Research Report 1358

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Use of Optical and Thermal Sights in Daylight Target Detection

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Training Research Laboratory

U. S. Army
Research Institute for the Behavioral and Social Sciences

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The Fort Knox Field Unit of ARI investigated the use of optical and thermal sights for daylight target detection. Armor soldiers were asked to detect targets in optical sight displays, thermal sight displays, and displays in which optical and thermal scenes alternated. Alternating between thermal and optical sights produced more target detections than using either sight alone over all terrain conditions, but did so at the expense of time. In dense vegetation, alternating between optical and thermal sights produced the highest target

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) detection performance. In contrast, when searching for targets in mixed terrain, optical sights alone produced the best target detection performance with respect to both speed and accuracy. Performance with the thermal sight improved over trials, demonstrating the need for target detection training with the thermal sight and the increase in performance that can occur when systematic feedback is provided to those undergoing training.

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Training and Simulation

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FOREWORD

The U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) conducted this research in response to the need for empirically based guidance on the use of thermal sights. The thermal sight provides a potential quantum leap in the capability of crewmen to detect and identify targets, but exploitation of this technological advance must be guided with a clear understanding of human perceptual capabilities for its use. This report describes the results of research dealing with target detection with an optical and a thermal sight, and integration of the information provided by each in target detection. The research responds to the requirements of the Deputy Assistant Commandant for Educational Technology, USAARMS, Fort Knox, Kentucky, under Human Research Need 81-225 "Training for target acquisition and recognition (Friend/Foe)," and provides initial guidance for daylight use of thermal and optical sights on weapon systems containing both. Results of the research can be applied to training in target detection techniques using thermal and optical sights that will increase target detection. The results also demonstrate the necessity of instituting a systematic target detection training program using thermal sights. The report contains important factors to consider in establishing a defensive position to maximize target detection. It also discusses implications of some of the major findings for combat and points out areas in which further research is needed.

EDGAR M. JOHNSON
Technical Director

USE OF OPTICAL AND THERMAL SIGHTS IN DAYLIGHT TARGET DETECTION

EXECUTIVE SUMMARY

Requirement:

The Fort Knox Field Unit of ARI investigated the use of optical and thermal sights for target detection during daylight hours. Under degraded viewing conditions, tank gunners clearly must choose the thermal sight for target acquisition. However, under clear, daylight conditions both thermal and optical sights could potentially be used to acquire targets. This research addressed some fundamental questions regarding use of the capability afforded by having both a thermal and an optical sight. It also examined the influence of vegetation on sight choice.

Procedure:

Armor soldiers in One Station Unit Training viewed slides containing from zero to three targets that were taken either through an optical sight or through a thermal sight. Observers were asked to detect and point out targets in optical sight displays, thermal sight displays, or displays in which optical and thermal sight slides of the same scene alternated. Observers' response times were recorded for both correct detections and false alarms (mistakenly saying there was a target at a given location when, in fact, there was none). Search time on each trial was limited to 30 seconds. After each trial, the experimenter pointed out correctly detected targets, missed targets, and areas that had been falsely identified as targets.

Findings:

Results revealed that alternating between optical and thermal sights provides increased target detection performance (in terms of maximizing the number of targets detected and minimizing the number of nontargets falsely identified as targets) over using either sight alone during daylight hours and in all terrain conditions. The increased target detection performance, however, occurs at the expense of time; the time required to detect targets was fastest when using the optical sight alone. When searching for targets in densely vegetated terrain, alternating between optical and thermal sights produced the highest target detection performance. In contrast, when searching terrain with bare or grassy areas and searching along woodlines, optical sights alone produced the best target detection performance with respect to both speed and accuracy. Performance with the thermal sight improved over trials, demonstrating the need for target detection training with the thermal sight and the increase in performance that can occur when systematic feedback is provided to those undergoing training.

USE OF OPTICAL AND THERMAL SIGHTS IN DAYLIGHT TARGET DETECTION

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INTRODUCTION

Target acquisition is a major problem on the modern battlefield. The increased lethality of modern weapons demands rapid, accurate target detection and identification if our soldiers are to survive. However, the Army finds itself on the horns of a dilemma, because while target acquisition is a critical determinant of combat effectiveness, the increasing ranges of modern weapon systems make threat weapons more difficult to detect and identify. One solution to this dilemma is to make the fullest possible use of available technology in concert with human perceptual capabilities to enhance target acquisition on the battlefield. The thermal sight provides a potential quantum leap in the capability of crewmen to detect and identify targets, but exploitation of this technological advance must be grounded in a clear understanding of human perceptual capabilities.

Clearly, crewmen must choose the thermal sight at night or under conditions of low visibility (smoke, dust, haze, etc.) for systems with both thermal and optical sights. However, existing literature provides little empirically supported information about how to incorporate the capabilities of thermal sights with those of optical sights to optimize target detection and identification during daylight with relatively clear visibility. At least three plausible and distinct possibilities exist for combining use of thermal and optical sights. First, perhaps the thermal sight should be the primary sight under all conditions because of special characteristics such as its ability to allow observers to overcome many kinds of camouflage, with the optical sight used as a backup during daylight hours in the event of a thermal sight failure. A second possibility is that the thermal sight should be the primary sight only during times of reduced visibility, with the optical sight being used as the primary sight under all unobscured daylight viewing conditions. Finally, perhaps the thermal sight should be the primary sight during reduced visibility, with the observer alternating between thermal and optical sights during good daylight conditions to take advantage of the slightly different kind of information provided by each. The three alternatives warrant investigation, not only with respect to the number of targets detected, but with attention to the time course of target detection.

A further important question related to target detection involves the potential for nontargets to be falsely detected and misidentified as targets to be attacked. These are called false alarms in the technical language of signal detection research. False alarms can result in costly errors in weapon system operation and tactics, the most obvious being an untimely loss of concealment and wasting of limited ammunition resources. Use of the thermal sight in particular may cause an inordinate number of such false alarms, since patches of bare ground heated by the sun or bare ground between vegetation can produce signatures that look very much like vehicles. Optimizing the use of thermal and optical sights not only calls for detecting as many targets as possible, but also calls for minimizing the number of false alarms. The primary question addressed by this research, then, is how one can best incorporate optical and thermal sight capabilities to maximize the number of targets detected, minimize the number of false alarms, and minimize the time necessary to detect targets.

BACKGROUND

Even a brief experience operating a tank sighting system will convince an observer that optical and thermal sights provide considerably different pictures of targets and terrain scenes. This fact alone suggests that the combined use of optical and thermal channels may increase detection performance. Such a conclusion follows from the principle of measurement by converging operations (see Garner, Hake, & Erikson, 1956), which may be generalized to predict that the combined information provided by two visual channels should more completely specify the characteristics of an object than the information provided by either channel used alone.

Past laboratory research has demonstrated that multiple and perceptually identical observations can increase the detectability of targets. Swets, Shipley, McKey, and Green (1964) showed that multiple, independent observations over time increased the detectability of a target, as measured by d' of signal detection theory, approximately as the square root of the number of observations. The same results hold when considering performance of independent observers attempting to detect targets. When observers' individual decisions are optimally combined, performance improves approximately as the square root of the number of independent observers (see Green & Swets, 1966). According to signal detection theory, multiple observations help the observer to distinguish relevant stimulus aspects (signal) from irrelevant aspects (noise) in much the same way that statistical averaging reduces the influence of random measurement errors.

Using the sensory input from both thermal and optical sights is analogous to using independent observations of a display or independent observers to evaluate a display. Input from each sight reflects a slightly different aspect, or dimension of the environment. It is a reasonable hypothesis that alternating views from optical and thermal sights should improve performance over using either sight separately. The improvement should increase as the amount of unique information provided by each sight increases, up to the limit established by the combination of completely independent information. However, any advantage of combining information from optical and thermal sights must be demonstrated empirically, and any environmental constraints placed on the use of either sight or a combination of the two must be determined.

METHOD

Observers

Thirty-five male Armor One Station Unit Training (OSUT) personnel (MOS 19E, rank E1-E4) from Fort Knox served as observers. None of the observers reported being familiar with detecting or identifying targets through thermal sights.

