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NAVAL POSTGRADUATE SCHOOL

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THESIS

AN ANALYSIS OF TARGET ACQUISITION BEHAVIOR FOR OBSERVERS IN TANKS EQUIPPED WITH THERMAL OR OPTICAL SIGHTING SYSTEMS

by

Cornell McKenzie

September 1985

Thesis Advisor: Donald R. Barr

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A162208	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) An Analysis of Target Acquisition Behavior for Observers in Tanks Equipped with Thermal or Optical Sighting Systems		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis September, 1985
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Cornell McKenzie		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943-5100		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943-5100		12. REPORT DATE September, 1985
		13. NUMBER OF PAGES 92
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report)
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution is unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Target Acquisition; Analysis of Variance, Functional Category, Factors.

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

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S N 0102-LF-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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Accession For	
NTIS GRA&I	☑
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

Approved for public release; distribution unlimited

An Analysis of Target Acquisition Behavior for Observers in Tanks Equipped with Thermal or Optical Sighting Systems

by

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Captain, United States Army
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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
September 1985

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ABSTRACT

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I. INTRODUCTION

A. GENERAL

On October 26, 1982, the Deputy Under Secretary of the Army for Operations Research, in a memorandum to the Director of the Army Staff, identified the need for a target acquisition experiment. The data generated by such an experiment would provide beneficial information to the Army's analytical and training development activities. The test was to provide a comparison of the capabilities of weapon systems equipped with thermal sighting systems with those having optical sighting systems under a variety of conditions and factors. In response to this requirement, Headquarters TRADOC appointed TRASANA as the proponent for a Thermal Pinpoint experiment. The United States Army Combat Developments Experimentation Center (CDEC) was subsequently appointed to conduct the field test and process the data generated by the experiment. The Thermal Pinpoint Test was a field experiment conducted to obtain data and information related to the problem of target acquisition by tanks and antitank weapons in overwatching and attacking roles. Controlled factors such as time of day, range, sight type, observer motion and target cues, as well as environmental factors such as temperature and sky/background visual contrast were incorporated into the test so that their effects on the target acquisition process could be investigated.

In the test, target acquisition for each observer crew was examined in terms of the following dependent variables:

1. The number of initial detections by each crew during a trial.

2. The number of correct recognitions (corresponding to initial detections).

3. The time required to detect targets (time interval from the trial start time or a begin search event until the detection of a target).

4. The time required to recognize (time interval from detection until recognition).

5. The time required to engage targets (time interval from recognition until firing).

6. Gunner lay error (the horizontal and vertical miss distances from the target aim point).

B. TEST DESIGN

The test was specifically designed to evaluate the effects of the following independent variables on the target acquisition processes:

1. Time of Day (morning/day/evening/night).

   a) morning: one hour before sunrise until one hour after sunrise.

   b) day: one hour after sunrise until two hours before sunset.

   c) evening: two hours before sunset until one hour after sunset.

   d) night: one hour after sunset until one hour before sunrise.

2. Observer Sight Type (thermal/optical).

3. Observer Motion (overwatch/attack).

4. Observer Hatch Status (tanks only) (open/clcsed).

5. Nominal Range to the target (long/medium/short).

   a) long: 2750 - 3250 meters.

   b) medium: 1750-2250 meters.

   c) short: 750-1250 meters.

6. Target Cues:

a) engine status (off/running/NA);

b) crew exposure (exposed/not exposed/NA);

c) motion (stationary/moving/NA);

d) camouflage (none/partial/full/NA);

e) firing (with/without);

f) other (glint, noise, dust, smoke).

7. Environmental Covariables:

a) target/background temperature contrast;

b) target/background visual contrast;

c) light level (night trials only);

d) sky/background visual contrast;

e) visibility;

f) windspeed and direction;

g) air temperature;

h) humidity;

i) cloud cover;

j) cloud height;

k) soil temperature;

l) dewpoint.

The test design plan [Ref. 1] provides a detailed discussion of the test objectives and the experimental design. NA status above applies to hulks and decoys, discussed below.

C. CONCEPT OF A TRIAL

In order to provide an adequate analysis, one must have a clear understanding of how the Thermal Pinpoint data were collected and subsequently reduced. The collection process is described below in the section entitled 'Data', and in the Test Design Plan [Ref. 1]. The following is a short description of a trial and the events that took place during a trial.

A trial consists of four tanks and two Tube Fired Optically Tracked Wire Guided (TOW) antitank weapons servicing a target array of ten targets (usually 4-tanks, 2-Armored Personnel Carriers, 2-decoys and 2-tank hulks). The observer force may be categorized as follows:

1. Tank, thermal sight, hatch closed.
2. Tank, thermal sight, hatch open.
3. Tank, optical sight, hatch closed.
4. Tank, optical sight, hatch open.
5. TOW, thermal sight.
6. TOW, optical sight.

This thesis will not address the TOW weapon system. The remainder of the thesis concerns tanks only.

In addition, a trial may be categorized as either moving or stationary. For moving trials, the observer tanks were in an attack role. Trial duration was a maximum of four minutes. For stationary trials, the observer tanks were in an overwatch role. Trial duration was ten minutes. During a trial, specific event data corresponding to a valid or nonvalid engagement are generated by the various observers. A valid engagement may be considered as the initial detection and acquisition of any one of the ten targets in the target array. A nonvalid engagement is detection and acquisition of 'targets' other than those in target array, such as false targets and hot spots, or subsequent re-detection of a valid target. The following events may occur:

1. Tank crew detects a target;
2. Member of crew detecting the target is identified (commander or gunner);
3. Type of detection cue is identified (possibly unknown);
4. Tank crew recognizes the target type;
5. Member of crew recognizing the target is identified (commander or gunner);
6. Claimed target type is recorded;
7. Tank gunner fires at target;
8. Tank crew begins search for next target (new start search time recorded);
9. Tank gunner changes field of view of sight (narrow or wide field of view);
10. Tank gunner changes contrast (polarity) of thermal sights (white hot or black hot);
11. Tank commander changes method of search (binoculars, vision blocks, etc.);
12. Tank tube azimuth recorded during the search interval for the next target.

Each event begins with a start search time and may or may not culminate in the detection and acquisition of a valid target.

D. LIMITATIONS OF THE EXPERIMENT

The Thermal Pinpoint test was a strictly controlled field test limited in tactical realism and hence, care must be exercised in the interpretation and extrapolation of the results. It must be remembered that the results apply only to crews working as individuals without communications between vehicles. The test was conducted this way to obtain data on the performance of individual crews. However, care must be exercised in applying these results to teams of weapon systems. Such applications may result in different findings from those obtained in this study in terms of their tactical implications. It should be noted that the experiment was performed in a temperate climate and the experimental results may or may not apply to operations in very hot or very cold climates, with different terrain, clutter, atmospheric conditions, etc.

E. SCOPE OF THE THESIS

This thesis applies to analysis of the Thermal Pinpoint database. It concerns only data generated by observers in tanks without nuclear and biological protective equipment. The dependent variables considered are number of detections (in the form of proportions) and times to detection.

II. DATA

A. GENERAL

The data used in this analysis were collected during the period 19 July to 10 December 1983 at Fort Hunter Ligget, California. The data were accumulated and reduced by the United States Army Combat Developments Experimentation Center, Fort Ord, California. Data from the test came from the following five sources:

1. The Range Measuring System (RMS).
2. Tube mounted closed circuit television.
3. Field forms and manually recorded information.
4. Environmental monitoring and measuring equipment.
5. Player questionaires and interviews.

The RMS [Ref. 1:pp. E36-38] is used to generate the two dimensional position of each player at the time of each event entry. It is a combination of position location and telemetry systems.

The analysis provided in this thesis will concern the independent variables described in the 'Test Design' section of this thesis. However, the only environmental covariables studied are sky/background visual contrast, target/background temperature contrast and target/background visual contrast. In addition, the various trial sites used during the test are be studied.

B. DESCRIPTION OF DATABASE

The Thermal Pinpoint database is composed of trial and engagement event data generated from 288 separate trials. The experimental design

[Ref. 1:pp. 3-9] provides for all combinations of the primary test design variables (time of day, range, observer motion, hatch status, sight type) with varying numbers of replications. Twenty of the trials were classified and another 36 were with nuclear and biological protective equipment. These trials are not used in the present analysis and hence, the analysis utilizes the event and trial data generated in the remaining 232 trials. Each trial provides data from four separate observer combinations, of the primary design variables, for analysis. During a trial, each observer generated a variable number of engagement events for valid and nonvalid targets. During an engagement event, the data for 15 variables of interest were collected and recorded. An additional 27 variable quantities were recorded for each trial. The test variables [Ref. 1:pp. 3-(4)-3-(5)] are manifestations of the physical environment, test design and observer actions.

C. PRELIMINARY DATA PREPARATION

The Thermal Pinpoint test design [Ref. 1] was not balanced. For example, there are twice as many replications for day and night trials than for evening and morning trials. For a priori reasons, and possibly to provide balance to the design, it is of interest to know whether evening and morning trials can be combined. A Friedman Test [Ref. 2:pp. 299-305], for all observer combinations of motion, hatch status, sight type and range as the blocks, was performed with the mean times to detection for evening and morning trials, within the blocks, as the criterion of interest. Evening and morning trials are the treatments. In this way, the results apply across all observer groups. The following null hypothesis was tested:

H_0: Each ranking of the mean times to detection for morning and evening trials, within a block is equally likely (i.e. the two treatments have identical effects).

The alternative hypothesis may be written as follows:

H_1: One of the treatments tends to yield larger observed values than the other treatment.

The null hypothesis is rejected if the Friedman Test statistic exceeds the 0.95 quantile of the F-distribution with 1 and ∞ (number of blocks/observations) degrees of freedom. The test statistic obtained is 2.60. The 0.95 quantile of the F-distribution is 3.84. Therefore, the null hypothesis is not rejected. In fact, the probability of getting a greater F value is 0.11. It was decided that evening and morning trials would be combined in the remainder of the analysis.

III. ANALYSIS OF TARGET ACQUISITION

A. DEFINITIONS

Before proceeding with the analysis, it is helpful to define some of the terminology that follows.

1. Factor--an independent variable to be analyzed in ANOVA or Functional Category Models (e.g. time of day).

2. Factor level--a particular form of a factor (such as day or evening for the factor time of day).

3. Treatment--in ANOVA models, this term refers to a specific combination of the factors being studied. In the Friedman Test, it describes the factor levels of a factor of interest.

4. Main effect--the effect on mean response associated with levels of a particular factor.

5. Interaction--occurs when the level of a second factor affects the relative scores (e.g. mean times to detection) across different levels of a first factor. Here, relative means the difference between the scores.

6. Population--the universe of all observations from which the sample is taken.

7. Contrasts--a linear combination of the population means such that the sum of the coefficient is zero.

B. ANALYSIS TECHNIQUE

The statistical procedures employed in this study were implemented with subprograms included in the Statistical Analysis System (SAS) [Ref. 3 and 4] and an APL System for Interactive Scientific/Engineering Graphics and Data Analysis (GRAFSTAT). The subprograms used were General Linear Models (GLM), Functional Category Models (FUNCAT), MEANS, Summary, Frequencies (FREQ), UNIVARIATE and MATRIX from the SAS library and the GRAFSTAT program for various plotting functions.

The subprogram GLM was used for the ANOVA models that follow. GLM uses the method of least squares to fit a general linear model. It is appropriate for analyses with unbalanced designs. It provides for four types of estimable functions of parameters for testing hypotheses. Since the Thermal Pinpoint design is unbalanced, "Type III" tests were utilized [Ref. 4:pp. 229-241].

The FUNCAT procedure computes a log-linear model of categorical responses. A response is categorical if the measured quantities are frequency counts. These counts are assumed to follow a multinomial distribution. Each treatment has a different multinomial distribution for the response counts. The procedure produces minimum chi-square estimates for parameters in a standard response function. The response function is called a logit function, since it models the logs of ratios of multinomial probabilities.

The subprograms MEANS, Summary, FREQ and UNIVARIATE were used to provide descriptive statistics and to display the distributional characteristics of various treatments, such as means, variances, quantiles, sums and numbers of values.

The subprogram MATRIX is both a SAS procedure and a programming language. It was used in this analysis to provide general purpose programming of procedures or programs unavailable in SAS.

C. SCATTER PLOTS

As a preliminary step in the analysis, the dependent variable detection time was plotted versus sky/background visual contrast, target/background visual contrast and target/background temperature contrast for all combinations of the primary design variables. If there appeared to be strong relationships between these variables, then the corresponding independent variables would be used as covariates in analysis of covariance to help reduce the experimental errors and make the analysis more powerful. Figure 1 shows typical examples of these plots. The displayed examples are for day, overwatch, optical sight, open hatch and short range trials. In these plots, a robust smooth curve is added. It can be seen that there is not a strong relationship among these variables and time to detection.

Mean times to detection and mean proportion of detections for each treatment are statistically correlated; Spearman's Rho [Ref. 2:p. 254] for these variables is 0.385, leading to rejection of a hypothesis of independence. The positive correlation suggests a tendency for larger values of mean times to detection and mean proportions of targets detected to be paired together. As a result of this correlation, it is plausible that conclusions that apply to detection time, as above, may also apply to proportions.

D. ANALYSIS OF TARGET COVARIABLES

Friedman Tests were performed to determine if significant differences in the mean times to detection occurred among the various observer types. An observer type is described by combinations of the primary design variables (such as day, overwatch, optical sight, hatch closed, short range). The comparisons of interest concern the trial sites and target cues and their possible significance in the target acquisition process. The results of tests for target cues and trial

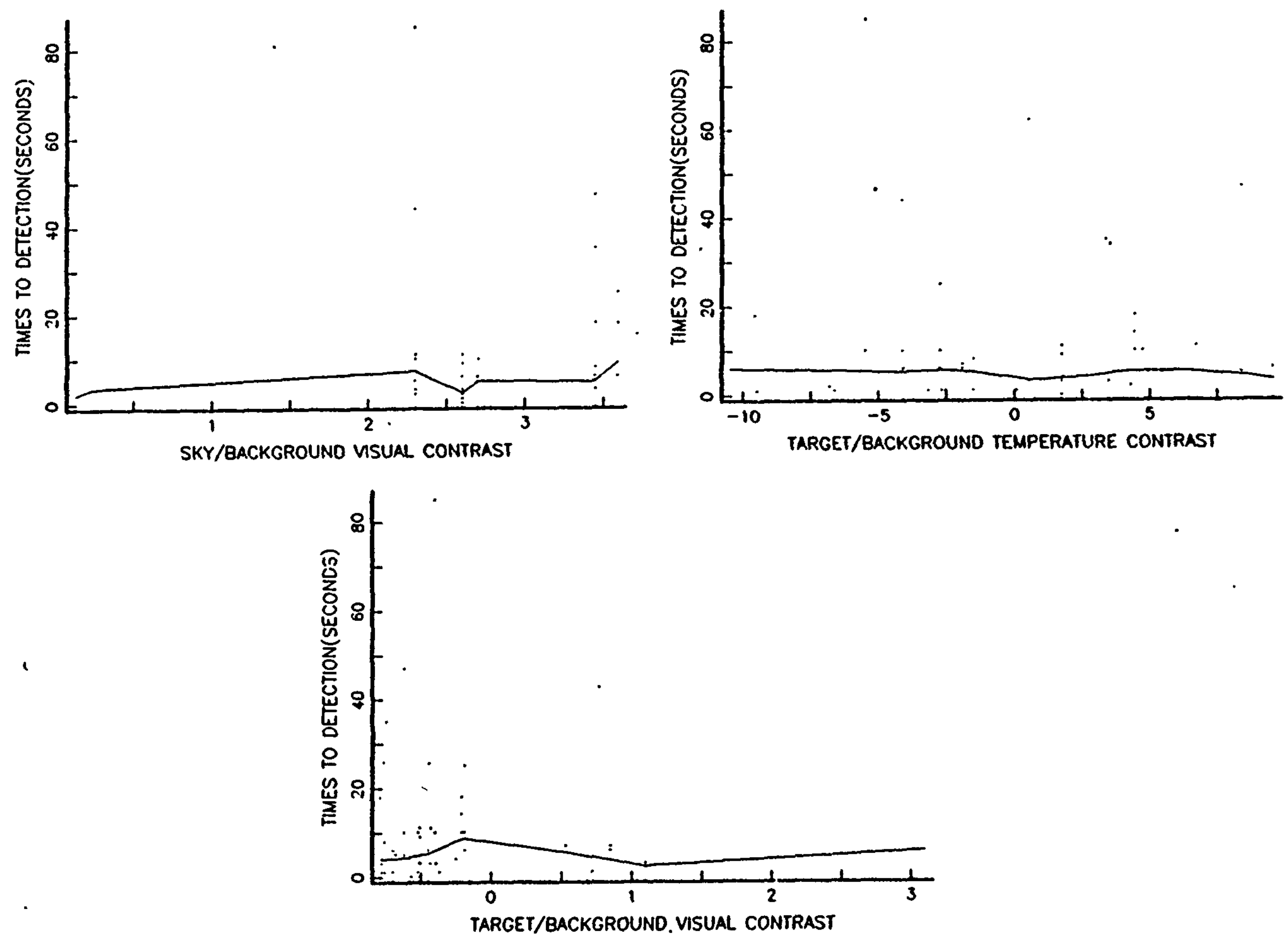

Figure 1

Scatter Plots of Times to Detection Versus Sky/Background Visual Contrast, Target/Background Temperature Contrast and Target/Background Visual Constrast sites are summarized in Table 1. The results indicate that all target cues, except firing, and trial sites are significant at the 0.05 level.

