 1991
Virginia Polytechnic Institute and State University Blacksburg, Virginia	M.S., 1994

EMPLOYMENT

American Blind Products Office Manager	9/90-12/90
United States Drug Enforcement Agency Reconnaissance Pilot	6/92-8/92;6/93-8-93
United States Army National Guard Commissioned officer, platoon leader, rated pilot	5/86-present

PROFESSIONAL ORGANIZATIONS

Virginia Army National Guard Officer's Association

2/224th Battalion Officer's Association

Student member of the Human Factors and Ergonomics Society

Student member of the American Psychological Association

PADI

Eric C Pierce