Stimuli

Stimuli consisted of slides taken between 0900 hours and 1500 hours at Training Area 9 of the Fort Knox reservation. Ambient temperature during that time ranged between approximately 80 and 100 degrees Fahrenheit. The brightness and contrast of the thermal sight were constantly checked and adjusted if necessary to provide the best display in the opinion of the photographer (i.e., high contrast and sharp edges of details in the sight display). One, two, or three targets were placed on the terrain at a given time, and two slides were taken with two Nikon F cameras; one photographed the target(s) and terrain through an optical sight, while the other photographed the display of a thermal sight aimed at the same point on the terrain as the optical sight. Targets were placed so that varying amounts of their area were exposed in order to produce a range of target detection performance. Targets were placed in different positions for each set of pictures taken, and the aiming point of the sights was changed so that targets appeared at various positions in the visual field. Both cameras were loaded with Kodak Ektachrome ASA 400 Daylight film for color slides.

Targets included an M151 jeep, an M60 tank, and several standard-size (4 x 5 1/2 foot) solar-heated, olive drab frontal target panels made of plywood. Vehicles had been driven for at least 15 minutes prior to being photographed, and their thermal signatures were like those that would be expected in combat under similar weather conditions. In addition to slides containing targets, seven optical and thermal slides were taken of terrain without any targets. The slides of terrain without any targets were used in control trials during the research. Two slides contained three targets, five slides contained two targets, and 14 slides contained only one target. Appendix A contains a sketch of the terrain with all target positions marked by the trial number on which a target appeared in that position. Appendix A also contains a table of the stimulus presentation sequence for each group of observers and provides range information and a target description for each trial.

For each target scene, two slides were taken through the thermal sight, one with each of two different polarity settings. On one slide, warm objects appeared darker than their surroundings (black hot), and on the other slide, warm objects appeared lighter than their surroundings (white hot). Due to technical problems, slides from only 21 target scenes (plus seven scenes of terrain without targets) yielded a usable optical sight slide and at least one usable slide taken through the thermal sight. Maximum target contrast ranged from approximately 10% to 80% for optical slides and approximately 35% to 90% for thermal slides.

Apparatus

Slides were displayed on a rear projection screen by two Kodak Ektagraphic carousel slide projectors. Two tachistoscopic shutters driven by an Iconix model 6188 shutter driver and an Iconix model 6246 timer timed presentations and controlled slide selection. Observers pointed out targets using a handheld pointer, which projected an arrow onto the screen. Observers' response positions and response times were recorded on scoring sheets consisting of photocopies of photographs of the terrain on which the target(s) appeared. Responses were timed by three Standard S-60 timers operated by the experimenter with three manual switches.

Procedure

Observers entered the experimental room singly and sat behind a desk, with their eyes approximately 196 cm from the rear projection screen on which slides of the sight pictures were displayed. At this distance, most targets subtended .2° to .4° of visual angle both horizontally and vertically. The targets ranged from approximately .2° to approximately .8° of visual angle vertically and from approximately .2° to approximately 1.2° of visual angle horizontally. The projected size of the targets was roughly the same as the size they would subtend while using the actual sights at the ranges at which the target slides were taken. From the observers' position, the entire display subtended approximately 16° of visual angle horizontally and 8.6° of visual angle vertically. One or two slides subtended smaller total visual angles because of misalignment of the camera with the sight when the slides were taken.

Observers saw a large color photograph of the entire target area and were told that it was the terrain in which targets could appear. The room was darkened and observers received instructions that they would see slides taken through either an optical sight or a thermal sight, or that they would see an alternating pair of slides of exactly the same scene--one taken through a daylight sight and another taken through a thermal sight. They were told that each scene contained anywhere from zero to three targets, that they would have 30 seconds to find all targets on the slide, and that they were to search until told to stop. Observers received instructions on pointing out targets with the hand-held pointer and were instructed to say "target" loudly and clearly as they pointed to each suspected target. Observers saw two slides of terrain taken through a thermal sight; on the first slide the sight polarity was set on black hot, and on the second the polarity was set to white hot. The experimenter then demonstrated the procedures for pointing out a target. Observers were then shown a daylight slide of a scene containing a partially concealed tank and were allowed to go through the procedures of searching for and pointing out a target. If they were unable to detect the target, it was pointed out to them and they were asked to go through the procedures for pointing out the target to the experimenter. Observers were told that after each trial they would be told how many targets there were and where they were, and each observer was asked if he had any questions. When all questions were answered, observers were informed that they would be timed and were asked to respond as quickly and accurately as they could.

Each trial began when the experimenter alerted the observer that a slide was about to appear. The slide for that trial appeared on the screen as the timers were started. The observer searched the display until he had reported three targets or until 30 seconds elapsed. Each time a target was reported, the experimenter stopped one of the timers and marked the position indicated by the observer on a scoresheet. After each trial, the experimenter recorded the time required for each response and informed the observer of all correct detections. The experimenter then pointed out any undetected targets and false alarms to the observer.

When only optical sight or thermal sight slides were shown, the slides remained on continually until the observer was given knowledge of results. When optical sight and thermal sight slides were alternated, the first slide appeared (centered on the screen) for 3.4 seconds, followed by a blank screen for .4 second.[1] The second slide then appeared (also centered on the screen)

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[1]The .4-second delay was inserted to simulate the time required for the observer to move his eye between an optical sight eyepiece and a thermal light eyepiece mounted fairly closely to one another.

and remained on for 3.4 seconds, followed by a blank screen for .4 second. The cycle then repeated until the trial was over and knowledge of results was provided to the observer. Observers received knowledge of results, including correct detections, missed targets, and false alarms, on both optical and thermal sight pictures following a trial on which optical and thermal slides alternated. The first slide shown to the first 20 observers was always a thermal sight slide for trials on which optical and thermal sight pictures alternated; the first slide shown to the last 15 observers was always an optical sight slide on trials during which thermal and optical views alternated.

All observers received trials under five different sight conditions: optical sight, thermal sight with the polarity set to white hot, thermal sight with the polarity set to black hot, optical sight alternating with thermal sight with the polarity set to white hot, and optical sight alternating with thermal sight with the polarity set to black hot. Observers were sequentially assigned to one of five different groups; each group received a different ordering of sight conditions on successive trials. The first group received a random ordering of sight conditions over successive trials; the other groups received variants of the same ordering so that each group received a different sight condition on a given trial.

RESULTS AND DISCUSSION

After the data were tabulated, the data from Trials 16, 21, and 24 were excluded from further analysis; performance under all conditions was perfect or nearly perfect on Trials 21 and 24 (the targets were very near, were relatively unobscured, and had extremely high contrast in both cases) and performance was uniformly poor on Trial 16 (the target was almost completely obscured by vegetation and target-to-background brightness contrast was extremely low). Observers' first responses on each trial containing targets were analyzed by classifying them as hits, misses, or false alarms, and the response times for the first "target" responses on each trial were also analyzed. Data from trials containing no targets were excluded from the analysis, since there are only two possible response categories rather than three for such trials. Catch trials were intended to promote a fairly conservative placement of observers' criteria, similar to that required in searching for targets on the battlefield when targets may or may not be present in a given area. The analyses concentrated on first responses because the first response is the most critical on the battlefield.

Data were collapsed across the two thermal polarities (black hot, white hot) since Sandler's *A*'s failed to show significant differences in performance between the two polarity settings, either when a thermal display was shown alone (*A* = .56, *df* = 9, n.s.) or when thermal and optical slides alternated (*A* = .92, *df* = 10, n.s.).[2] There was no significant relationship between target detection performance and number of targets, so all trials were analyzed together.

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[2]Results for target identification may differ from those obtained for target detection in this search.

Collapsing data across black hot and white hot thermal displays left three main sight conditions: optical sight alone (the Optical condition), thermal sight alone (the Thermal condition), and alternating optical sight and thermal sight (the Alternating condition). Figures 1 and 2 show plots of the proportion of first response detections and false alarms over all three sight conditions for all trials containing targets. Figures 3 and 4 show the corresponding response times.[3] The figures also show the regression equation and r^2 value for each graph. Examination of these figures reveals that performance in all conditions is highly variable over trials. The amount of variability is not surprising considering the number of variables that have gained some support as having an impact on target detection (see, e.g., Maxey, Ton, Warnick, & Kubala, 1976).