TABLE 1

SUMMARIZED RESULTS OF FRIEDMAN TESTS FOR TARGET CUES

Criterion: Mean Times to Detection

Target Cue/ Trial Site	Test Statistic	DF	0.95 Quantile F-Distribution	Significance Level
Motion	8.33	(2,∞)	3.00	0.00*
Firing	1.21	(1.∞)	3.84	0.27
Engines	9.26	(2,∞)	3.00	0.00*
Crew Exposure	8.42	(2,∞)	3.00	0.00*
Camouflage	7.41	(3,∞)	2.60	0.00*
Vehicle Type	6.00	(3,∞)	2.60	0.00*
Trial Site	43.64	(7,∞)	2.01	0.00*

* Indicates significance at the 0.05 level.

This suggests that the treatments may not have identical effects for the various observer combinations. The treatments for each target covariable were contrasted to determine which are significantly different. The results are summarized in Table 2. For all target cues, the differences are associated with hulks and decoys. Treatments that were applicable during a trial, such as engines on versus engines off, are not signifiantly different. Trial sites, in general, display significant differences. Trial site is incorporated as a factor in the

TABLE 2

TREATMENT COMPARISONS: FOR FRIEDMAN TESTS RESULTING IN REJECTION OF THE NULL HYPOTHESIS

Criterion: Mean Times to Detection

Trial Site

Pairwise Difference	Sample Sizes	Conclusion
0 vs. 1	(44, 311)	Significant
0 vs. 2	(44, 415)	Significant
0 vs. 3	(44, 29)	Significant
0 vs. 4	(44, 1422)	Significant
0 vs. 6	(44, 202)	Significant
0 vs. 8	(44, 1524)	Significant
0 vs. 9	(44, 886)	Significant
1 vs. 2	(3111, 415)	Not Significant
1 vs. 3	(3111, 29)	Not Significant
1 vs. 4	(3111, 1422)	Significant
1 vs. 6	(3111, 202)	Not Significant
1 vs. 8	(3111, 1524)	Significant
1 vs. 9	(3111, 886)	Significant
2 vs. 3	(415, 29)	Significant
2 vs. 4	(415, 1422)	Significant
2 vs. 6	(415, 202)	Not Significant
2 vs. 8	(415, 1524)	Not Significant
2 vs. 9	(415, 886)	Not Significant
3 vs. 4	(29, 1422)	Significant
3 vs. 6	(29, 202)	Not Significant
3 vs. 8	(29, 1524)	Significant
3 vs. 9	(29, 886)	Significant
4 vs. 6	(1422, 202)	Significant
4 vs. 8	(1422, 1524)	Significant
4 vs. 9	(1422, 886)	Significant
6 vs. 8	(202, 1524)	Significant
6 vs. 9	(202, 886)	Not Significant
8 vs. 9	(1524, 886)	Not Significant

Crew Exposure

Pairwise Difference	Sample Sizes	Conclusion
Not Exposed vs. Exposed	(2861, 487)	Not Significant
Not Exposed vs. NA	(2861, 1967)	Significant
Exposed vs. NA	(487, 1967)	Significant

TABLE 2 (continued)

Target Camouflage

Pairwise Difference	Sample Sizes	Conclusion
None vs. Full	(2956, 162)	Not Significant
None vs. Partial	(2956, 230)	Not Significant
None vs. NA	(2956, 1967)	Significant
Partial vs. Full	(230, 162)	Not Significant
Partial vs. NA	(230, 1967)	Not Significant
Full vs. NA	(162, 1967)	Not Significant

Target Firing

Pairwise Difference	Sample Sizes	Conclusion
No vs. Yes	(4791, 460)	Not Significant

Target Motion

Pairwise Difference	Sample Sizes	Conclusion
Stationary vs. Moving	(2055, 804)	Not Significant
Stationary vs. NA	(2055, 1967)	Significant
Moving vs. NA	(804, 1967)	Significant

Vehicle Type

Pairwise Difference	Sample Sizes	Conclusion
Tank vs. APC	(2200, 1044)	Not Significant
Tank vs. Hulk	(2200, 634)	Significant
Tank vs. Decoy	(2200, 582)	Not Significant
APC vs. Hulk	(1044, 634)	Significant
APC vs. Decoy	(1044, 582)	Not Significant
Hulk vs. Decoy	(634, 582)	Not Significant

Target Engines

Pairwise Difference	Sample Sizes	Conclusion
Off vs. On	(2055, 1293)	Not Significant
Off vs. NA	(2055, 1967)	Significant
On vs. NA	(1293, 1967)	Significant

Where NA above refers to status for hulks and decoys.

ANOVA models that follow. The trial site significance is in agreement with published reports by G. E. Corrick [Ref. 3] and Lynn A. Olzak [Ref. 4] who conducted experiments to determine the effects of target background on target acquisition for aerial observers. Their results show that the physical environment of targets is significant in the target acquisition process for aerial observers. The author believes that this issue should be pursued further for ground observers.

E. ANOVA FOR PRIMARY DESIGN VARIABLES AND TRIAL SITE

1. Full Model

The ANOVA procedure is performed to determine which variables (factors) have noteworthy effects on the times to detection and proportion of targets detected. The procedure also provides quantitative information about the relative importance of different factors and their levels.

The linear model for the primary design variables associated with a factorial design, may be written as follows:

$$\begin{aligned} y_{ijklmno} = {} & \mu + \alpha_i + \beta_j + \gamma_k + \tau_l + \psi_m + \theta_n \\ & + (\alpha\beta)_{ij} + (\alpha\gamma)_{ik} + (\alpha\tau)_{il} + (\alpha\psi)_{im} \\ & + (\beta\gamma)_{jk} + (\beta\tau)_{jl} + (\beta\psi)_{jm} + (\gamma\tau)_{kl} \\ & + (\gamma\psi)_{km} + (\tau\psi)_{lm} + (\alpha\beta\gamma)_{ijk} \\ & + (\alpha\beta\tau)_{ijl} + (\alpha\beta\psi)_{ijm} + (\beta\gamma\tau)_{jkl} \\ & + (\beta\gamma\psi)_{jkm} + (\gamma\tau\psi)_{klm} + (\alpha\beta\gamma\tau)_{ijkl} \end{aligned}$$

$$+ (\alpha\beta\gamma\psi)_{ijkm} + (\beta\gamma\tau\psi)_{jklm}$$

$$+ (\alpha\beta\gamma\tau\psi)_{ijklm} + \varepsilon_{ijklmno}$$

where,

$y_{ijklmno}$ = true value of the dependent variable of interest at various levels of the design factors (o indicates the replication number).

μ = fixed, but unknown, population mean;

α_i = observer motion main effects;

β_j = time of day main effects;

γ_k = type of sight main effects;

τ_ℓ = hatch status main effects;

ψ_m = range main effects;

$(\cdot)$ = interaction effects;

$\varepsilon_{ijklmno}$ = random experimental error.

It is assumed that the experimental errors are distributed $N(o,\sigma^2)$ and are independent and identically distributed. The experimental error variance is estimated over a wide range of test conditions and there is an adequate sample size (degrees of freedom) available for its estimation.

2. Effects of Departures from Model

Major departures from the model assumptions may be found by examining various plots of the residuals. Normality of the error terms is studied by plotting the residuals in the form of a frequency distribution to see whether this distribution differs markedly from a

Normal distribution. The cumulative distribution function of the residuals is plotted versus a theortical Normal cumulative distribution function to see whether the points fall on the theoretical curve. In a similar fashion the residual cumulative distribution function may be plotted on Normal probability paper to see whether or not the points fall approximately on a straight line. Chi-square goodness of fit tests may also be employed. The homogeneity of variances assumption is studied by plotting the standard deviations, (s), versus the mean times to detection or mean proportion of targets detected, ($\bar{x}$), for each treatment to determine the nature of the relationship between them.

Figure 2 shows plots of the residuals for times to detection, in the form of a frequency distribution, a cumulative distribution function and a Normal probability plot. The plots show that the residuals are not Normally distributed. The Chi-square goodness-of-fit test significance level is 0.00. The $\bar{x}$-s plot is shown in the left panel of Figure 3 for times to detection. As the treatment mean times to detection increases, the standard deviation also increases in a linear fashion. Figure 4 shows the same plots as Figure 2 for proportion of targets detected. The plots show that the residuals are appoximately Normal. The Chi-squared goodness of fit test significance level is 0.11. The $\bar{x}$-s plot for proportion of targets detected is shown in the right panel of Figure 3. The plotted points display a curvilinear pattern which indicates a possible quadratic relationship.

In both plots of the treatment standard deviations versus the means, Figure 3, the points form two distinct groups. One group is associated with Overwatch/Stationary trials and the other with Moving

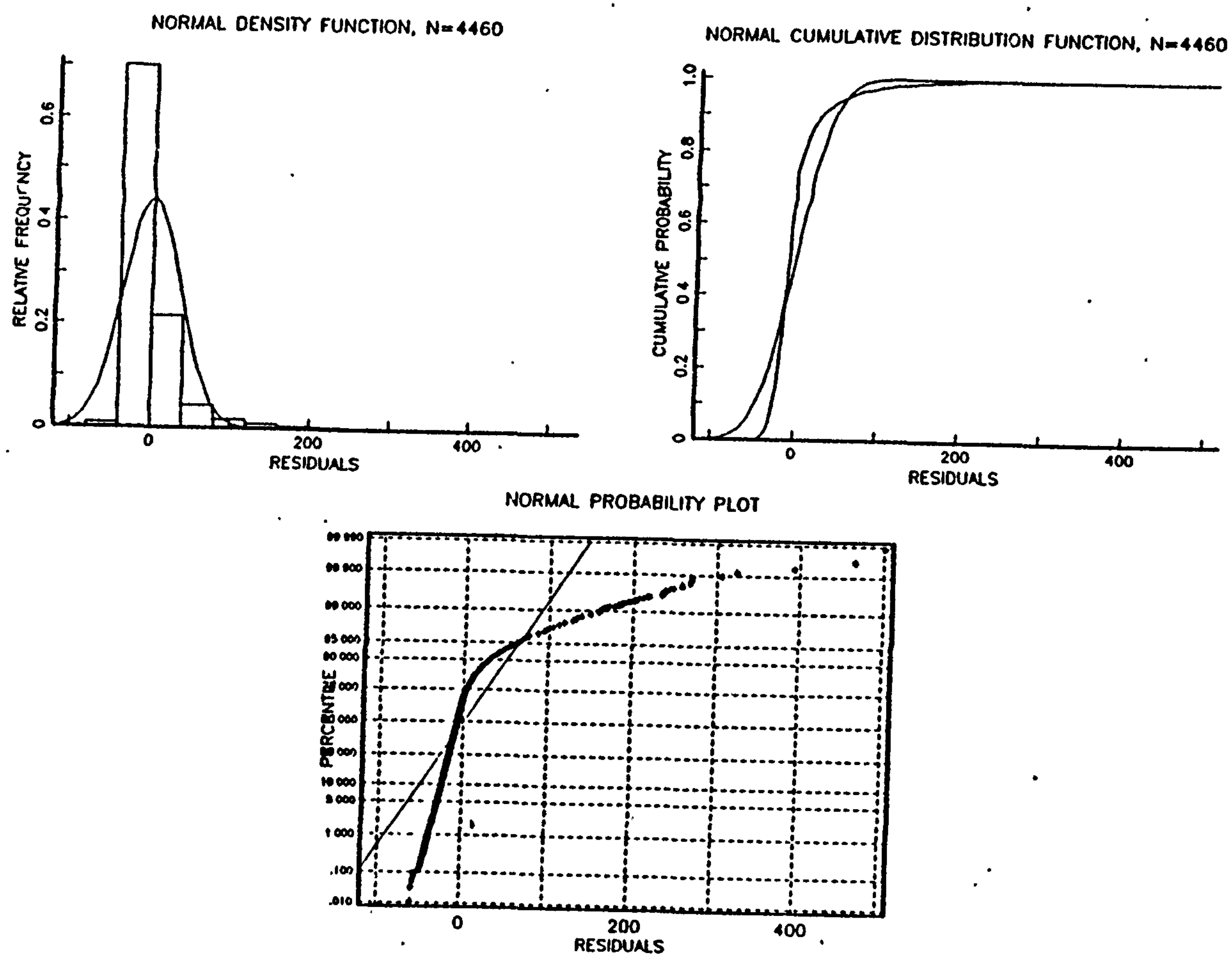

Figure 2

Plots of Residuals for Times to Detection: Untransformed Variables

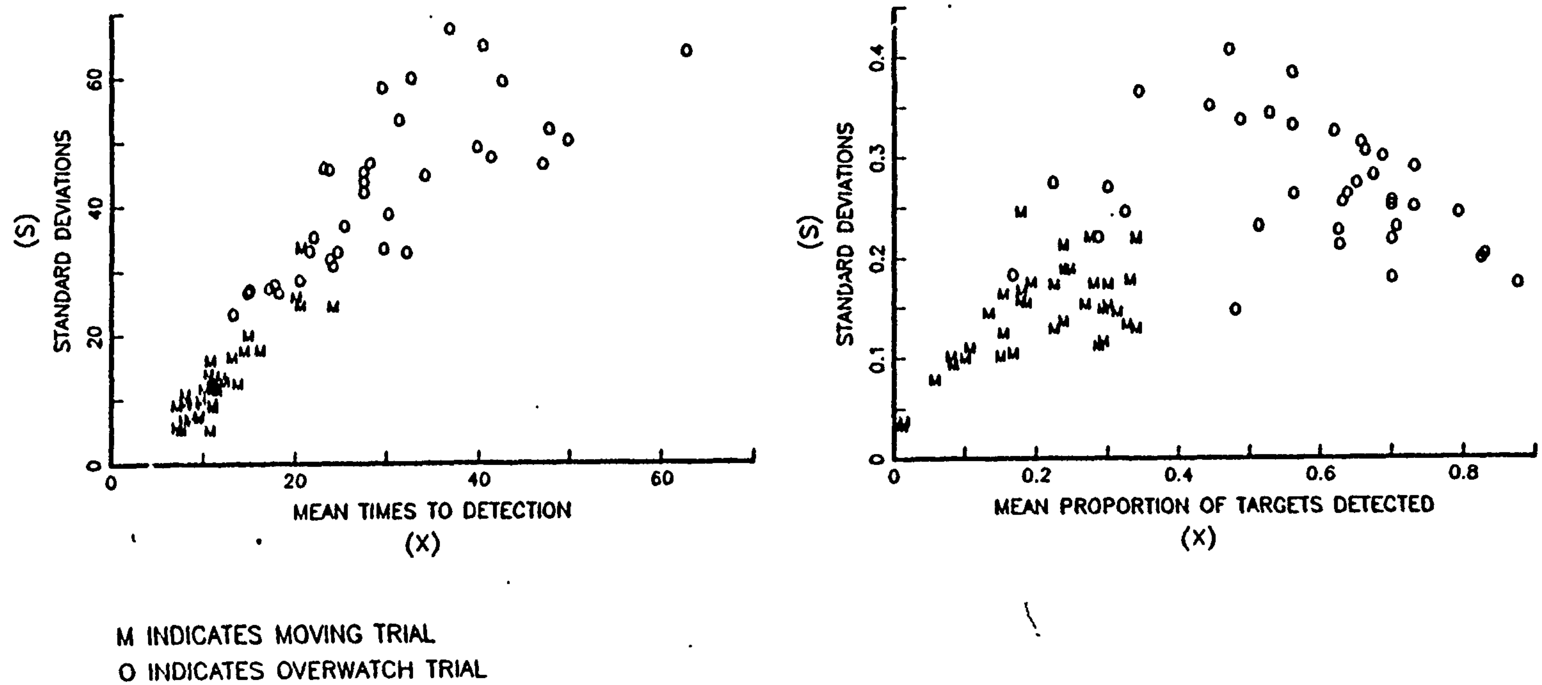

Figure 3

$\bar{x}$-s Plots for Mean Times to Detection and Mean Proportion of Targets Detected: Untransformed Variables

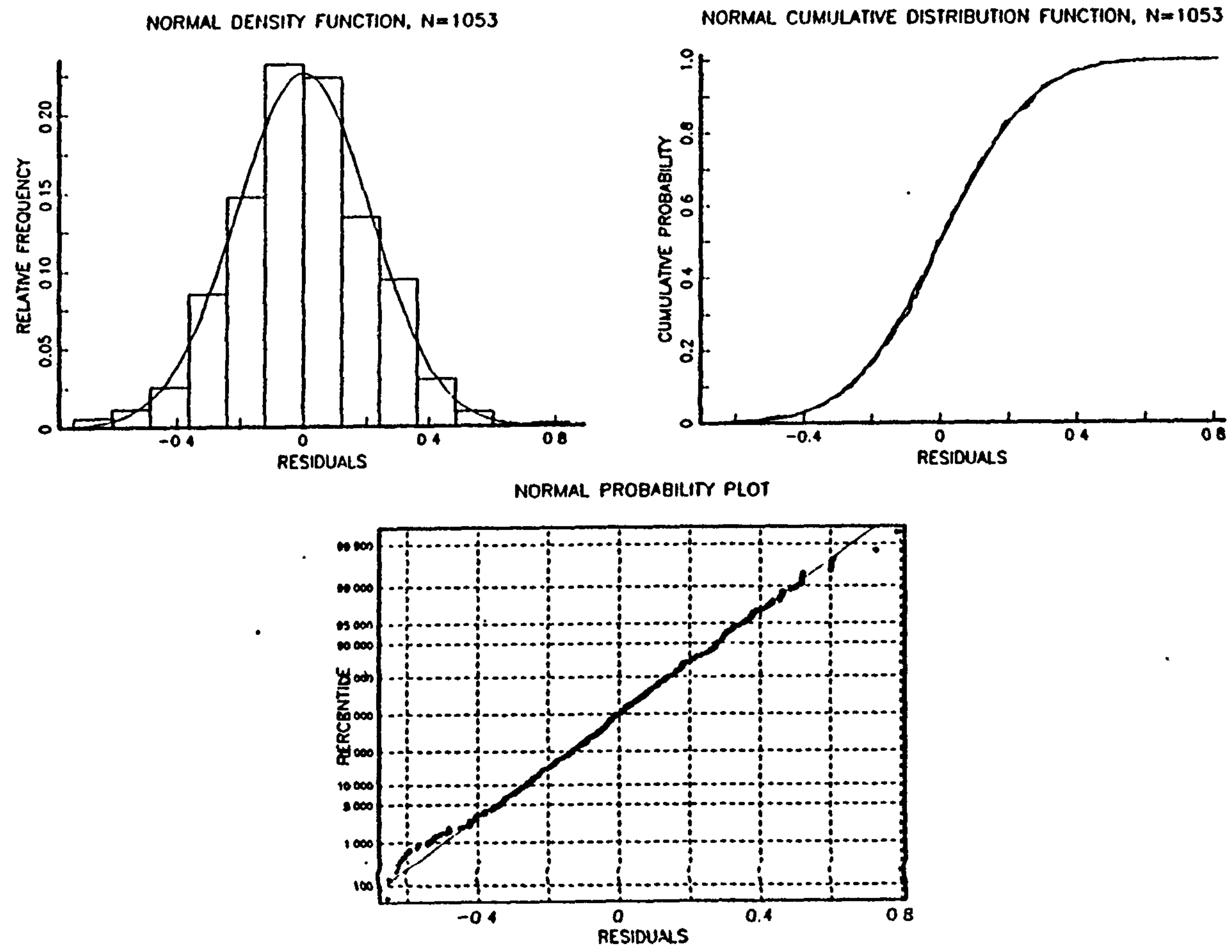

Figure 4

Plots of Residuals for Proportion of
Targets Detected Untransformed Variables

trials. This implies that the two types of trials are quite different. One would anticipate this, since moving trials lasted a maximum of four minutes and overwatch trials were ten minutes in duration. The disparity in trial duration, as well as the nature of the trials, attacking versus defending, could very easily account for the observed grouping.

3. Transformation of Variables

The results of the analysis performed on the residuals for both dependent variables indicate that the model assumptions are not satisfied. In particular, the standard deviation versus means plots indicate that the assumption of homogeneity of variances is false. An appropriate corrective measure is to use a transformation on the data to stabilize the variances. For the times to detection, a log transformation was chosen since the plot in Figure 3 appears linear [Ref. 7:p. 507]. For the proportions, an appropriate transformation is the arc sine [Ref. 7:p. 507], since we are concerned with the percent of valid targets identified. The transformation may be written as follows: for times to detection;

$$Y' = \log(Y+1);$$

for proportions of targets detected;

$$Y' = \arcsin\sqrt{Y/N+1} + \arcsin\sqrt{Y+1/N+1},$$

where N refers to the number of cases on which the proportion is based.

The residual and $\bar{x}$-s plots for transformed data are shown in Figures 5 and 7, respectively, for times to detection. The residual plots show a closer approximation to a theoretical Normal distribution. The Chi-square goodness-of-fit significance level is 0.04. In the $\bar{x}$-s plot, the linear relationship between the means and standard deviations is no longer present. However, the groupings by observer motion are still present. In general, within these groups, as one looks from left to right, the points form a band with constant vertical scatter. The residual and $\bar{x}$-s plots for transformed data are shown in Figures 6 and 7, respectively, for proportion of targets detected. In the residual plots, the frequency distribution is still quite bell-shaped. The Chi-square goodness of fit significance level is 0.00. The $\bar{x}$-s plots do not display the curvilinear relationship shown in Figure 3. The comment concerning groupings above also applies to the proportions. The $\bar{x}$-s plots for both dependent variables display isolated points that are remote from the rest of the plotted values. Since the author is unsure of why this occurred, the values that were used to compute these means will not be discarded.

For a fixed effects model, such as this one, lack of Normality is not an important matter, provided the departure from Normality is not of extreme form [Ref. 7:p. 513]. The point estimators of factor level means and contrasts are unbiased whether or not the populations are Normal. The F test for the equality of factor level means is affected very little by departures from Normality which are not of extreme form; in terms of the level of significance. If the residual variances are unequal, the F test for equality of the means with the fixed effects