Figure 5 provides a clearer indication of target detection performance for the three different sight conditions than can be obtained from evaluating hit and false alarm performance separately. It shows the proportion of "target" or "yes" responses that were hits over trials for each sight condition separately. For each condition Figure 5 includes the plot of the regression line fit to the means over trials, the regression equation, and the r^2 value. The mean performance scores on each trial for all conditions were subjected to a repeated measures analysis of variance (ANOVA) (Bruning & Kintz, 1968). The ANOVA table is presented in Appendix B, along with summary tables for all ANOVAs done. The analysis revealed a significant effect of sight condition ($F = 5.8$, $df = 2, 34$, $p < .01$). This significance reflects higher performance in the Alternating sight condition than in the other two conditions; Tukey's HSD shows that the Alternating sight condition produced significantly higher performance than either the optical sight alone ($p < .05$) or the thermal sight alone ($p < .01$). While the data are indeed highly variable, detection performance when alternating between the two sights significantly exceeds detection performance with either sight alone over the length of training provided in the present research.

Figure 5 presents a rather puzzling paradox; while performance with the thermal sight increases over trials, performance with the optical sight actually drops over trials! Both of these effects can be shown to be significant by comparing performance on the first four and the last four trials for each sight condition. (These are approximately the first and last quarter of the trials.) Performance on the first four trials with the optical sight is significantly higher than on the last four trials by a two-tailed t ($t = 2.50$, $df = 6$, $p < .05$); conversely, performance on the last four trials with the thermal sight is higher than on the first four trials by a two-tailed t ($t = 2.71$, $df = 6$, $p < .05$). The same result occurs if one compares performance on the first and the last third of the trials for each condition. One possible interpretation is that the increase in performance in the Thermal condition represents a learning effect, while optical performance drops because of increased difficulty of late versus early trials in the Optical condition. Two pieces of information support this conclusion for the Optical condition. First, target-to-background contrast in the Optical condition was

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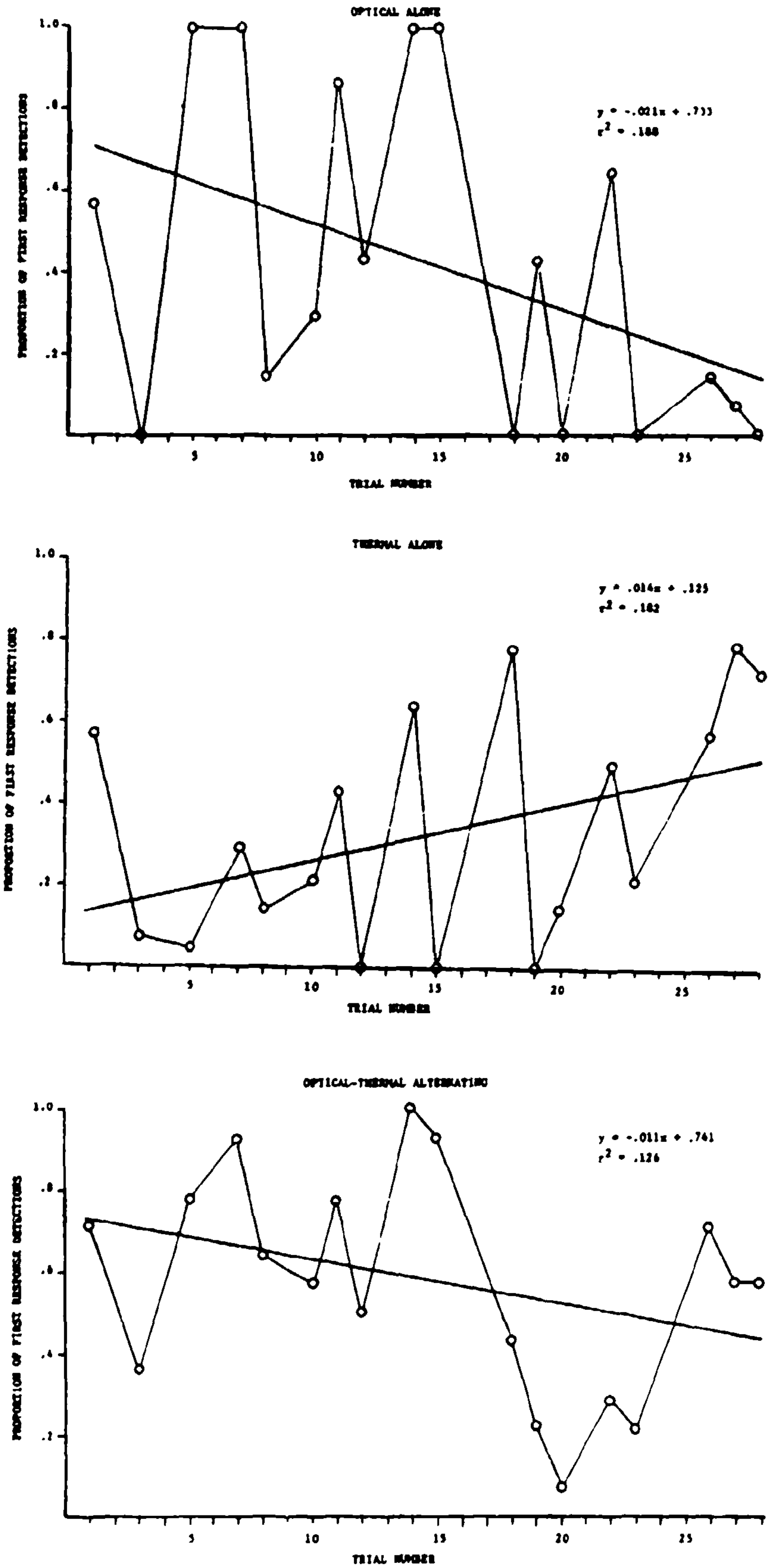
[3] The figures for response times may not contain points for all 18 trials on which data were analyzed. When the hit probability or false alarm probability for a trial was zero, the point representing the time for that trial was not included on the graph or in the computation of the regression line indicated on the graph, since no times were available.



<u>Figure 1</u>. Proportion of first response detections over trials for each sight condition.

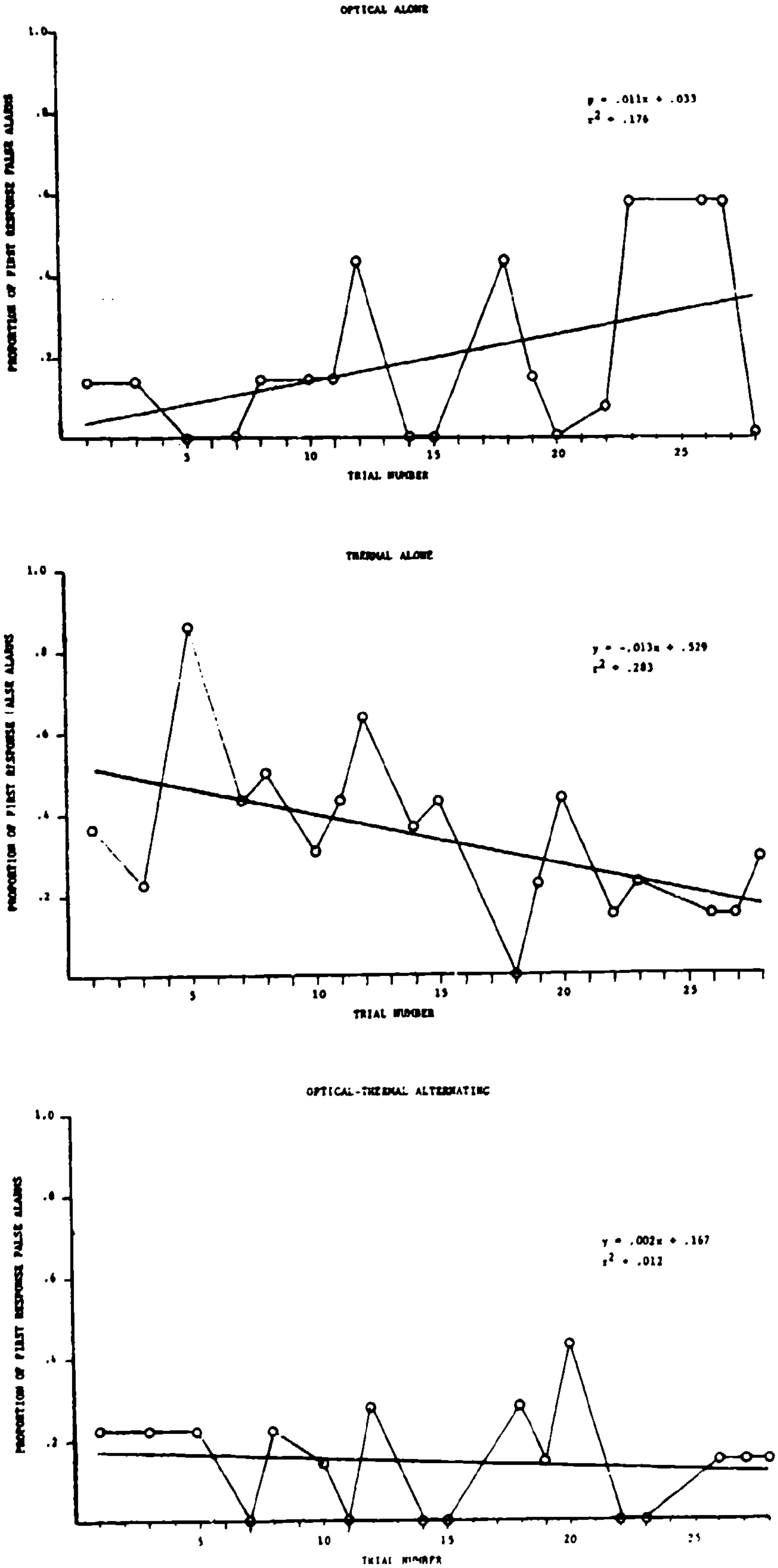


Figure 2. Proportion of first response false alarms over trials for each sight condition.

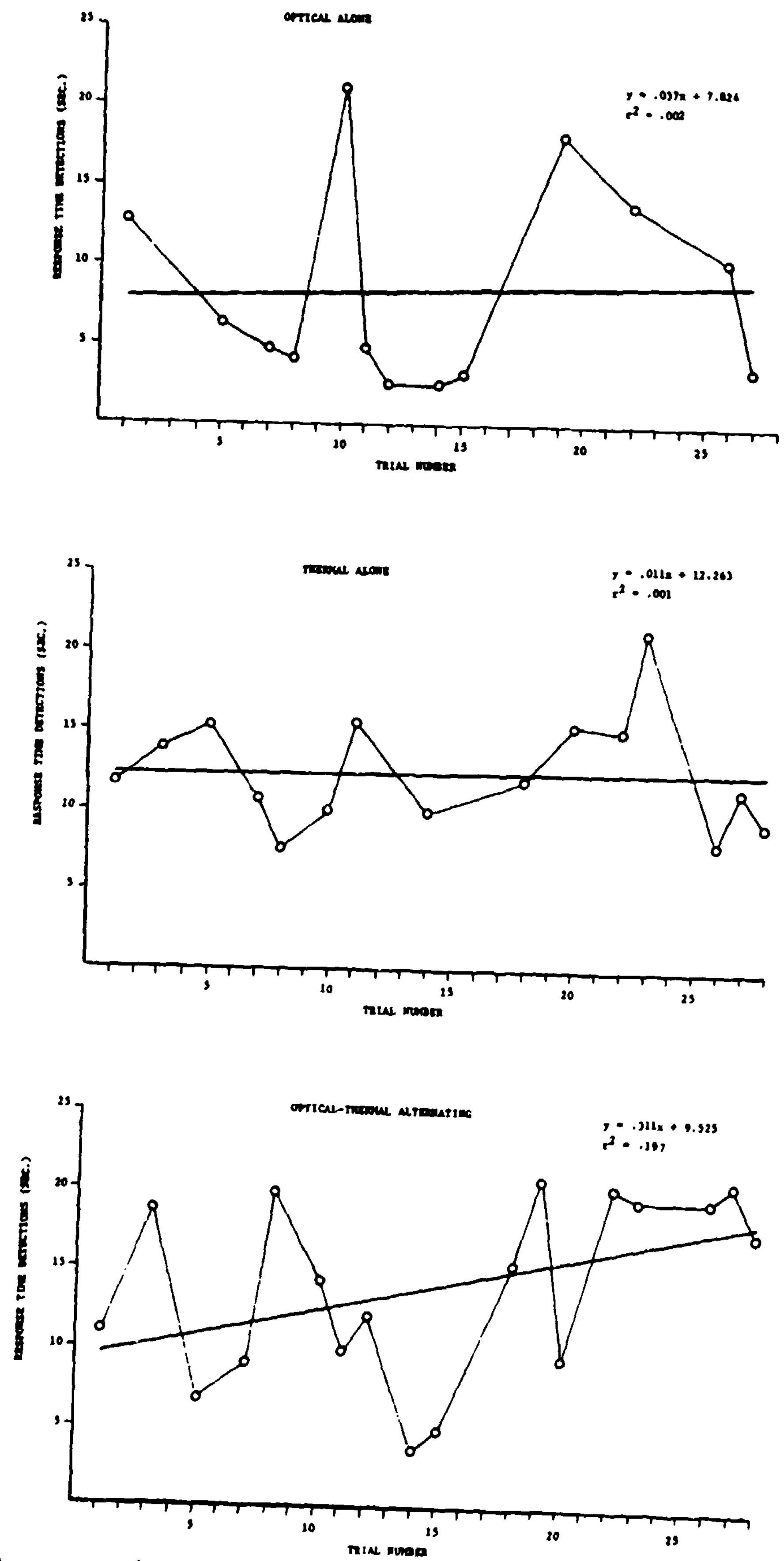


Figure 3. Response times for correct detections over trials for each sight condition.

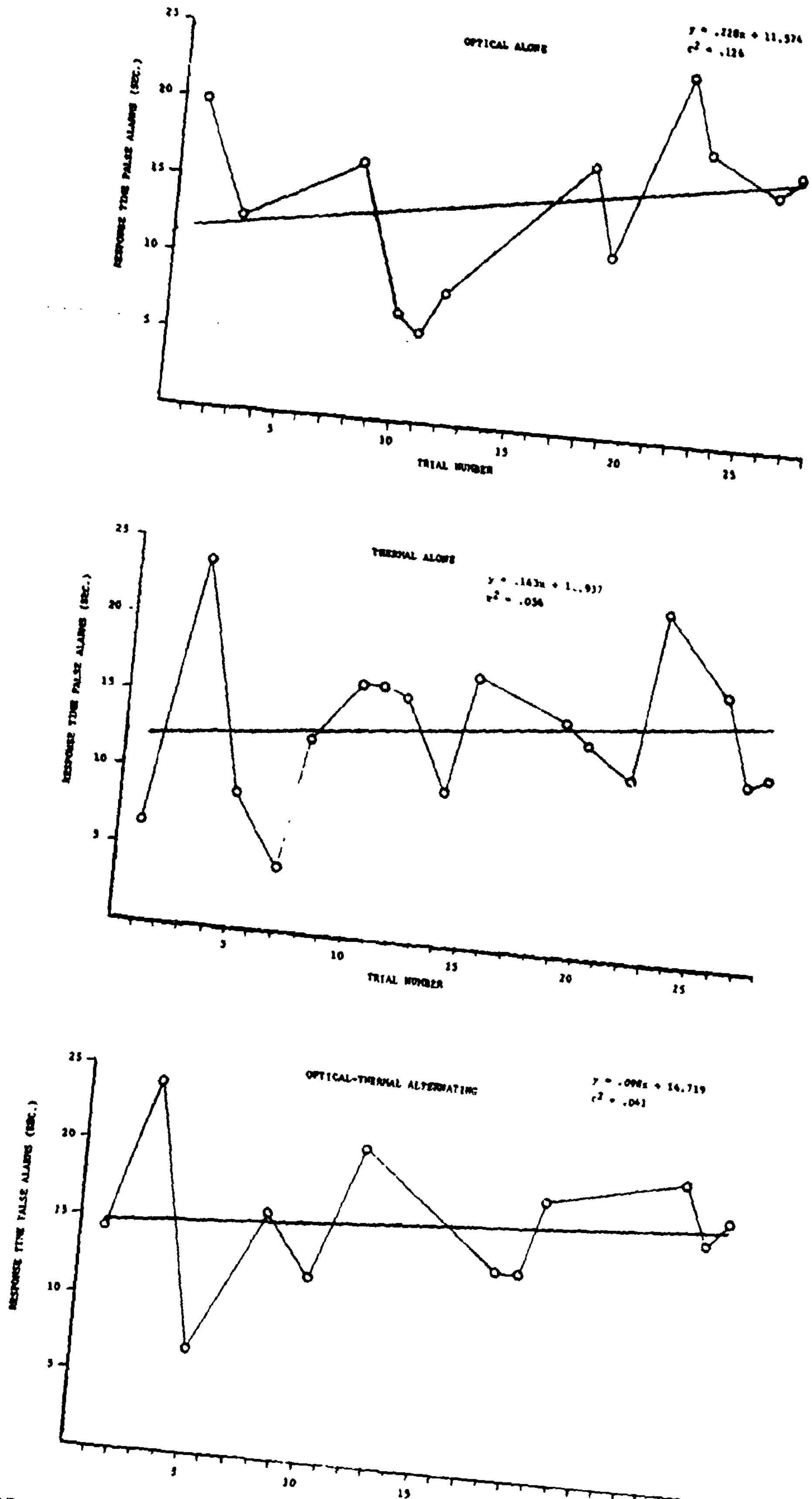


Figure 4. Response times for false alarms over trials for each sight condition.