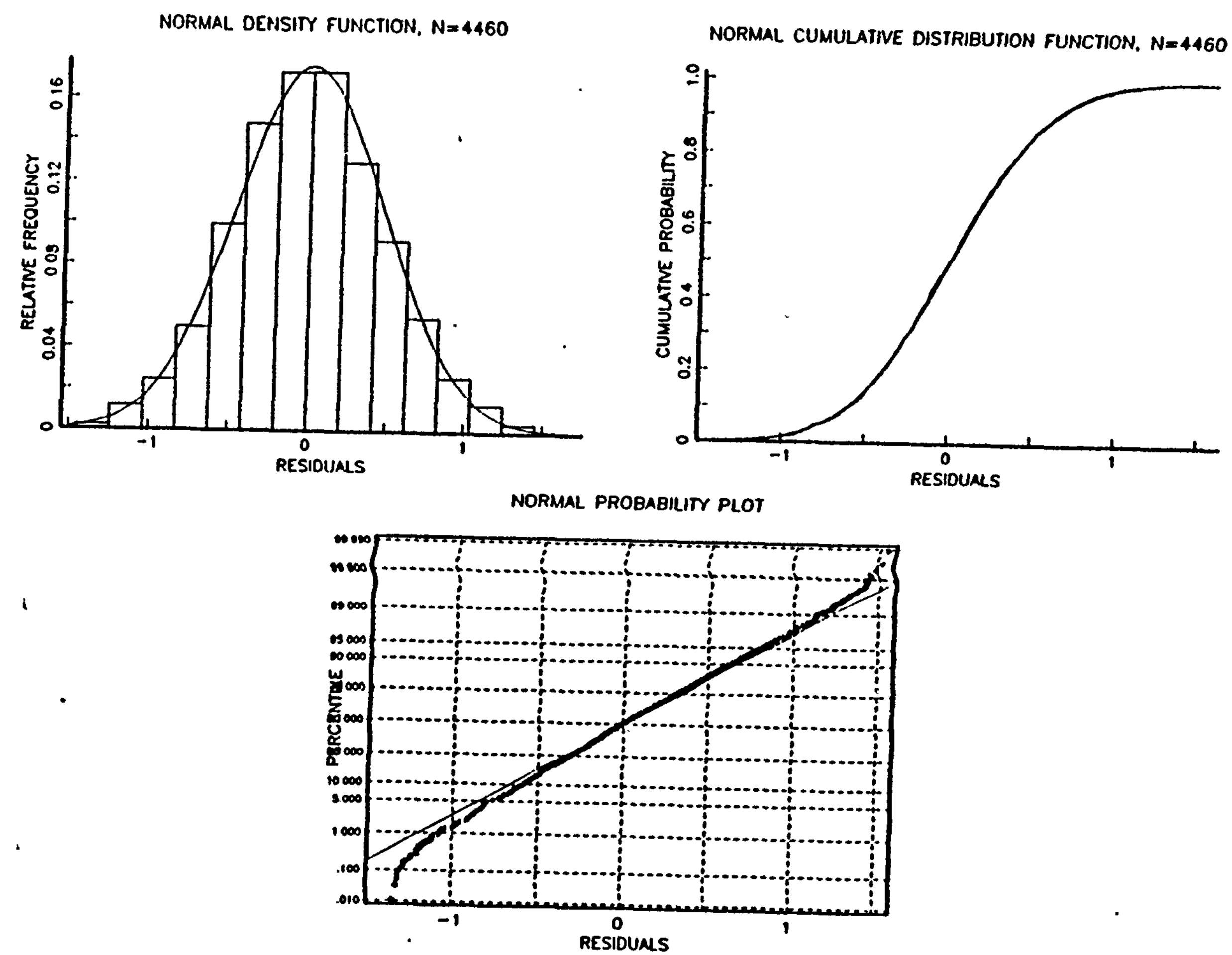

Figure 5

Plots of Residuals for Times to Detection: Transformed Variables

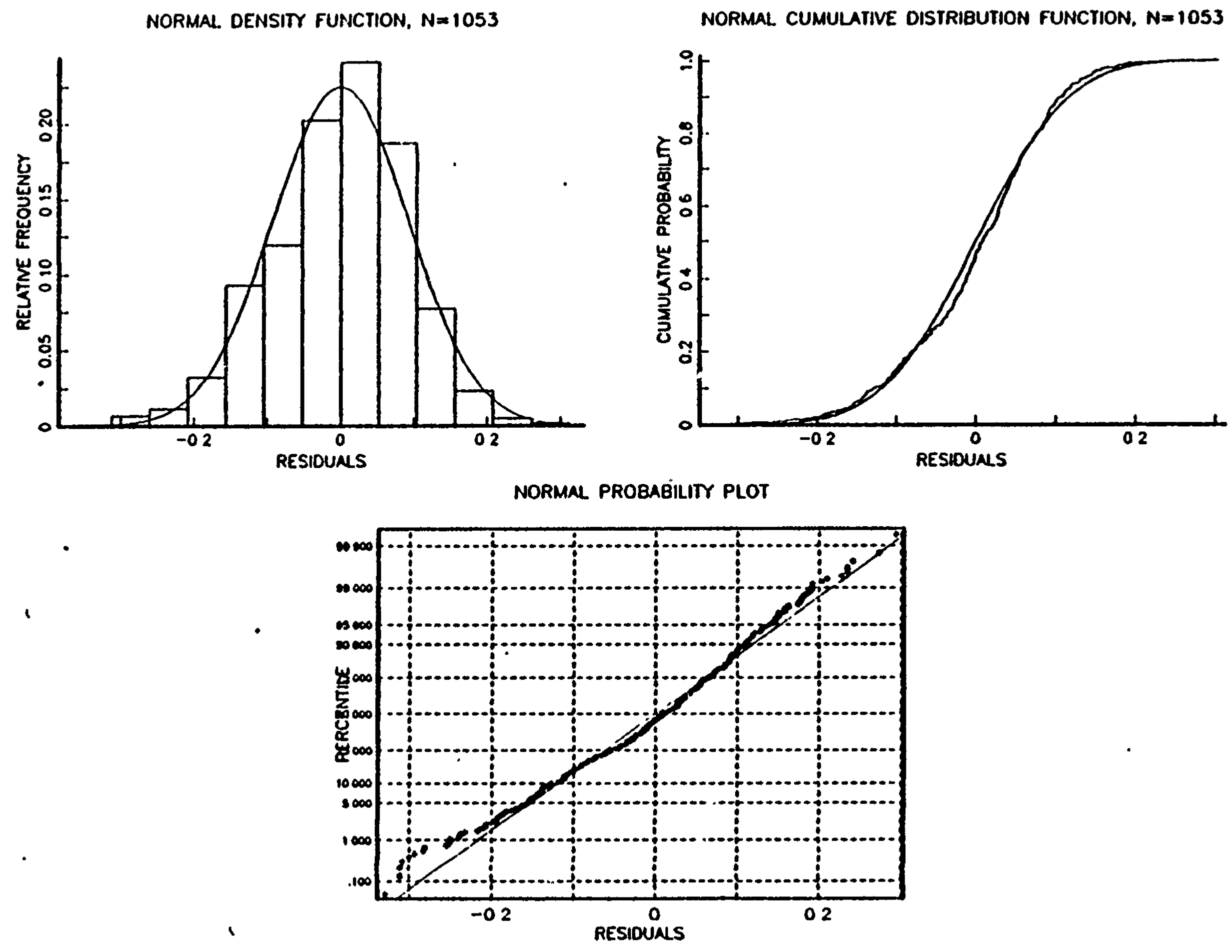

Figure 6

Plots of Residuals for Proportion of Targets Detected: Transformed Variables

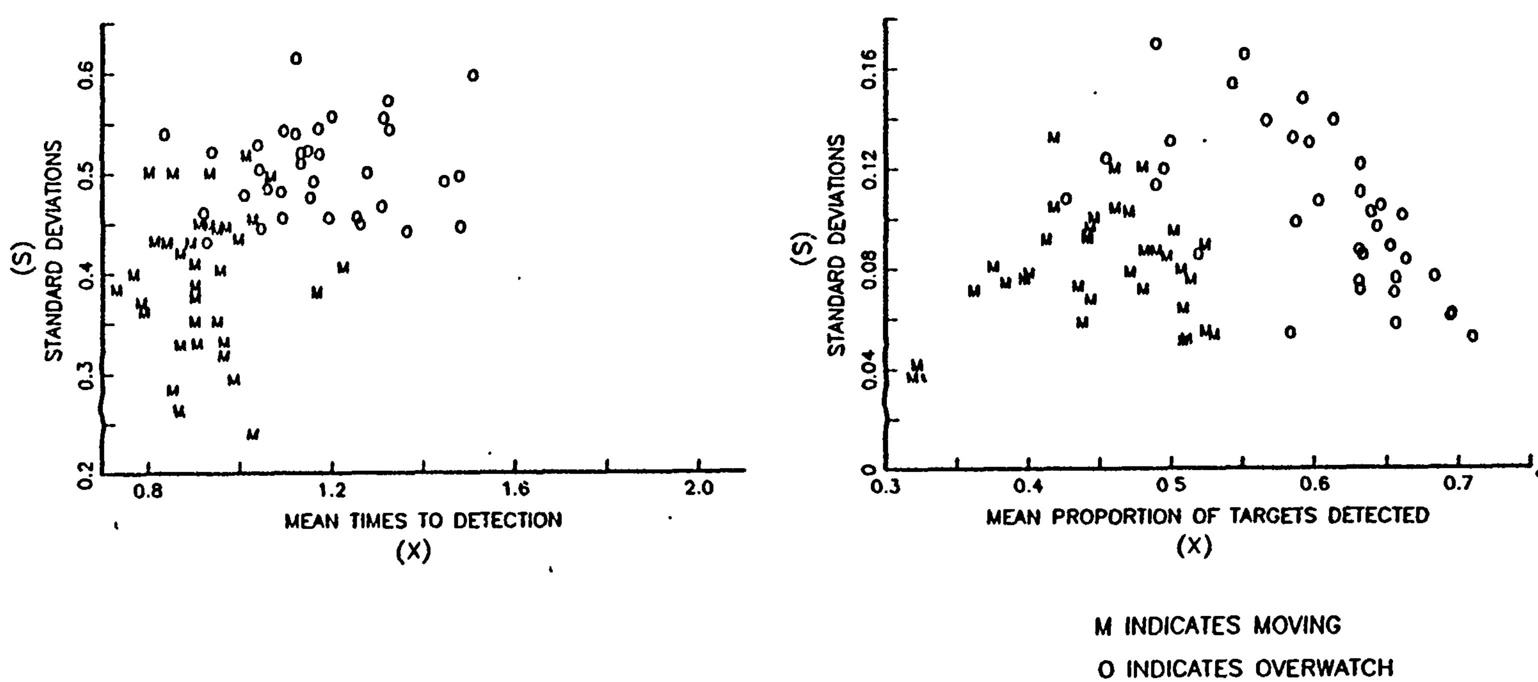

Figure 7

$\bar{x}$-s Plots for Mean Times to Detection and Mean Proportion of Targets Detected: Transformed Variables model is only slightly affected when the design is balanced. However, since this design is unbalanced, comparisons between factor level means may be substantially affected by unequal variances. The author feels that the transformations have, in general, brought about approximate equality of variances for both dependent variables within the groupings described for the levels of the factor observer motion.

4. ANOVA Results for Transformed Variables

Summarized results of the ANOVA's are shown in Table 3 for times to detection and proportions of targets detected. For proportions, time of day interacts with all other factors except hatch status. There is also a significant three-factor interaction between observer motion, sight type and range. For times to detection, time of day interacts strongly with observer motion and sight type. There is also a significant two-factor interaction between hatch status and range. A three-factor interaction between time of day, sight type and range is also significant. The presence of significant interactions implies that one cannot make generalizations about the effects of each factor separately in terms of the factor level mean time to detection or mean proportion of detections. For both dependent variables, the factor time of day interacts strongly with other factors. Recall the $\bar{x}$-s plots for times to detection and proportions of targets detected displayed groupings by observer motion. Thus, it seems prudent to perform separate ANOVA's for each combination of observer motion and time of day. The results are shown in the next section.

TABLE 3

ANALYSIS OF VARIANCE SUMMARIES: TEST STATISTICS AND SIGNIFICANCE LEVELS FOR DETECTION TIME AND PROPORTION OF DETECTIONS (TRANSFORMED VARIABLES)

Source	DF	Proportions	Detection
TOD (Time of Day)	2	31.15(0.0001)*	19.07(0.0001)*
OM (Observer Motion)	1	551.68(0.0001)*	54.21(0.0001)*
TOS (Sight Type)	1	63.23(0.0001)*	3.05(0.0809)
HS (Hatch Status)	1	0.05(0.8282)	8.20(0.0042)*
RANGE	2	20.48(0.0001)*	2.26(0.1041)
TRSITE (Trial Site)	7	5.68(0.0001)*	7.25(0.0001)*
TOD×OM	2	9.34(0.0001)*	3.48(0.0309)*
TOD×TOS	2	59.24(0.0001)*	20.48(0.0001)*
TOD×HS	2	2.22(0.1087)	1.58(0.2068)
TOD×RANGE	4	2.40(0.0483)	0.09(0.9844)
OM×TOS	1	1.31(0.2527)	0.71(0.4002)
OM×HS	1	0.12(0.7284)	1.24(0.2656)
OM×RANGE	2	1.26(0.2852)	0.88(0.4167)
TOS×HS	1	0.00(0.9702)	1.57(0.2109)
TOS×RANGE	2	0.27(0.7635)	1.15(0.3180)
HS×RANGE	2	0.08(0.9197)	4.90(0.0075)*
TOD×OM×TOS	2	0.05(0.9545)	0.52(0.5958)
TOD×OM×HS	2	0.86(0.2408)	1.80(0.1656)
TOD×OM×RANGE	4	1.65(0.1595)	1.01(0.3994)
TOD×TOS×HS	2	2.51(0.0815)	4.00(0.0184)
TOD×TOS×RANGE	4	1.39(0.2367)	0.31(0.8746)
TOD×HS×RANGE	4	0.98(0.4201)	2.01(0.0908)
OM×TOS×HS	1	0.00(0.9805)	1.81(0.1790)
OM×TOS×RANGE	2	3.69(0.0254)*	0.78(0.4586)
OM×HS×RANGE	2	0.55(0.5751)	0.42(0.6566)
TOS×HS×RANGE	2	0.59(0.5525)	0.59(0.5550)
TOD×OM×TOS×HS	2	0.08(0.9226)	2.39(0.0914)
TOD×OM×TOS×RANGE	4	1.69(0.1505)	1.88(0.1112)
TOD×OM×HS×RANGE	4	2.23(0.0644)	1.73(0.1401)
TOD×TOS×HS×RANGE	4	0.76(0.5495)	1.94(0.1010)
OM×TOS×HS×RANGE	2	1.33(0.2626)	2.14(0.1183)
TOD×OM×TOS×HS×RANGE	4	0.20(0.9368)	0.76(0.5516)
MSE	974	0.009	0.228

* Denotes significance at the 0.05 level.

5. Results of ANOVA Models for Time of Day and Observer Motion Combinations

The factors range, sight type, hatch status and trial site are analyzed for each time of day and observer motion combination. ANOVA summaries are shown in Tables 4 and 5 for times to detection and proportions of targets detected, respectively. For times to detection, the sight type is significant for all combinations of observer motion and time of day, except Evening/Morning trials. Trial site is significant for all combinations. For proportion of targets detected, the sight type is significant in all cases except Day Overwatch trials. Range is significant in all cases except Evening/Morning Overwatch trials. These two cases would be significant at the 0.1 level of significance. However, there are also significant two-way interactions in both cases. For detection time, the sight type and hatch status interaction for Day Overwatch and Night Moving trials are significant, as well as sight type and range for Evening/Morning Overwatch trials and hatch status and range for Night Overwatch trials. For the proportions, the only significant two-way interaction is sight type and range for Night Overwatch trials. The only significant three-way interaction is for times to detection in Day Overwatch trials.

F. COMPARISONS OF MEANS

If there are no significant interactions, comparisons of the factor level mean times to detection or proportion of targets detected are

TABLE 4

ANALYSIS OF VARIANCE SUMMARIES: TEST STATISTICS AND SIGNIFICANCE LEVELS FOR TIME OF DAY AND OBSERVER MOTION: TIMES TO DETECTION

	TOS	HS	RANGE	TOS×HS
(DO)	48.50(0.0001)*	5.27(0.0218)*	1.83(0.1609)	5.04(0.0249)*
(DM)	7.10(0.0080)*	0.06(0.8134)	3.56(.5674)	0.59(0.4422)
(EO)	0.42(0.5173)	1.30(0.2536)	1.15(0.3180)	0.93(0.3355)
(EM)	2.34(0.1269)	0.37(0.5417)	0.86(0.4261)	0.30(0.5833)
(NO)	52.19(0.0001)*	1.10(0.2949)	0.78(0.4576)	0.26(0.6123)
(NM)	4.45(0.0358)*	6.43(0.0117)*	1.58(0.2076)	6.69(0.0102)*

	TOS×RANGE	HS×RANGE	TOS×HS×RANGE	TRSITE
(DO)	1.66(0.1910)	1.27(0.2824)	6.23(0.0020)*	8.41(0.0001)*
(DM)	0.52(0.5949)	0.46(0.6298)	0.38(0.6813)	4.75(0.0092)*
(EO)	5.24(0.0054)*	2.41(0.0901)	2.08(0.1252)	3.00(0.0065)*
(EM)	2.82(0.0609)	1.20(0.3025)	0.20(0.8193)	3.49(0.0316)*
(NO)	0.14(0.8733)	3.68(0.0256)*	1.41(0.2436)	4.34(0.0007)*
(NM)	1.01(0.3648)	2.73(0.0667)	2.38(0.0947)	7.86(0.0005)*

	MSE	DF
(DO)	0.253	1423
(DM)	0.157	377
(EO)	0.244	1144
(EM)	0.142	364
(NO)	0.245	761
(NM)	0.167	298

* Indicates significance at the 0.05 level.

Where,

DO = Day Overwatch.
DM = Day Moving.
EO = Evening/Morning Overwatch.
EM = Evening/Morning Moving.
NO = Night Overwatch.
NM = Night Moving.
MSE = Mean Square Error

TABLE 5

ANALYSIS OF VARIANCE SUMMARIES: TEST STATISTICS AND SIGNIFICANCE LEVELS FOR TIME OF DAY AND OBSERVER MOTION: PROPORTION OF TARGETS DETECTED

	TOS	HS	RANGE	TOS×HS
(DO)	3.16(0.0770)	3.13(0.0786)	3.17(0.0446)*	0.37(0.5449)
(DM)	8.18(0.0048)*	0.09(0.7608)	3.37(0.0366)*	1.10(0.2951)
(EO)	9.06(0.0030)*	0.19(0.6640)	2.75(0.0668)	0.37(0.5447)
(EM)	5.49(0.0205)*	0.60(0.4406)	12.69(0.0001)*	0.19(0.6668)
(NO)	72.01(0.0001)*	2.00(0.1592)	3.33(0.0382)*	1.35(0.2475)
(NM)	107.02(0.0001)*	1.06(0.3050)	12.64(0.0001)*	2.97(0.0871)

	TOS×RANGE	HS×RANGE	TOS×HS×RANGE	TRSITE
(DO)	2.17(0.1176)	1.44(0.2406)	1.76(0.1747)	1.38(0.2415)
(DM)	0.73(0.4841)	0.85(0.4272)	0.38(0.6852)	3.64(0.0283)*
(EO)	0.01(0.9924)	0.43(0.6539)	0.73(0.4818)	2.76(0.0140)*
(EM)	3.00(0.0529)	2.59(0.0782)	0.39(0.6745)	2.08(0.1290)
(NO)	4.00(0.0201)*	0.50(0.6067)	0.09(0.9124)	7.42(0.0001)*
(NM)	1.02(0.3632)	2.19(0.1152)	1.08(0.3439)	0.62(0.5400)

	MSE	DF
(DO)	0.007	175
(DM)	0.008	168
(EO)	0.014	165
(EM)	0.008	144
(NO)	0.011	160
(NM)	0.006	148

* Indicates significance at 0.05 level.

Where

DO = Day Overwatch.
DM = Day Moving.
EO = Evening/Morning Overwatch.
EM = Evening/Morning Moving.
NO = Night Overwatch.
NM = Night Moving.
MSE = Mean Square Error

analyzed. For two factor or three factor interactions, comparisons of the means for all combinations of the interacting factors are analyzed. The 95% confidence intervals are presented for the contrasts between means, based on the untransformed data. In addition, the mean times to detection and mean proportions of targets detected for the interacting factors were viewed graphically as an aid to understanding the nature and significance of the interactions. The means are compared using a method developed by Tukey and Kramer [Ref. 5:pp. 473-477]. The use of this method insures that the confidence coefficient, 0.95, applies to the entire set of estimates and not to single estimates of the contrasts of interest.

The comparisons that follow will be displayed in terms of the untransformed dependent variables. In some cases, the untransformed variables do not display significant differences detected with transformed variables. To some extent this is expected, since the transformation was applied to stabilize the variability in the model and the power of the tests with the transformed data can be expected to be higher than those without transformed data. With untransformed data, the mean square error, an estimate of the error variance, is large and one would expect the derived Tukey-Kramer confidence intervals to be large. In these cases, the differences in the means of the dependent variables of interest will be highlighted in terms of the transformed variables.