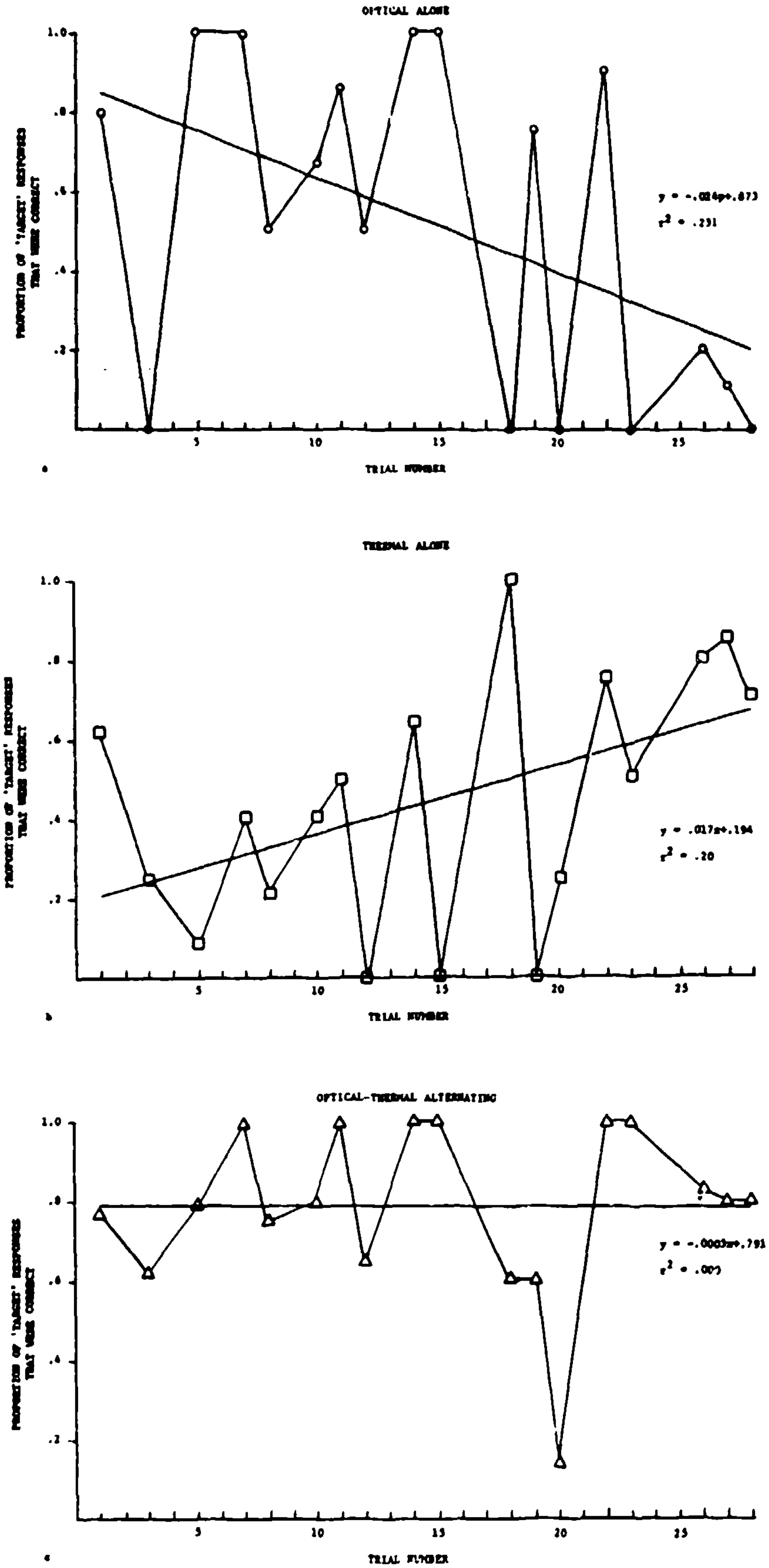


Figure 5. Proportion of "target" responses that were correct over trials for each sight condition.

much lower for the last four than the first four trials (17.5% for the last four trials versus 37.5% for the first four trials), with contrast calculated by the following equation:

$$C = \frac{|L_o - L_b|}{L_b} \times 100\%$$

where L_o is the luminance of the object and L_b is the luminance of the background. Given the strong relationship between target-to-background contrast and detection that has been demonstrated innumerable times (see, for example, Chapanis, 1949; Graham, 1965) and the significant relationship between target-to-background contrast demonstrated in this research (see Table 1), it is clear that this variable had an effect on performance. Second, the proportion of target perimeter visible in the last four trials was lower than for the first four trials. One can see from Table 1 that this variable had a marginally significant effect on target detection performance in this research, and almost certainly shared some responsibility, along with contrast, for the declining performance over Optical trials. The combination of these variables may well have offset any learning that occurred with practice.

Further examination of Table 1 reveals that neither contrast nor proportion of target perimeter visible were significantly related to thermal detection performance. Even if these variables had affected performance, their values were relatively homogeneous over the first four and last four trials. One must conclude that either learning occurred over trials, which is certainly feasible given observers' initial unfamiliarity with the thermal sight, or that detection was driven by some variable or variables more abstract than the fundamental visual variables of contrast and target perimeter visible. The possibilities provide interesting and important questions for further research.

In addition to target detections, response times to correct detections and to false alarms were analyzed separately over all trials. Since no detections or false alarms occurred on some trials for one or more sight conditions, there were no average times for those trials to input to the repeated measures analysis of variance. Missing data values for each sight condition were estimated from the regression equation for that sight condition. The analyses showed a significant difference among correct detection times for the three conditions ($F = 7.79$, $df = 2, 34$, $p < .005$). The significant F reflected that the times for the Optical condition were significantly faster than for the Thermal condition ($p < .05$ by HSD) and also were faster than those in the Alternating condition ($p < .01$ by HSD). Response times for the Thermal and Alternating conditions did not differ significantly. False alarm times showed no significant differences among sight conditions ($F = 1.12$, $df = 2, 34$, $p < .20$).

Thus, while the probability of detecting a target is greater when alternating between the optical and thermal sights than when using either sight separately, detecting targets correctly was fastest when using the optical sight. These data are summarized in Table 2. Decisions about which sighting condition is "best" in combat must consider the speed-accuracy trade-off in the three different modes and sight choice must clearly be mediated by the tactical situation.