1. Plots of Mean Times to Detection and Mean Proportion of Targets Detected for Interacting Factors

Figures 8 and 9 depict, graphically, the mean times to detection and mean proportion of targets detected. Figure 8 depicts the mean

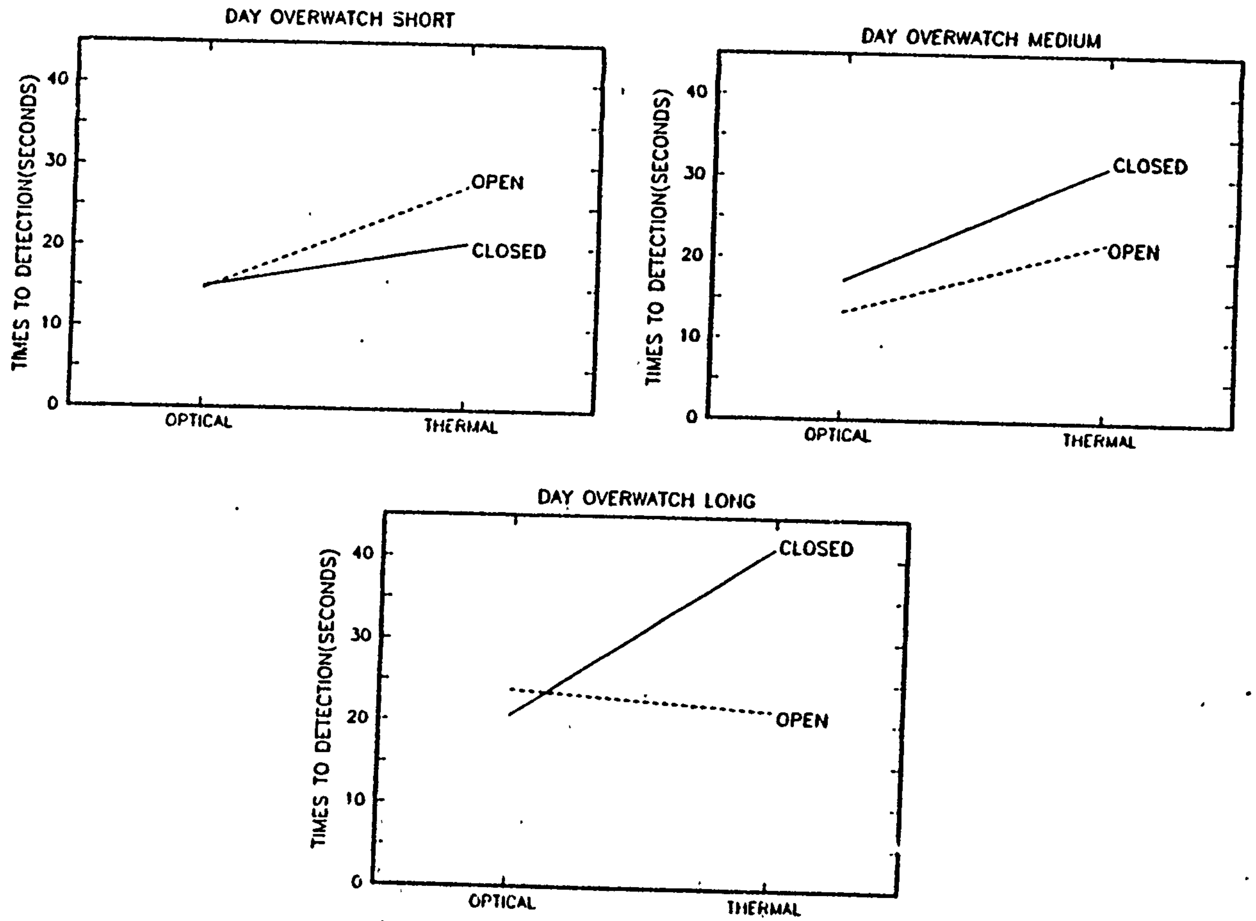

Figure 8

Plots of Mean Times to Detection for Sight Type, Hatch Status and Range in Day Overwatch Trials

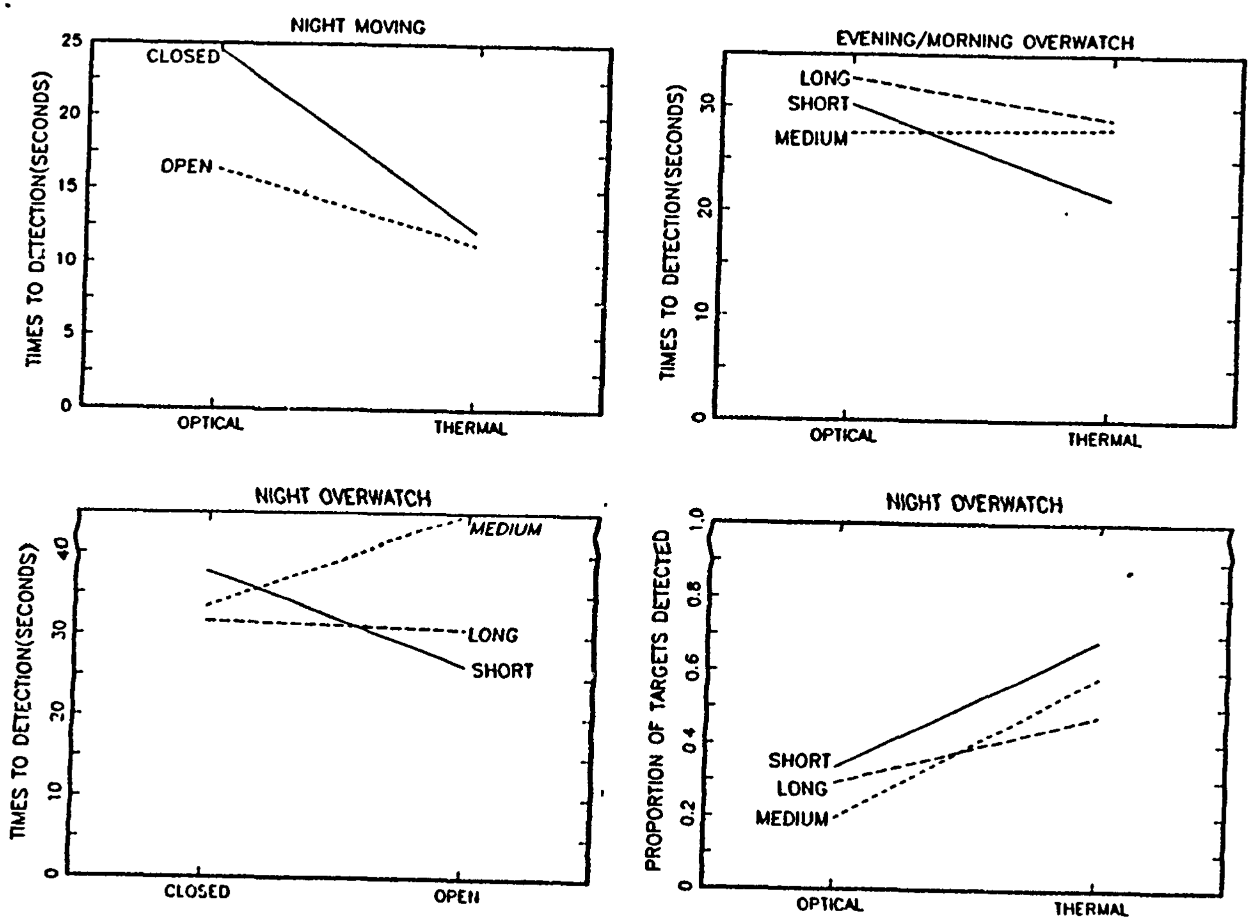

Figure 9

Plots of Mean Times to Detection and Mean Proportion of Targets Detected for Various Combinations of Sight Type, Hatch Status and Range in Night Moving, Evening/Morning Overwatch, and Night Overwatch Trials times to detection for sight type and hatch status in Day Overwatch trials. Since there is also a three-way interaction with range, the sight type and hatch status curves for each range are plotted. The curves indicate that the mean times to detection for optical sights are similar for each range. The opposite is true for thermal sights. For short range, the open hatch curve is above the closed, while for medium range, the opposite is true. The mean times to detection for sight type and hatch status in Night Moving trials are shown in Figure 9. The curves are similar to those in Day Overwatch, except it is the thermal sight which displays similarity in the mean times to detection. These are pleasing results in that they follow what one would intuitively expect. In the daytime, optical observers perform similarly, regardless of hatch status. The same is true for thermal sights at night. The mean times to detection for sight type and range in Evening/Morning Overwatch trials are shown in Figure 9. Though one can see the presence of strong interactions, in the form of nonparallel and crossing curves, note that the mean times to detection for thermal sights are about equal or better than optical sights in all cases. The mean times to detection for hatch status and range in Night Overwatch trials are shown in Figure 9. The interactions here are quite obvious. What is interesting about this graph is the fact that it does not follow what one would intuitively expect. One would expect that the times to detection for open hatch would, in general, be smaller than closed hatch. In this particular case, we run the gambit of possibilities. For short range, intuition holds, however for medium range, the opposite is true. For long range, the mean times to detection for open and closed hatch is the same. The mean proportion of targets detected for sight type and range in Night Overwatch trials are shown in Figure 9. The short and medium range curves are almost parallel (indicating no interaction). The thermal sight performs better than the optical sight in all cases.

2. Analysis of Factor Level Means

Recall in Tables 4 and 5, one can see that there are factors, for combinations of observer motion and time of day, which do not interact significantly with other factors. For times to detection, trial site is significant over all combinations of observer motion and time of day. Significance is also seen for sight type in Day Moving and Night Overwatch trials. For proportion of targets detected, sight type is significant over all combinations of observer motion and time of day except Day Overwatch trials. Range is significant in all cases except Evening/Morning Overwatch trials. Trial site is significant in Day Moving, Evening/Morning Overwatch and Night Overwatch trials.

Table 6 displays the comparisons of the factor level mean times to detection for trial sites over all combinations of observer motion and time of day. It is apparent that trial site 9 provides significant differences in observer performance, depending on the combination, with all other trial sites except 0. Generally, performance at trial site 9 is better than the other sites, except during the Evening/Morning trials. This implies that the physical characteristics of trial site 9 are, in general, conducive to good performance. Trial site 1 displays significant differences in observer performance with trial site 8 in Day

TABLE 6

TUKEY-KRAMER METHOD FOR PAIRWISE COMPARISONS: COMPARISONS OF FACTOR LEVEL MEAN TIMES TO DETECTION FOR TRIAL SITES OVER ALL COMBINATIONS OF OBSERVER MOTION AND TIME OF DAY

Day Overwatch

Trial Site Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
0 - 1	-19.81	-1.16	17.50
0 - 4	-19.96	-1.571	16.81
0 - 8	-17.76	1.12	19.99
0 - 9	-10.58	8.48	27.54
1 - 4	-6.85	-0.42	6.02
1 - 8	-5.46	2.27	10.01
1 - 9	1.48	9.64	17.80*
4 - 8	-4.37	2.69	9.75
4 - 9	2.53	10.05	17.57*
8 - 9	-1.29	7.36	16.02**

Evening/Morning Overwatch

Trial Site Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
1 - 2	-10.22	5.80	21.82
1 - 3	-12.61	14.27	41.15
1 - 4	-6.86	1.94	10.74
1 - 6	-16.77	0.18	17.14
1 - 8	-9.01	2.42	13.85
1 - 9	-4.47	-22.41	49.29
2 - 3	-21.88	8.47	38.82
2 - 4	-20.48	-3.862	12.755
2 - 6	-27.67	-5.62	16.43
2 - 8	-21.53	-3.38	14.77
2 - 9	-58.56	-28.21	2.14**
3 - 4	-39.57	-12.33	14.90
3 - 6	-44.942	-14.09	16.77
3 - 8	-40.05	-11.85	16.35
3 - 9	-73.92	-36.68	0.558**
4 - 6	-19.28	-1.76	19.28
4 - 8	-11.77	0.481	12.73
4 - 9	-51.59	-24.35	2.89
6 - 8	-16.75	2.24	21.22
6 - 9	-53.45	-22.59	8.26
8 - 9	-53.03	-24.83	3.37

TABLE 6 (continued)

Day Moving

Trial Site Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
1 - 8	-6.73	-3.75	-0.76*
1 - 9	-5.76	-1.38	3.01
8 - 9	-2.25	2.37	6.99

Evening/Morning Overwatch

Trial Site Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
1 - 8	-6.73	-3.75	-0.76*
1 - 9	-5.76	-1.38	3.01
8 - 9	-2.25	2.37	6.99

Evening/Morning Moving

Trial Site Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
1 - 8	-0.48	2.41	5.30
1 - 9	-0.70	3.17	7.05**
8 - 9	-3.55	0.76	5.08

* Indicates significance at the 0.05 level for untransformed variables.
** Indicates significance at the 0.05 level for transformed variables.

TABLE 6 (continued)

Night Overwatch

Trial Site Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
1 - 2	-18.38	-3.85	10.68
1 - 4	-33.20	-10.97	11.27
1 - 6	-55.38	-29.47	-3.57*
1 - 8	-19.62	-6.59	6.44
1 - 9	-11.14	6.27	23.68
2 - 4	-30.57	-7.12	16.32
2 - 6	-52.58	-25.63	1.33
2 - 8	-17.75	-2.74	12.26
2 - 9	-8.81	10.12	29.04**
4 - 6	-50.28	-18.50	13.27
4 - 8	-18.17	4.38	26.93
4 - 9	-8.09	17.24	42.57
6 - 8	-3.29	22.88	49.06
6 - 9	4.14	35.74	64.35*
8 - 9	-4.94	12.86	30.66

Night Moving

Trial Site Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
1 - 8	-13.50	-7.71	-2.25*
1 - 9	-5.35	-0.10	5.51
8 - 9	1.02	7.61	14.19*

* Indicates significance at the 0.05 level for untransformed variables.
** Indicates significance at the 0.05 level for transformed variables.

Moving and Night Moving trials, and trial site 6 in Night Overwatch trials. In these cases, performance at this site is better than at the other sites. The implication is the same as above.

Table 7 displays the comparisons of the factor level mean times to detection for sight type in Day Moving and Night Overwatch trials.The results confirm what one might expect. Namely, observers with optical sights perform better in the day time and observers with thermal sights perform better at night. The difference in Night Overwatch trials appears to be larger in comparison to the Day trials.

Table 8 shows the comparisons of the factor level mean proportion of targets detected for sight types over all observer motion and time of day combinations, except Day Overwatch and Night Overwatch trials. Note that observers with optical sights perform better than observers with thermal sights in the Evening/Morning trials. Evening and morning are something of a 'gray' area in terms of light level. The other results in Table 8 follow what one would intuitively expect.

Table 9 displays the comparisons of the factor level mean proportion of targets detected for range over all observer motion and time of day combinations except Evening/Morning Overwatch and Night Overwatch trials (in which case the range factor was not significant). The results are surprising. Note that in those cases where significant differences exist, the differences suggest that observer performance is better at longer ranges. This is not what one would expect. Generally, one would think that performance would be better at shorter ranges.

TABLE 7

TUKEY-KRAMER METHOD FOR PAIRWISE COMPARISONS:
COMPARISONS OF FACTOR LEVEL MEAN TIMES TO DETECTION
FOR SIGHT TYPES IN DAY MOVING AND NIGHT OVERWATCH TRIALS.

Day Moving

Sight Type Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
Optical-Thermal	-4.65	-2.32	0.015**

Night Overwatch

Sight Type Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
Optical-Thermal	11.16	18.65	26.14*

* Indicates significance at the 0.05 level for untransformed variables.
** Indicates significance at the 0.05 level for transformed variables.