TABLE 1

CORRELATION MATRIX OF TARGET DETECTION PARAMETERS AND REACTION TIMES WITH SEVERAL STIMULUS PARAMETERS

	OPTICAL DETECTIONS (N=18)	THERMAL DETECTIONS (N=18)	ALTERNATING DETECTIONS (N=18)	OPTICAL DETECTION TIMES (N=13)	THERMAL DETECTION TIMES (N=15)	ALTERNATING DETECTION TIMES (N=18)
NR. TARGETS	-.09	.00	-.05	-.01	-.04	-.22
OPTICAL CONTRAST OF TARGET WITH HIGHEST CONTRAST	.34	-.11	.30	-.36	-.32	-.28
PROPORTION OF TARGET PERIMETER VISIBLE FOR MOST EXPOSED TARGET (OPTICAL)	.34	-.04	.17	-.12	.04	-.44
THERMAL SIGHT CONTRAST OF TARGET WITH HIGHEST CONTRAST	.14	-.08	.03	.04	-.24	-.02
PROPORTION OF TARGET PERIMETER VISIBLE FOR MOST EXPOSED TARGET (THERMAL)	-.25	.41	.12	.23	-.31	.08

	OPTICAL HITS/ YESES (N=16)	THERMAL HITS/ YESES (N=18)	ALTERNATING HITS/ YESES (N=18)	AVERAGE OPTICAL RESPONSE TIMES (N=16)	AVERAGE THERMAL RESPONSE TIMES (N=18)	AVERAGE ALTERNATING RESPONSE TIMES (N=18)
NR. TARGETS	.20	.16	-.36	-.14	-.30	.01
OPTICAL CONTRAST OF TARGET WITH HIGHEST CONTRAST	.66**	-.22	.01	-.48*	-.37	-.27
PROPORTION OF TARGET PERIMETER VISIBLE FOR MOST EXPOSED TARGET (OPTICAL)	.53*	-.10	-.12	-.37	-.38	-.25
THERMAL SIGHT CONTRAST OF TARGET WITH HIGHEST CONTRAST	.41	-.18	-.16	-.23	-.31	.03
PROPORTION OF TARGET PERIMETER VISIBLE FOR MOST EXPOSED TARGET (THERMAL)	-.33	.46	-.17	.27	-.34	.11

*p<.05
**p<.01

Note. One correlation was significant at or beyond the .01 level properly used as the significance level for this number of correlations.

TABLE 2
TARGET DETECTION SPEED AND ACCURACY PERFORMANCE
OVER ALL TRIALS CONTAINING TARGETS

PERFORMANCE	SIGHT CONDITION		
	Optical	Thermal	Alternating
ACCURACY (PROPORTION OF TRIALS)			
FIRST RESPONSE HITS	.421	.341	.571
FIRST RESPONSE FALSE ALARMS	.216	.203	.125
AVERAGE RESPONSE TIME (SEC.)			
CORRECT DETECTIONS	8.43	11.48	13.62
FALSE ALARMS	14.98	14.07	16.18

After additional consideration of the stimulus materials and data, it became clear that the context in which targets appeared affected performance. Trials containing targets in dense vegetation and those containing targets in an area containing open or grassy areas (mixed terrain) were analyzed separately.

Targets in Dense Vegetation

Data for dense vegetation trials are plotted, along with the regression lines for each of the three conditions, in Figures 6 through 9. The detection data for dense vegetation can be summarized by considering the proportion of "target" or "yes" responses that were hits on each trial. These proportions, averaged across pairs of trials to smooth the curves, are graphed in Figure 10. An analysis of variance conducted on these data revealed a significant effect of sight condition ($F = 6.25$, $df = 2, 14$, $p < .025$). The significant F reflects superior performance in the Alternating sight condition compared with performance in the Optical condition ($p < .01$ by HSD). All other pairwise differences were nonsignificant. Analysis of response times (with missing values estimated from the regression equation) showed no significant effects of sight condition on response times for either correct detections or false alarms. Average detection proportions and response times for targets in dense vegetation are shown in Table 3.

One must be cautious about drawing the conclusion that there is no difference in detection times, however. The analysis of correct detection times revealed a marginally significant effect ($F = 2.76$, $df = 2, 14$, $p < .10$), reflecting a faster average detection time with the optical sight than with alternating optical and thermal sights (8.26 sec. for optical vs. 14.68 sec. for alternating). Although this difference failed to reach significance at the .05 level, further research might reveal a difference since the number of trials in dense vegetation was small ($n = 8$). Pending further research on response

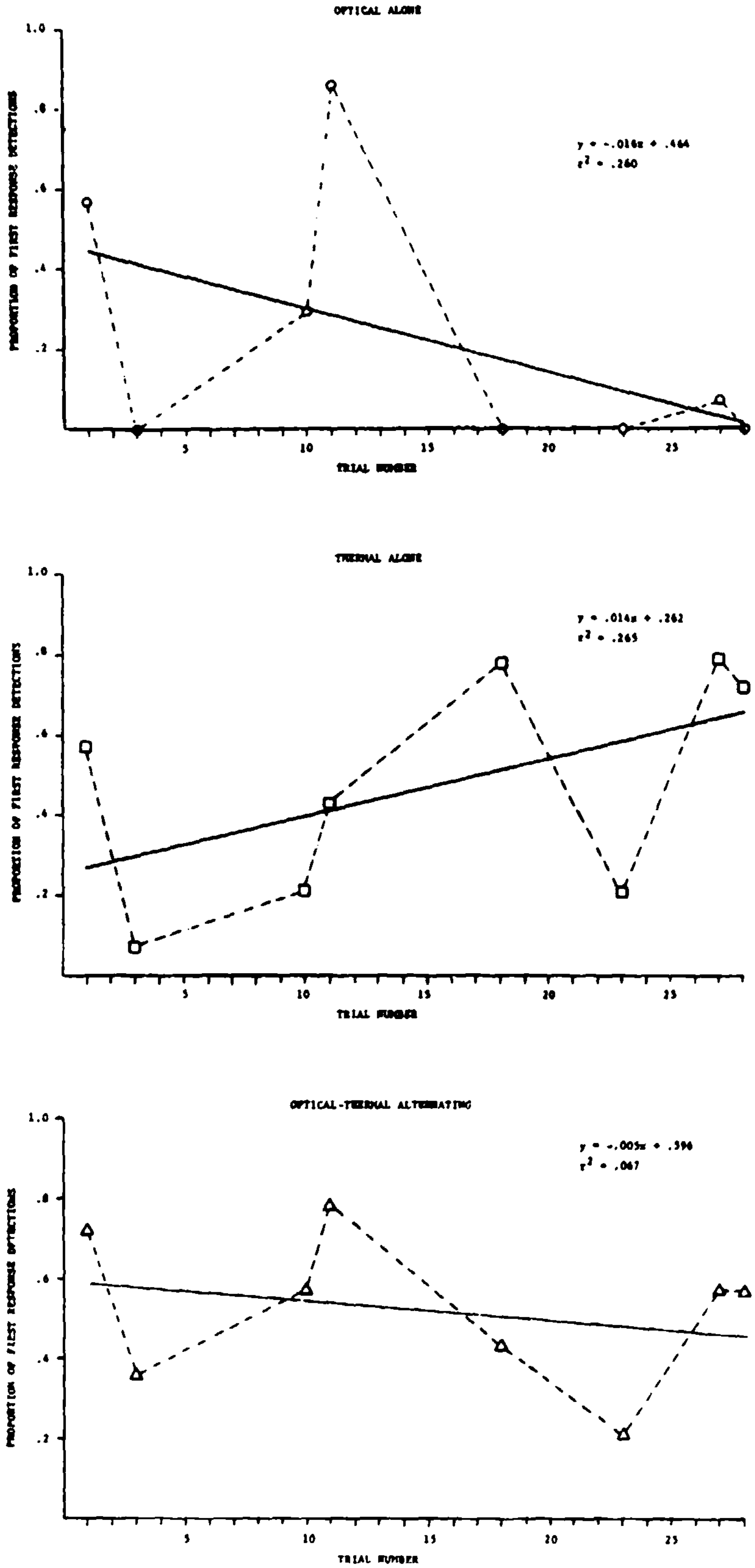


Figure 6. Proportion of first response detections over trials containing targets in dense vegetation for each sight condition.

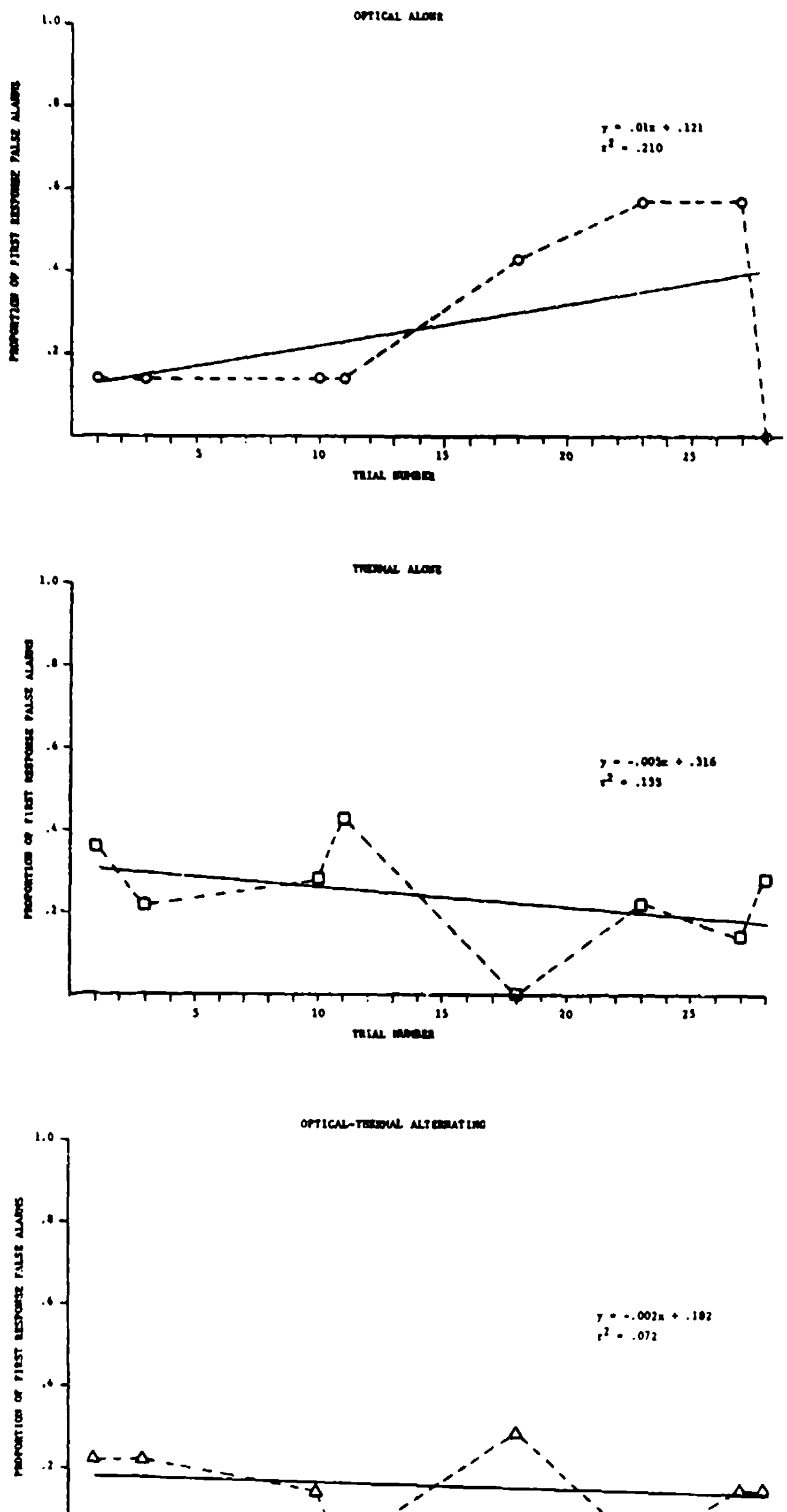


Figure 7. Proportion of first response false alarms over trials containing targets in dense vegetation for each sight condition.

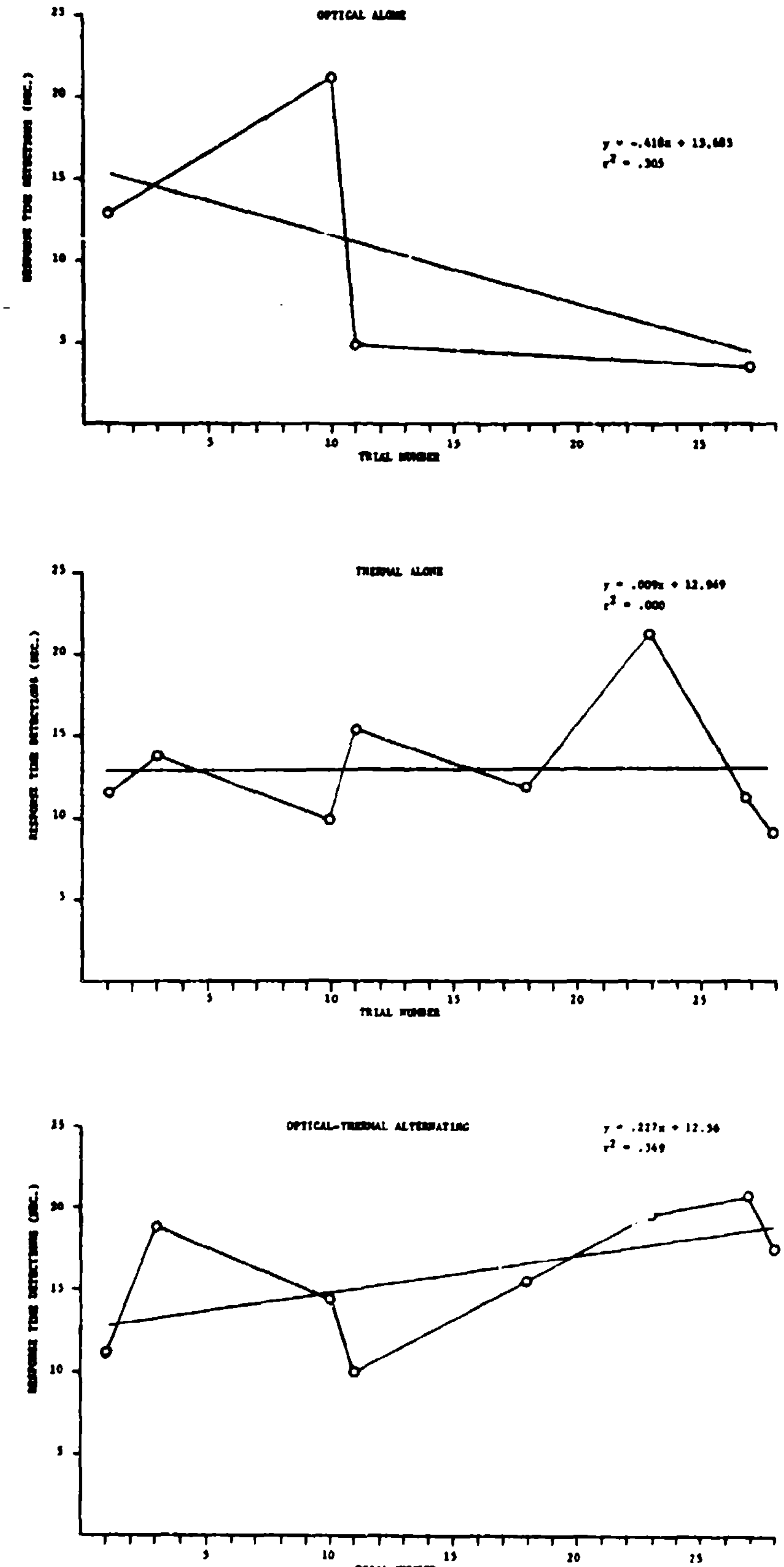


Figure 8. Response times for correct detections over trials containing targets in dense vegetation for each sight condition.