TABLE 8

TUKEY-KRAMER METHOD FOR PAIRWISE COMPARISONS: COMPARISONS OF FACTOR LEVEL MEAN PROPORTION OF TARGETS DETECTED FOR SIGHT TYPES IN DAY MOVING, EVENING/MORNING OVERWATCH, EVENING/MORNING MOVING AND NIGHT MOVING TRIALS

Day Moving

Sight Type Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
Optical-Thermal	0.03	0.08	0.12*

Evening Overwatch

Sight Type Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
Optical-Thermal	-0.21	-0.13	-0.04*

Evening Moving

Sight Type Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
Optical-Thermal	-0.11	-0.05	0.002**

Night Moving

Sight Type Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
Optical-Thermal	0.16	0.20	0.24*

* Indicates significance at the 0.05 level for untransformed variables.
** Indicates significance at the 0.05 level for transformed variables.

TABLE 9

TUKEY-KRAMER METHOD FOR PAIRWISE COMPARISONS: COMPARISONS OF FACTOR LEVEL MEAN PROPORTION OF TARGETS DETECTED FOR RANGE IN DAY OVERWATCH, DAY MOVING, EVENING/MORNING MOVING AND NIGHT MOVING TRIALS

Day Overwatch

Range Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
Short-Medium	-0.14	-0.04	0.06
Short-Long	-0.02	0.08	0.18
Medium-Long	0.02	0.12	0.22*

Day Moving

Range Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
Short-Medium	-0.06	0.0032	0.07
Short-Long	-0.04	0.02	0.09
Medium-Long	-0.046	0.02	0.09

Evening Moving

Range Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
Short-Medium	0.02	0.09	0.17*
Short-Long	0.07	0.15	0.24*
Medium-Long	-0.02	0.06	0.15

Night Moving

Range Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
Short-Medium	-0.02	0.03	0.09
Short-Long	0.02	0.08	0.14*
Medium-Long	-0.01	0.05	0.11

* Indicates significance at the 0.05 level for untransformed variables.

Table 10 displays the comparisons of the factor level mean proportion of targets detected for trial sites in Day Moving, Evening Overwatch and Night Overwatch trials. Observers at trial site 6 display significant differences with observers at trial sites 1, 2 and 4 in Evening Overwatch trials and trial sites 8 and 9 in Night Overwatch trials. In these cases, performance at this site is better than at the other sites. In Night Overwatch trials, observers at trial site 1 display significant differences with observers at trial site 9 and observers at trial site 2 display differences with observers at trial site 8 and 9. In general, performance at trial site 6 is better than the other sites in all cases, except sites 8 and 9 in Evening Overwatch trials. However, note that the mean proportion of targets detected are not significantly different.

2. Analysis of Mean Times to Detection and Mean Proportion of Targets Detected for Interacting Factors

Since there are 65 comparisons of interest, and only three treatments provide significant differences in the mean times to detection, only those comparisons resulting in significant differences will be displayed. Table 11 displays the comparisons of the treatment mean times to detection for Day Overwatch trials. Note that the observers with the thermal sight, closed hatch and long range (TCL) treatment display significant differences with all other observer treatments except thermal sight, closed hatch, medium range (TCM) and thermal sight, open hatch, short range (TOS). Treatment TCM observers display significant differences with the observer treatments optical

TABLE 10

TUKEY-KRAMER METHOD FOR PAIRWISE COMPARISONS: COMPARISONS OF FACTOR LEVEL MEAN PROPORTION OF DETECTIONS FOR TRIAL SITE IN DAY MOVING, EVENING OVERWATCH AND NIGHT OVERWATCH TRIALS

Day Moving

Trial Site Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
1 - 8	-0.04	0.02	0.08
1 - 9	-0.05	0.04	0.12
8 - 9	-0.07	0.02	0.10

Evening Overwatch

Trial Site Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
1 - 2	-0.54	-0.21	0.13
1 - 3	-0.40	0.06	0.52
1 - 4	-0.24	-0.07	0.09
1 - 6	0.01	0.25	0.50*
1 - 8	-0.23	-0.02	0.19
1 - 9	-0.38	0.08	0.54
2 - 3	-0.29	0.26	0.81
2 - 4	-0.21	0.13	0.48
2 - 6	0.07	0.46	0.84*
2 - 8	-0.18	0.19	0.55
2 - 9	-0.26	0.29	0.84
3 - 4	-0.60	-0.13	0.34
3 - 6	-0.31	0.19	0.70
3 - 8	-0.56	-0.08	0.41
3 - 9	-0.61	0.03	0.66
4 - 6	0.06	0.33	0.59*
4 - 8	-0.18	0.06	0.29
4 - 9	-0.31	0.16	0.63
6 - 8	-0.56	-0.27	0.02
6 - 9	-0.67	-0.17	0.33
8 - 9	-0.38	0.10	0.59

TABLE 10 (continued)

Night Overwatch

Trial Site Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
1 - 2	-0.00	0.14	0.28
1 - 4	-0.30	-0.05	0.20
1 - 6	-0.05	0.18	0.40
1 - 8	-0.22	-0.08	0.07
1 - 9	-0.45	-0.22	-0.00*
2 - 4	-0.45	-0.19	0.07
2 - 6	-0.19	0.04	0.27
2 - 8	-0.37	-0.22	-0.06*
2 - 9	-0.59	-0.36	-0.13*
4 - 6	-0.09	0.23	0.54
4 - 8	-0.29	-0.03	0.23
4 - 9	-0.49	-0.18	0.14
6 - 8	-0.49	-0.25	-0.02*
6 - 9	-0.69	-0.40	-0.11*
8 - 9	-0.38	-0.15	0.09

* Indicates significance at the 0.05 level for transformed variables.

TABLE 11

TUKEY-KRAMER METHOD FOR PAIRWISE COMPARISONS: COMPARISONS OF TREATMENT MEAN TIMES TO DETECTION IN DAY OVERWATCH TRIALS

Treatment Comparison	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
TCL - OCS	10.43	26.32	42.22
TCL - OCM	8.95	24.17	39.38
TCL - OCL	4.31	20.68	37.05
TCL - OOS	11.07	26.54	42.00
TCL - OOM	13.05	28.06	43.06
TCL - OOL	1.63	17.53	33.42
TCL - TCS	4.18	20.83	37.49
TCL - TOM	3.16	19.35	35.54
TCL - TOL	3.61	19.76	35.92
TCM - OCS	1.61	16.31	31.02
TCM - OCM	0.19	14.16	28.13
TCM - OOS	2.29	16.53	30.77
TCM - OOM	4.31	18.05	31.78
TOS - OOM	1.09	14.15	27.22

O - in first position indicates optical sight and in second position indicates open hatch.

T - indicates thermal sight.

C - indicates open hatch.

L - indicates long range.

M - indicates medium range.

S - indicates short range.

sight, closed hatch and optical sight, open hatch at short and medium ranges. Treatment TOS observers display significant differences with the optical sight, open hatch, medium range observers. It is clear that in Day Overwatch trials, the performance of thermal sights with hatch closed at medium and long ranges is consistently poorer than the other treatments, especially at long range. In general, observers with optical sights perform better in Day trials.

The comparisons of the mean times to detection for combinations of sight type and range in Evening/Morning trials is shown in Table 12. Significant differences displayed are for observers with thermal sights, short range versus observers with thermal sights at medium and long ranges. Short range performance is better. Note that for Evening/Morning trials, performance is similar. This is intuitively pleasing in that during the evening and morning, it is not quite dark and not quite light. One would expect performance, in general, to be similar. However, one would expect performance at shorter ranges to be better than longer ranges for <u>both</u> sight types. This is not the case.

Table 13 displays the comparisons of mean times to detection for combinations of hatch status and range in Night Overwatch trials. The results show as would be expected, that performance for open hatch, short range observers is better than closed hatch short range and open hatch medium range observers.

Comparisons of means time to detection for combinations of sight type and hatch status in Night Moving trials are shown in Table 14. The results show that the performance of tank observers with optical sights and closed hatches is poorer than thermal sight observers with open or closed hatches. Note that the observers with optical sights and open hatchs do not perform significantly different from observers with thermal sights and open or closed hatches. One might think that thermal sights, regardless of hatch status, would perform better than optical sights if the time of day is night.

TABLE 12

TUKEY-KRAMER METHOD FOR PAIRWISE COMPARISONS:
COMPARISONS OF MEAN TIMES TO DETECTION FOR COMBINATIONS
OF SIGHT TYPE AND RANGE IN EVENING/MORNING TRIALS

Combination	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
OS - OM	-9.95	2.77	15.49
OS - OL	-15.42	-2.45	10.52
OS - TS	-2.61	9.07	20.76
OS - TM	-0.57	2.30	14.17
OS - TL	-10.47	1.43	13.33
OM - OL	-18.69	-5.22	8.25
OM - TS	-5.93	6.31	18.55
OM - TM	-12.88	-0.47	11.95
OM - TL	-13.78	-1.33	11.11
OL - TS	-0.97	11.53	24.02
OL - TM	-7.92	4.75	17.42
OL - TL	-8.81	3.88	16.58
TS - TM	-18.13	-6.77	4.58**
TS - TL	-19.02	-7.64	3.74**
TM - TL	-12.44	-0.87	10.71

** Indicates significance at 0.05 level for transformed variables, where,

O = optical sight.

T = thermal sight.

S = short range.

M = medium range.

L = long range.

TABLE 13

TUKEY-KRAMER METHOD FOR PAIRWISE COMPARISONS:
COMPARISONS OF MEAN TIMES TO DETECTION FOR COMBINATIONS
OF HATCH STATUS AND RANGE IN NIGHT OVERWATCH TRIALS

Combination	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
CS - CM	-12.70	4.40	21.50
CS - CL	-11.27	6.12	23.51
CS - OS	-4.56	11.56	27.67**
CS - OM	-26.22	-7.11	12.01
CS - OL	-10.43	7.00	24.43
CM - CL	-16.15	1.72	19.58
CM - OS	-9.47	7.16	23.79
CM - OM	-31.05	-11.51	8.04
CM - OL	-15.31	2.60	20.50
CL - OS	-11.49	5.44	22.37
CL - OM	-33.03	-13.22	6.58
CL - OL	-17.30	0.88	19.06
OS - OM	-37.35	-18.66	0.03**
OS - OL	-21.53	-4.56	12.41
OM - OL	-5.73	14.10	33.94

** Indicates significance at 0.05 level for transformed variables, where,

C = closed hatch.

O = open hatch.

S = short range.

M = medium range.

L = long range.

TABLE 14

TUKEY-KRAMER METHOD FOR PAIRWISE COMPARISONS: COMPARISONS OF MEAN TIMES TO DETECTION FOR COMBINATIONS OF SIGHT TYPE AND HATCH STATUS IN NIGHT MOVING TRIALS

Combination	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
OC - OO	-2.69	8.14	18.96
OC - TC	3.53	12.37	21.22*
OC - TO	4.24	13.21	22.19*
OO - TC	-3.81	4.24	12.28
OO - TO	-3.12	5.08	13.27
TC - TO	-4.48	0.84	6.16

* Indicates significance at 0.05 level,
where,

O = in first position denotes optical sight and in second position, open hatch.

C = closed hatch.

T = thermal sight.

Table 15 displays the mean proportion of detections for combinations of sight type and range in Night Overwatch trials.Observers with thermal sights perform consistently better in comparisons with observers with optical sights at the same ranges. In addition, for observers with optical sights at medium and long ranges, all thermal observers perform better. The same is true for optical sights at short range, except for observers with thermal sights at long ranges. Observers with optical sights do not perform in a significantly different manner over all ranges. Thermal observers at short ranges perform better than thermal observers at long ranges. All results are consistent with the author's a priori expectation.

TABLE 15

TUKEY-KRAMER METHOD FOR PAIRWISE COMPARISONS:
COMPARISONS OF MEAN PROPORTION OF DETECTIONS FOR COMBINATIONS
OF SIGHT TYPE AND RANGE IN NIGHT OVERWATCH TRIALS

Combination	Lower Confidence Limit	Difference Between Means	Upper Confidence Limit
OS - OM	-0.06	0.14	0.33
OS - OL	-0.14	0.04	0.23
OS - TS	-0.53	-0.35	-0.16*
OS - TM	-0.43	-0.25	-0.06*
OS - TL	-0.33	-0.14	0.04
OM - TS	-0.67	-0.49	-0.30*
OM - TM	-0.58	-0.39	-0.20*
OM - TL	-0.47	-0.28	-0.09*
OL - TS	-0.57	-0.39	-0.21*
OL - TM	-0.47	-0.29	-0.11*
OL - TL	-0.36	-0.19	-0.00*
TS - TM	-0.08	0.10	0.28
TS - TL	0.03	0.20	0.38*
TM - TL	-0.07	0.11	0.29

* Indicates significance at 0.05 level,
where,

O = optical sight.

T = thermal sight.

S = short range.

M = medium range.

L = long range.

G. FUNCTIONAL CATEGORY MODELS

1. General

The FUNCAT procedure is like ANOVA with qualitative independent variables, but with a categorical response variable rather than continuous. A response may have two or more levels. The model is described by the response and design effects. The design effects group the experimental units, factors, into populations. Therefore, each population is a unique combination of the independent variables or factors. For example, if sight type and hatch status are the factors in the model, there will be four unique combinations, since each factor has two levels (e.g. optical sight, hatch closed or hatch open, and thermal sight, hatch closed or hatch open).

Each population has a different multinomial distribution for the response counts as shown below [Ref. 4:p. 257]:

Population	Response 1	. . .	Response r	Sample Size
1	n_{11}	. . .	n_{1r}	n_1
2	n_{21}	. . .	n_{2r}	n_2
⋮				
s	n_{s1}	. . .	n_{sr}	n_s

For each population i, i=1,...,s, the probability of the j^{th} response (Π_{ij}) j=1,...r, is estimated by $p_{ij}=n_{ij}/n_i$. These estimates are used to construct values for a logit function defined on the response probabilities. The function may be written as follows:

$$f_j = \ln(p_j/p_r) \qquad j = 1,\ldots,4$$

for each population i=1,...s.

The function compares every response to the last response, as specified by the user. This function of the true probabilities is assumed to follow a linear model in terms of the design structure of the samples. The same function is applied to each population. The model may be written as follows:

$$f(\Pi_i) = X_i\beta + \varepsilon_i \qquad i = 1,\ldots,s,$$

where

$$\Pi_i = (\Pi_{i1},\ldots,\Pi_{ir})$$

and

$$\hat{f}(\pi_i) = X_i b \qquad i=1,\ldots,s,$$

where b is the vector of parameter estimates for each effect specified in the model.

The model parameters are best described in terms of the factor main effects. If factor A has four levels, then it will have three parameters. Each parameter compares the response from the first three levels with the fourth. Thus, each parameter corresponds to a design column in the design matrix, X. Crossed effects are formed by the horizontal direct product of main effects. The degrees of freedom, (df), for crossed effects are equal to the product of the df for each separate effect. The design matrix, X, is specified such that each row corresponds to a population. A typical design matrix might look like the sample below for a model with four populations:

DATA		MAIN-A	MAIN-B	CROSSED
A	B	A(1)	B(1)	AB(1)
1	1	1	1	1
1	2	1	-1	-1
2	1	-1	1	-1
2	2	-1	-1	1

The vector of parameter estimates, b, is used to test the fit of the model to the data. Grizzle, Starmer and Koch [Ref. 4] have shown that if the hypothesized model fits the data, then b is the best asymptotic Normal estimate of the true model parameters. Given a model provides an adequate fit to the data, then the parameter estimates are used to test hypotheses concerning the model effects. For example, the main effects for the factor A equal zero, versus the alternative not all A main effects equal zero.

In order to maintain consistency in the analysis, the FUNCAT models that follow were computed for the six separate combinations of the factors time of day and observer motion.

2. Problems Associated with Categorical Responses

Special problems arise, unfortunately, when the dependent variable is categorical [Ref. 7:pp. 322-323].

1) Given a response has r levels, the residual terms can only take on r values. Clearly, an assumption of Normally distributed residuals is not appropriate.

2) The residual terms do not have equal variances when the dependent variable is categorical. The error variances depend on the parameters.

Even though the residual are not Normal when the dependent variable 's categorical, the method of least squares still provides unbiased estimators of the parameters which, under very general conditions, are asymptotically Normal. When the population sample sizes are reasonably large, such as is the case of the models that follow, inferences concerning the parameter estimates and mean responses are made in the same way as when the error terms are assumed to be Normally distributed.

The use of the weighted least squares method is a solution to the problem concerning unequal error variances. By employing this method, the FUNCAT procedure gives more weight to the population response functions with smaller variances. The weighted least squares method requires the population sample sizes to be reasonably large.

In general, if the population sample sizes are reasonably large (greater than thirty observations) then the problems associated with the model do not preclude using the model. In almost all cases, the population sample sizes for the procedures that follow meet the sample size requirement.

3. FUNCAT Procedure for Target Detection as Response Variable

The response variable, Target Detection has two levels. A valid detection is considered to be an initial detection of one of the ten targets purposely put in the observer field of view during a trial. Hence, a non-valid engagement corresponds to subsequent detection of targets or detection of unknown or false targets. Valid detections are considered as response category 1 and non-valid detections are response category 2. In terms of the model parameters, the last level of the factor, hatch status, is open, and the last level of the factor, crew member detecting, is the tank commander. Therefore, the hatch status parameter is a comparison of closed versus open and the crew member detecting parameter is a comparison of the gunner versus the tank commander.

The factors crew member (gunner or tank commander) detecting and hatch status were analyzed for each time of day and observer motion combination. FUNCAT summaries are shown in Tables 16 through 21. As one views the tables, the presence of similarities is evident. In all cases, the differences in the response probabilities across populations are not significant for hatch status or crew-member-detecting x hatch status interaction effects. The crew member detecting main effects were significantly different in overwatch trials, but not in moving trials. This implies that during moving trials, the probability of a valid detection is not significantly different, among the populations examined, for the tank commander or gunner. The opposite is true in overwatch trials. In all cases, the gunner probability of valid detection is higher. This is seen by viewing the response probabilities for each population. It should be noted, that in terms of the primary design variables, the responses in the model have been aggregated over the factors sight type and range. Even with this variability not being accounted for in the model, the significance of the crew member

TABLE 16

FUNCAT SUMMARIES FOR
TARGET DETECTION AS RESPONSE: DAY OVERWATCH

FUNCAT PROCEDURE

RESPONSE: DETECTION

RESPONSE LEVELS	(R)=	2
POPULATIONS	(S)=	4
TOTAL COUNT	(N)=	2268
OBSERVATIONS	(OBS)=	2268

ONE-WAY FREQUENCIES

VARIABLE	VALUE	COUNT
DETECT	1	1436
	2	832
CREWMBR	1	1272
	2	996
HS	CLOSED	1053
	OPEN	1215

SAMPLE	DESIGN CREWMBR	HS	RESPONSE PROBABILITIES 1	2	TOTAL
1	1	CLOSED	0.7643	0.2357	628.0
2	1	OPEN	0.7640	0.2360	644.0
3	2	CLOSED	0.4447	0.5553	425.0
4	2	OPEN	0.4816	0.5184	571.0

SOURCE	DF	CHI-SQUARE	PROB
INTERCEPT	1	124.29	0.0001
CREWMBR	1	206.09	0.0001
HS	1	0.63	0.4268
CREWMBR*HS	1	0.67	0.4144
RESIDUAL	0	0.00	1.0000

CREWMBR = CREW MEMBER DETECTING;

HS = OBSERVING TANK HATCH STATUS;

DETECT = DETECTION OF VALID OR NONVALID TARGET.

TABLE 17

FUNCAT SUMMARIES FOR
TARGET DETECTION AS RESPONSE: DAY MOVING

FUNCAT PROCEDURE

RESPONSE: DETECT

RESPONSE LEVELS (R)=	2
POPULATIONS (S)=	4
OBSERVATIONS (OBS)=	856

ONE-WAY FREQUENCIES

VARI. [illegible]	VALUE	COUNT
DETEC	1	390
	2	466
CREWMBR	1	499
	2	357
HS	CLOSED	421
	OPEN	435

SAMPLE	DESIGN CREWMBR	HS	RESPONSE PROBABILITIES 1	2	TOTAL
1	1	CLOSED	0.4351	0.5649	239.0
2	1	OPEN	0.4462	0.5538	260.0
3	2	CLOSED	0.5055	0.4945	182.0
4	2	OPEN	0.4457	0.5543	175.0

SOURCE	DF	CHI-SQUARE	PROB
INTERCEPT	1	5.83	0.0157
CREWMBR	1	1.02	0.3133
HS	1	0.49	0.4835
CREWMBR*HS	1	1.04	0.3072
RESIDUAL	0	0.00	1.0000

CREWMBR = CREW MEMBER DETECTING;

HS = OBSERVING TANK HATCH STATUS;

DETECT = DETECTION OF VALID OR NONVALID TARGET.

TABLE 18

FUNCAT SUMMARIES FOR TARGET DETECTION AS RESPONSE: EVENING/MORNING OVERWATCH

FUNCAT PROCEDURE

RESPONSE: DETECTION

RESPONSE LEVELS	(R)=	2
POPULATIONS	(S)=	4
TOTAL COUNT	(N)=	1650
OBSERVATIONS	(OBS)=	1650

ONE-WAY FREQUENCIES

VARIABLE	VALUE	COUNT
DETECT	1	1173
	2	477
CREWMBR	1	935
	2	715
HS	CLOSED	840
	OPEN	810

SAMPLE	DESIGN CREWMBR	HS	RESPONSE PROBABILITIES 1	2	TOTAL
1	1	CLOSED	0.7923	0.2077	491.0
2	1	OPEN	0.8108	0.1892	444.0
3	2	CLOSED	0.5845	0.4155	349.0
4	2	OPEN	0.6011	0.3989	366.0

SOURCE	DF	CHI-SQUARE	PROB
INTERCEPT	1	250.13	0.0001
CREWMBR	1	83.02	0.0001
HS	1	0.68	0.4084
CREWMBR*HS	1	0.05	0.8303
RESIDUAL	0	-0.00	1.0000

CREWMBR = CREW MEMBER DETECTING;

HS = OBSERVING TANK HATCH STATUS;

DETECT = DETECTION OF VALID OR NONVALID TARGET.

TABLE 19

FUNCAT SUMMARIES FOR
TARGET DETECTION AS RESPONSE: EVENING/MORNING MOVING

FUNCAT PROCEDURE

RESPONSE: DETECTION	RESPONSE LEVELS (R)=	2
	POPULATIONS (S)=	4
	TOTAL COUNT (N)=	822
	OBSERVATIONS (OBS)=	822

ONE-WAY FREQUENCIES

VARIABLE	VALUE	COUNT
DETECT	1	382
	2	440
CREWMBR	1	499
	2	323
HS	CLOSED	431
	OPEN	391

	DESIGN		RESPONSE PROBABILITIES		TOTAL
SAMPLE	CREWMBR	HS	1	2	
1	1	CLOSED	0.4436	0.5564	275.0
2	1	OPEN	0.4554	0.5446	224.0
3	2	CLOSED	0.5192	0.4808	156.0
4	2	OPEN	0.4611	0.5389	167.0

SOURCE	DF	CHI-SQUARE	PROB
INTERCEPT	1	2.85	0.0917
CREWMBR	1	1.29	0.2558
HS	1	0.42	0.5182
CREWMBR*HS	1	0.95	0.3291
RESIDUAL	0	0.00	1.0000

CREWMBR = CREW MEMBER DETECTING;

HS = OBSERVING TANK HATCH STATUS;

DETECT = DETECTION OF VALID OR NONVALID TARGET.

TABLE 20

FUNCAT SUMMARIES FOR
TARGET DETECTION AS RESPONSE: NIGHT OVERWATCH

FUNCAT PROCEDURE

RESPONSE: DETECTION

RESPONSE LEVELS	(R)=	2
POPULATIONS	(S)=	4
TOTAL COUNT	(N)=	1260
OBSERVATIONS	(OBS)=	1260

ONE-WAY FREQUENCIES

VARIABLE	VALUE	COUNT
DETECT	1	803
	2	457
CREWMBR	1	704
	2	556
HS	CLOSED	633
	OPEN	627

SAMPLE	DESIGN CREWMBR	HS	RESPONSE PROBABILITIES 1	2	TOTAL
1	1	CLOSED	0.6984	0.3016	368.0
2	1	OPEN	0.6250	0.3750	336.0
3	2	CLOSED	0.6000	0.4000	265.0
4	2	OPEN	0.6082	0.3918	291.0

SOURCE	DF	CHI-SQUARE	PROB
INTERCEPT	1	86.49	0.0001
CREWMBR	1	4.57	0.0325
HS	1	1.55	0.2127
CREWMBR*HS	1	2.37	0.1240
RESIDUAL	0	-0.00	1.0000

CREWMBR = CREW MEMBER DETECTING;

HS = OBSERVING TANK HATCH STATUS;

DETECT = DETECTION OF VALID OR NONVALID TARGET.

TABLE 21

FUNCAT SUMMARIES FOR
TARGET DETECTION AS RESPONSE: NIGHT MOVING

FUNCAT PROCEDURE

RESPONSE: DETECT

RESPONSE LEVELS	(R)=	2
POPULATIONS	(S)=	4
TOTAL COUNT	(N)=	693
OBSERVATIONS	(OBS)=	693

ONE-WAY FREQUENCIES

VARIABLE	VALUE	COUNT
DETECT	1	319
	2	374
CREWMBR	1	437
	2	256
HS	CLOSED	365
	OPEN	328

SAMPLE	DESIGN CREWMBR	HS	RESPONSE PROBABILITIES 1	2	TOTAL
1	1	CLOSED	0.4635	0.5365	233.0
2	1	OPEN	0.4363	0.5637	204.0
3	2	CLOSED	0.4470	0.5530	132.0
4	2	OPEN	0.5081	0.4919	124.0

SOURCE	DF	CHI-SQUARE	PROB
INTERCEPT	1	3.40	0.0653
CREWMBR	1	0.49	0.4833
HS	1	0.18	0.6694
CREWMBR*HS	1	1.26	0.2615
RESIDUAL	0	0.00	1.0000

CREWMBR = CREW MEMBER DETECTING;

HS = OBSERVING TANK HATCH STATUS;

DETECT = DETECTION OF VALID OR NONVALID TARGET.

differences in the response across populations speaks to the strength of the difference.

4. <u>FUNCAT Procedure for Crew Member Detecting as Response Variable</u>

The response variable, Crew Member Detecting has two levels. Detection of targets, valid or non-valid, by the gunner are considered as response category 1 and detections by the tank commander as response category 2.

The factor target attributes is analyzed for each time of day and observer motion combination. Each target detected, including unknowns and false targets, has several attributes which are associated with it during a trial. Table 22 provides a description of the attributes associated with a target during a trial. Since there is only one factor studied, the ten levels of the factor target attributes are the populations considered in the analysis. In terms of the model parameters, the last level of the factor target attributes is the baseline target. As seen in the table, a baseline target has no attributes. Therefore, each parameter is a comparison of one of the first nine levels with the baseline target.

FUNCAT summaries are shown in Tables 23 through 28. Significant differences in the response probabilities across populations were seen in Day Overwatch and Evening/Morning Overwatch trials. It is of interest to determine, for these trials, which target attribute populations are significantly different in terms of the response. Target attribute comparisons are shown in Tables 29 and 30 for Day Overwatch and Evening/Morning Overwatch trials, respectively. For both

TABLE 22

TARGET POPULATION ATTRIBUTES:
A DESCRIPTION OF TARGET ATTRIBUTES
APPLICABLE DURING A TRIAL

Population	Camouflage	Firing	Engines	Motion	Crew Exposure
Target 1	None	No	No	No	Exposed
Target 2	None	Yes	No	No	Not Exposed
Target 3	None	No	Yes	No	Not Exposed
Target 4	None	No	No	Yes	Not Exposed
Target 5	Partial	No	No	No	Not Exposed
Target 6	Partial	Yes	No	No	Not Exposed
Target 7	NA	NA	NA	NA	NA
Target 8	Unknown	Unknown	Unknown	Unknown	Unknown
Target 9	Full	No	No	No	Not Exposed
Target 10	None	No	No	No	Not Exposed

NA above applies to hulks and decoys.

TABLE 23

FUNCAT SUMMARIES FOR
CREW MEMBER DETECTING AS RESPONSE: DAY OVERWATCH

FUNCAT PROCEDURE

RESPONSE: CREWMBR

RESPONSE LEVELS	(R)=	2
POPULATIONS	(S)=	10
TOTAL COUNT	(N)=	2268
OBSERVATIONS	(OBS)=	2268

ONE-WAY FREQUENCIES

VARIABLE	VALUE	COUNT
CREWMBR	1	1272
	2	996
TARGET	1	156
	2	142
	3	156
	4	265
	5	60
	6	11
	7	663
	8	551
	9	62
	10	202

SAMPLE	DESIGN TARGET	RESPONSE PROBABILITIES 1	2	TOTAL
1	1	0.6090	0.3910	156.0
2	2	0.5634	0.4366	142.0
3	3	0.6538	0.3462	156.0
4	4	0.6113	0.3887	265.0
5	5	0.6167	0.3833	60.0
6	6	0.4545	0.5455	11.0
7	7	0.6546	0.3454	663.0
8	8	0.3521	0.6479	551.0
9	9	0.6452	0.3548	62.0
10	10	0.6089	0.3911	202.0

SOURCE	DF	CHI-SQUARE	PROB
INTERCEPT	1	15.44	0.0001
TARGET	9	129.63	0.0001
RESIDUAL	0	0.00	1.0000

CREWMBR = crew member detecting;
TARGET = populations of the factor target attributes.

TABLE 24

FUNCAT SUMMARIES FOR
CREW MEMBER DETECTING AS RESPONSE: DAY MOVING

FUNCAT PROCEDURE

RESPONSE: CREWMBR	RESPONSE LEVELS	(R)=	2
	POPULATIONS	(S)=	10
	TOTAL COUNT	(N)=	856
	OBSERVATIONS	(OBS)=	856

ONE-WAY FREQUENCIES

VARIABLE	VALUE	COUNT
CREWMBR	1	499
	2	357
TARGET	1	35
	2	39
	3	45
	4	69
	5	11
	6	3
	7	195
	8	371
	9	23
	10	65

SAMPLE	DESIGN TARGET	RESPONSE PROBABILITIES 1	2	TOTAL
1	1	0.5429	0.4571	35.0
2	2	0.5641	0.4359	39.0
3	3	0.6444	0.3556	45.0
4	4	0.5217	0.4783	69.0
5	5	0.3636	0.6364	11.0
6	6	0.6667	0.3333	3.0
7	7	0.5846	0.4154	195.0
8	8	0.5822	0.4178	371.0
9	9	0.5217	0.4783	23.0
10	10	0.6923	0.3077	65.0

SOURCE	DF	CHI-SQUARE	PROB
INTERCEPT	1	3.12	0.0775
TARGET	9	7.66	0.5692
RESIDUAL	0	-0.00	1.0000

CREWMBR = crew member detecting;
TARGET = populations of the factor target attributes.

TABLE 25

FUNCAT SUMMARIES FOR
CREW MEMBER DETECTING AS RESPONSE: EVENING/MORNING OVERWATCH

FUNCAT PROCEDURE

RESPONSE: CREWMBR	RESPONSE LEVELS (R)=	2
	POPULATIONS (S)=	10
	TOTAL COUNT (N)=	1650
	OBSERVATIONS (OBS)=	1650

ONE-WAY FREQUENCIES

VARIABLE	VALUE	COUNT
CREWMBR	1	935
	2	715
TARGET	1	125
	2	97
	3	111
	4	194
	5	45
	6	12
	7	512
	8	324
	9	44
	10	186

SAMPLE	DESIGN TARGET	RESPONSE PROBABILITIES 1	RESPONSE PROBABILITIES 2	TOTAL
1	1	0.6480	0.3520	125.0
2	2	0.5258	0.4742	97.0
3	3	0.6126	0.3874	111.0
4	4	0.5361	0.4639	194.0
5	5	0.6444	0.3556	45.0
6	6	0.5000	0.5000	12.0
7	7	0.6719	0.3281	512.0
8	8	0.3395	0.6605	324.0
9	9	0.5000	0.5000	44.0
10	10	0.6452	0.3548	186.0

SOURCE	DF	CHI-SQUARE	PROB
INTERCEPT	1	9.33	0.0023
TARGET	9	98.45	0.0001
RESIDUAL	0	-0.00	1.0000

CREWMBR = crew member detecting;
TARGET = populations of the factor target attributes.

TABLE 26

FUNCAT SUMMARIES FOR CREW MEMBER DETECTING AS RESPONSE: EVENING/MORNING MOVING

FUNCAT PROCEDURE

RESPONSE: CREWMBR	RESPONSE LEVELS (R)=	2
	POPULATIONS (S)=	10
	TOTAL COUNT (N)=	822
	OBSERVATIONS (OBS)=	822

ONE-WAY FREQUENCIES

VARIABLE	VALUE	COUNT
CREWMBR	1	499
	2	323
TARGET	1	34
	2	42
	3	51
	4	68
	5	22
	6	2
	7	161
	8	359
	9	4
	10	79

SAMPLE	DESIGN TARGET	RESPONSE PROBABILITIES 1	2	TOTAL
1	1	0.6176	0.3824	34.0
2	2	0.5476	0.4524	42.0
3	3	0.6275	0.3725	51.0
4	4	0.5588	0.4412	68.0
5	5	0.5909	0.4091	22.0
6	6	1.0000	0.0000	2.0
7	7	0.5963	0.4037	161.0
8	8	0.6240	0.3760	359.0
9	9	0.5000	0.5000	4.0
10	10	0.6076	0.3924	79.0

SOURCE	DF	CHI-SQUARE	PROB
INTERCEPT	1	4.92	0.0265
TARGET	9	2.47	0.9818
RESIDUAL	0	0.00	1.0000

CREWMBR = crew member detecting;
TARGET = populations of the factor target attributes.

TABLE 27

FUNCAT SUMMARIES FOR
CREW MEMBER DETECTING AS RESPONSE: NIGHT OVERWATCH

FUNCAT PROCEDURE

RESPONSE: CREWMBR			
	RESPONSE LEVELS	(R)=	2
	POPULATIONS	(S)=	10
	TOTAL COUNT	(N)=	1260
	OBSERVATIONS	(OBS)=	1260

ONE-WAY FREQUENCIES

VARIABLE	VALUE	COUNT
CREWMBR	1	704
	2	556
TARGET	1	96
	2	74
	3	90
	4	154
	5	34
	6	12
	7	268
	8	369
	9	19
	10	144

SAMPLE	DESIGN TARGET	RESPONSE PROBABILITIES 1	2	TOTAL
1	1	0.5625	0.4375	96.0
2	2	0.5405	0.4595	74.0
3	3	0.5333	0.4667	90.0
4	4	0.6039	0.3961	154.0
5	5	0.5882	0.4118	34.0
6	6	0.4167	0.5833	12.0
7	7	0.5485	0.4515	268.0
8	8	0.5339	0.4661	369.0
9	9	0.6316	0.3684	19.0
10	10	0.6111	0.3889	144.0

SOURCE	DF	CHI-SQUARE	PROB
INTERCEPT	1	5.84	0.0157
TARGET	9	5.73	0.7670
RESIDUAL	0	-0.00	1.0000

CREWMBR = crew member detecting;
TARGET = populations of the factor target attributes.

TABLE 28

FUNCAT SUMMARIES FOR
CREW MEMBER DETECTING AS RESPONSE: NIGHT MOVING

FUNCAT PROCEDURE

RESPONSE: CREWMBR

RESPONSE LEVELS	(R)=	2
POPULATIONS	(S)=	10
TOTAL COUNT	(N)=	693
OBSERVATIONS	(OBS)=	693

ONE-WAY FREQUENCIES

VARIABLE	VALUE	COUNT
CREWMBR	1	437
	2	256
TARGET	1	39
	2	30
	3	35
	4	53
	5	14
	6	3
	7	136
	8	299
	9	10
	10	74

SAMPLE	DESIGN TARGET	RESPONSE PROBABILITIES 1	2	TOTAL
1	1	0.7692	0.2308	39.0
2	2	0.5333	0.4667	30.0
3	3	0.8000	0.2000	35.0
4	4	0.6038	0.3962	53.0
5	5	0.5714	0.4286	14.0
6	6	0.6667	0.3333	3.0
7	7	0.5882	0.4118	136.0
8	8	0.6388	0.3612	299.0
9	9	0.4000	0.6000	10.0
10	10	0.6216	0.3784	74.0

SOURCE	DF	CHI-SQUARE	PROB
INTERCEPT	1	9.29	0.0023
TARGET	9	12.00	0.2132
RESIDUAL	0	-0.00	1.0000

CREWMBR = crew member detecting;
TARGET = populations of the factor target attributes.

TABLE 29

TARGET ATTRIBUTE COMPARISONS
FOR DAY OVERWATCH TRIALS

CONTRAST	DF	CHI-SQUARE	PROB
TARGET1-TARGET2	1	0.64	0.4248
TARGET1-TARGET3	1	0.67	0.4116
TARGET1-TARGET4	1	0.00	0.9620
TARGET1-TARGET5	1	0.01	0.9173
TARGET1-TARGET6	1	0.99	0.3189
TARGET1-TARGET7	1	1.15	0.2841
TARGET1-TARGET8	1	31.79	0.0001
TARGET1-TARGET9	1	0.25	0.6198
TARGET1-TARGET10	1	0.59	0.4440
TARGET2-TARGET3	1	2.55	0.1103
TARGET2-TARGET4	1	0.88	0.3480
TARGET2-TARGET5	1	0.49	0.4837
TARGET2-TARGET6	1	0.48	0.4868
TARGET2-TARGET7	1	4.19	0.0407
TARGET2-TARGET8	1	20.44	0.0001
TARGET2-TARGET9	1	1.19	0.2759
TARGET2-TARGET10	1	0.12	0.7257
TARGET3-TARGET4	1	0.76	0.3838
TARGET3-TARGET5	1	0.26	0.6095
TARGET3-TARGET6	1	1.70	0.1929
TARGET3-TARGET7	1	0.00	0.9858
TARGET3-TARGET8	1	42.79	0.0001
TARGET3-TARGET9	1	0.01	0.9034
TARGET3-TARGET10	1	3.54	0.0598
TARGET4-TARGET5	1	0.01	0.9388
TARGET4-TARGET6	1	1.05	0.3044
TARGET4-TARGET7	1	1.54	0.2144
TARGET4-TARGET8	1	47.38	0.0001
TARGET4-TARGET9	1	0.24	0.6217
TARGET4-TARGET10	1	0.99	0.3189
TARGET5-TARGET6	1	0.99	0.3198
TARGET5-TARGET7	1	0.35	0.5552
TARGET5-TARGET8	1	15.01	0.0001
TARGET5-TARGET9	1	0.11	0.7444
TARGET5-TARGET10	1	0.41	0.5221
TARGET6-TARGET7	1	1.81	0.1787
TARGET6-TARGET8	1	0.49	0.4848
TARGET6-TARGET9	1	1.39	0.2380
TARGET6-TARGET10	1	0.83	0.3637
TARGET7-TARGET8	1	106.69	0.0001
TARGET7-TARGET9	1	0.02	0.8813
TARGET7-TARGET10	1	8.94	0.0028
TARGET8-TARGET9	1	18.60	0.0001
TARGET8-TARGET10	1	66.87	0.0001
TARGET9-TARGET10	1	1.27	0.2590

TABLE 30

TARGET ATTRIBUTE COMPARISONS FOR EVENING/MORNING OVERWATCH TRIALS

CONTRAST	DF	CHI-SQUARE	PROB
TARGET1-TARGET2	1	3.36	0.0666
TARGET1-TARGET3	1	0.32	0.5739
TARGET1-TARGET4	1	3.89	0.0487
TARGET1-TARGET5	1	0.00	0.9659
TARGET1-TARGET6	1	1.01	0.3147
TARGET1-TARGET7	1	0.26	0.6117
TARGET1-TARGET8	1	33.33	0.0001
TARGET1-TARGET9	1	2.96	0.0856
TARGET1-TARGET10	1	3.58	0.0586
TARGET2-TARGET3	1	1.59	0.2073
TARGET2-TARGET4	1	0.03	0.8680
TARGET2-TARGET5	1	1.75	0.1863
TARGET2-TARGET6	1	0.03	0.8661
TARGET2-TARGET7	1	7.50	0.0062
TARGET2-TARGET8	1	10.72	0.0011
TARGET2-TARGET9	1	0.08	0.7766
TARGET2-TARGET10	1	0.58	0.4454
TARGET3-TARGET4	1	1.68	0.1953
TARGET3-TARGET5	1	0.14	0.7104
TARGET3-TARGET6	1	0.57	0.4520
TARGET3-TARGET7	1	1.43	0.2325
TARGET3-TARGET8	1	24.42	0.0001
TARGET3-TARGET9	1	1.63	0.2017
TARGET3-TARGET10	1	1.09	0.2955
TARGET4-TARGET5	1	1.72	0.1895
TARGET4-TARGET6	1	0.06	0.8080
TARGET4-TARGET7	1	11.06	0.0009
TARGET4-TARGET8	1	19.03	0.0001
TARGET4-TARGET9	1	0.19	0.6652
TARGET4-TARGET10	1	0.53	0.4683
TARGET5-TARGET6	1	0.82	0.3646
TARGET5-TARGET7	1	0.14	0.7077
TARGET5-TARGET8	1	14.34	0.0002
TARGET5-TARGET9	1	1.88	0.1701
TARGET5-TARGET10	1	1.36	0.2443
TARGET6-TARGET7	1	1.50	0.2205
TARGET6-TARGET8	1	1.28	0.2587
TARGET6-TARGET9	1	0.00	1.0000
TARGET6-TARGET10	1	0.24	0.6246
TARGET7-TARGET8	1	84.44	0.0001
TARGET7-TARGET9	1	5.15	0.0233
TARGET7-TARGET10	1	15.04	0.0001
TARGET8-TARGET9	1	4.23	0.0397
TARGET8-TARGET10	1	47.08	0.0001
TARGET9-TARGET10	1	0.82	0.3647

types of trials, the target attribute population described as unknown provides significant differences in the response when compared with all other target attribute populations, except targets firing from partial concealment. This is a very interesting result. By viewing the response probabilities for the unknown population, one can see that the tank commander is more likely to detect an unknown target. This result suggests that the false target rate for the tank commander is higher than the gunner's false target rate. In this particular data set, the tank commander is about twice as likely to detect an unknown or false target is compared to the gunner. In Evening/Morning trials, there are also significant differences in the response for hulks as compared to targets in full concealment and target motion with engines remaining onafter movement. By viewing the response probabilities, one can see that the gunner is more likely to detect hulks as compared to the tank commander.

IV. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

1. Problem

To determine the effects of several specific factors on the target acquisition process for tanks.

2. Discussion

In order to acquire information related to the problem of target acquisition, a field experiment was designed and conducted by members of the United States Army Combat Developments Experimentation Center (CDEC) at Fort Hunter Ligget, California, during the period, 19 July through 10 December 1983. Tank crews, consisting of a tank commander and gunner, were placed in tanks and presented with various target arrays (e.g. 4 tanks, 2 decoys). These observers were in both moving (attacking) and overwatch (defending) roles. The tank crews were required to locate, as accurately as possible, the positions of the target vehicles and to engage those vehicles which posed a threat to the observers.

Controlled factors such as time of day, observer-target range, observer sight type, observer hatch status and observer motion were incorporated into the test, so that the impact of such factors on the target acquisition process could be investigated. Target cues, such as motion, concealment level, firing status, crew exposure and engine status, as well as, environmental factors such as sky/background visual contrast, target/background temperature contrast, and target/background visual constrast were also incorporated into the test.

The data were analyzed to determine the time required to locate targets (times to detection) and number of targets located (proportion of targets detected) by various populations of observers specified by the controlled observer factors (e.g. observer during daylight hours, at short range, with thermal sighting system). Both nonparametric and parametric methods were used in the analytical process, to test hypotheses concerning the effects of the various factors on the observer groups.

B. CONCLUSIONS

1. Effect of Time of Day

The factor time of day has significant effect on the mean times to detection and mean proportions of targets detected for the observer groups studied. Because of its pervasive influence, it was necessary to conduct the analyses for remaining factors of interest at each level of this factor.

2. Effect of Observer Motion

The motion of the observing tank has significant effect on its mean times to detection and mean proportions of targets detected. Because of its pervasive influence, it was necessary to conduct the analyses for remaining factors of interest at each level of this factor.

3. Effect of Observer Sight Type

The sight type of the observing tank has significant effect on its mean times to detection and mean proportion of targets detected. For the analyses conducted, optical sights perform better in the day and thermal sight performance is better at night. Performance during evening and morning trials does not appear significantly different with either sight type.

4. Effect of Observer Hatch Status

The hatch status of the observing tank has no significant effect on the mean times to detection or mean proportion of targets detected.

5. Effect of Range

The observer-target range has no significant effect on the mean times to detection.

The observer-target range does have a significant effect on the mean proportion of targets detected. The significance runs counter to what one might expect. Performance appears to be better at longer ranges than at shorter ranges.

6. Effect of Target Cues

Target cues do not appear to have significant effect on the mean times to detection or mean proportion of targets detected. For example, given a target cue, such as target motion, there are no significant differences in the mean times to detection for a moving or stationary target.

7. Effect of Environment

The physical environment in which targets are presented does appear to have a significant effect on mean times to detection and mean proportion of targets detected. The data indicates that trial sites 8 and 9 were conducive to good performance in terms of mean times to detection and trial site 6 was good for mean proportion of detections.

8. <u>Effect of Crew Member Detecting</u>

The crew member making a detection does significantly effect the detection of a valid (target placed in the observer's field of view), or non-valid (false targets or subsequent detection of targets) target in Day Overwatch and Evening/Morning Overwatch trials. The gunner of the observing tank is more likely to have a valid detection as compared to the tank commander. In addition, the tank commander is about twice as likely to detect false or unknown targets as compared to the gunner.

C. RECOMMENDATION

Additional investigation should be made into the physical environment in which targets are presented. Review of the closed circuit television tapes would be a good first step in this process.

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