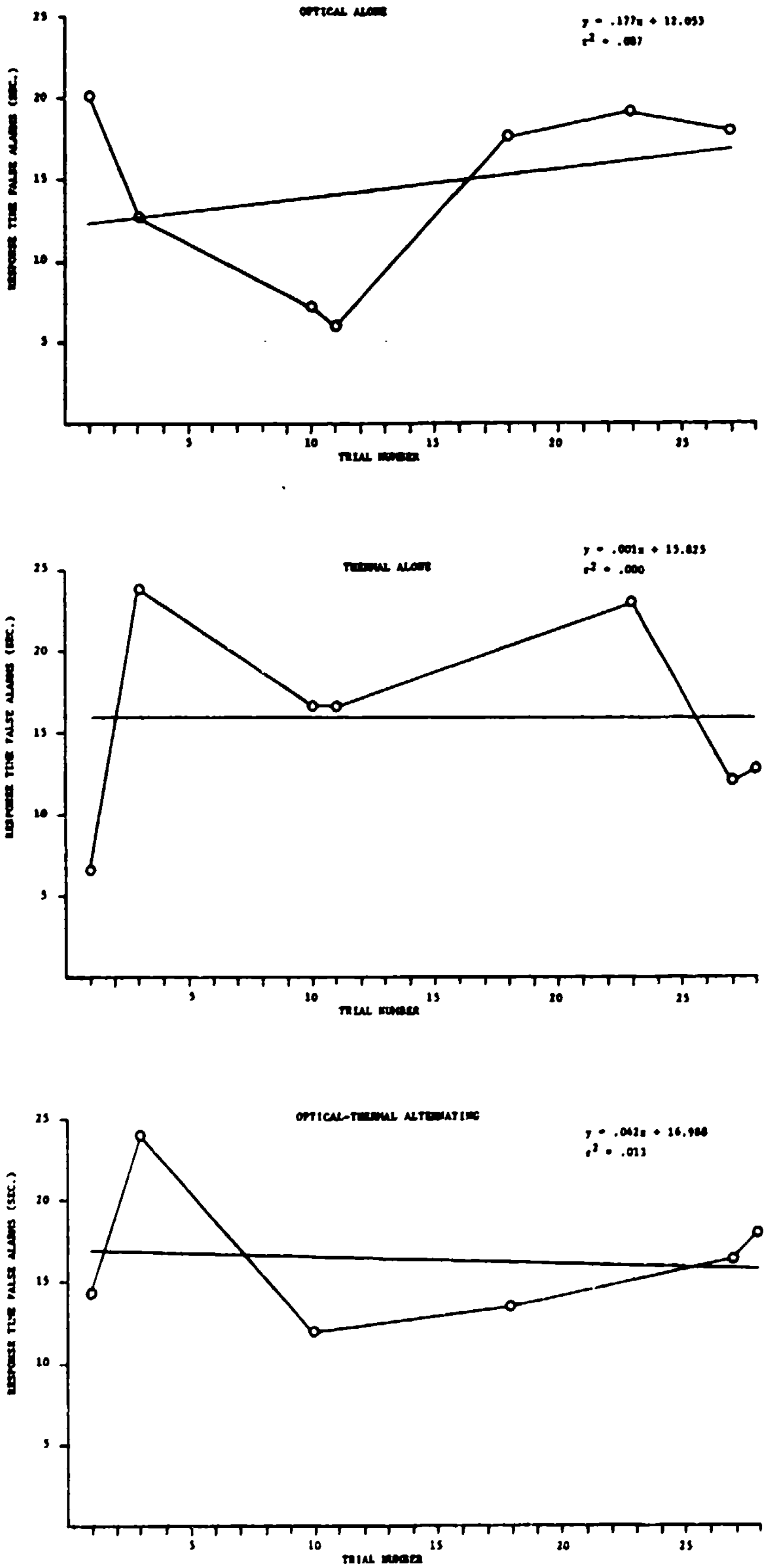


Figure 9. Response times for false alarms over trials containing targets in dense vegetation for each sight condition.

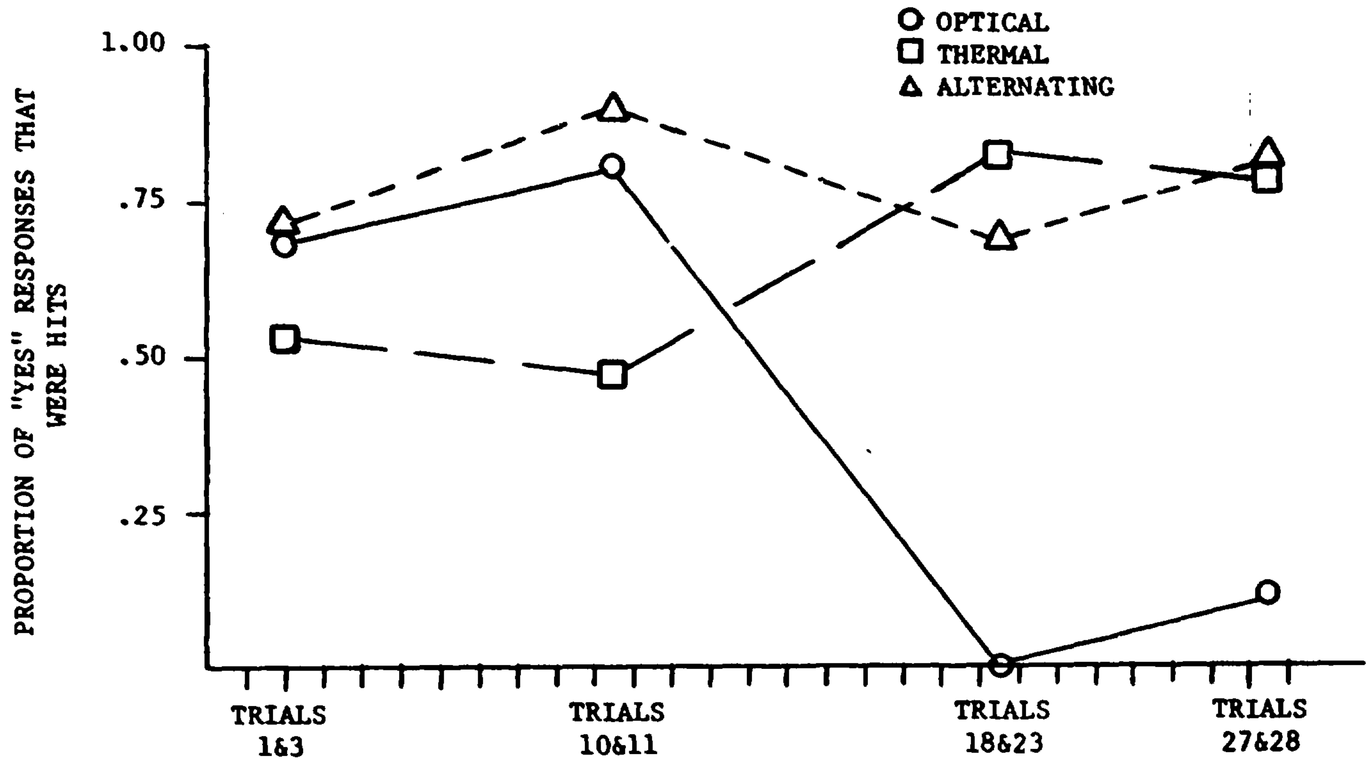


Figure 10. Proportion of "yes" responses that were correct across pairs of trials in dense vegetation.

speed, Armor crewmen should alternate using thermal and optical sights during daylight hours to detect targets in dense vegetation. Although it may be tempting to draw conclusions about increasing performance over trials with the thermal sight, performance on the last four trials does not significantly exceed performance on the first four trials.

TABLE 3
AVERAGE RESPONSE PROPORTIONS AND RESPONSE TIMES FOR TARGETS IN DENSELY VEGETATED TERRAIN
(MISSING RESPONSE TIMES ESTIMATED BY LINEAR REGRESSION)

PERFORMANCE	SIGHT CONDITION		
	Optical	Thermal	Alternating
ACCURACY (PROPORTION OF TRIALS)			
FIRST RESPONSE DETECTIONS	.22	.47	.53
FIRST RESPONSE FALSE ALARMS	.27	.24	.14
AVERAGE RESPONSE TIMES (SEC.)			
DETECTIONS	8.26	13.25	14.68
FALSE ALARMS	14.73	15.84	16.36

Targets in Mixed Terrain

Performance detecting targets in mixed terrain differs slightly from that in dense vegetation. Figures 11 through 14 show plots of the proportion of first response detections, response times for first response detections, proportion of first response false alarms, and response times for first response false alarms. A repeated measures analysis of variance showed a significant effect of sight condition ($F = 4.44$, $df = 2, 18$, $p < .025$), reflecting that detection performance with the thermal sight alone was significantly poorer than in the other two conditions (both $p < .01$ by HSD). Pairwise comparisons revealed no significant difference between Optical and Alternating sight conditions. Figure 15 shows the detection results graphically in a plot of the proportion of "target" or "yes" responses that were hits in each condition. As in Figure 10, data were averaged across pairs of trials in Figure 15 to smooth the curves somewhat.

Analysis of response times in mixed terrain revealed a significant effect of sight condition ($F = 4.36$, $df = 2, 18$, $p < .05$). This reflects faster detection times when using the optical sight alone than when alternating thermal and optical sights ($p < .05$ by HSD). Detection times with the thermal sight alone did not differ significantly from those in the other two sighting conditions, nor were there any differences among any of the sight conditions with respect to false alarm times. Table 4 shows the speed-accuracy trade-off for mixed terrain.

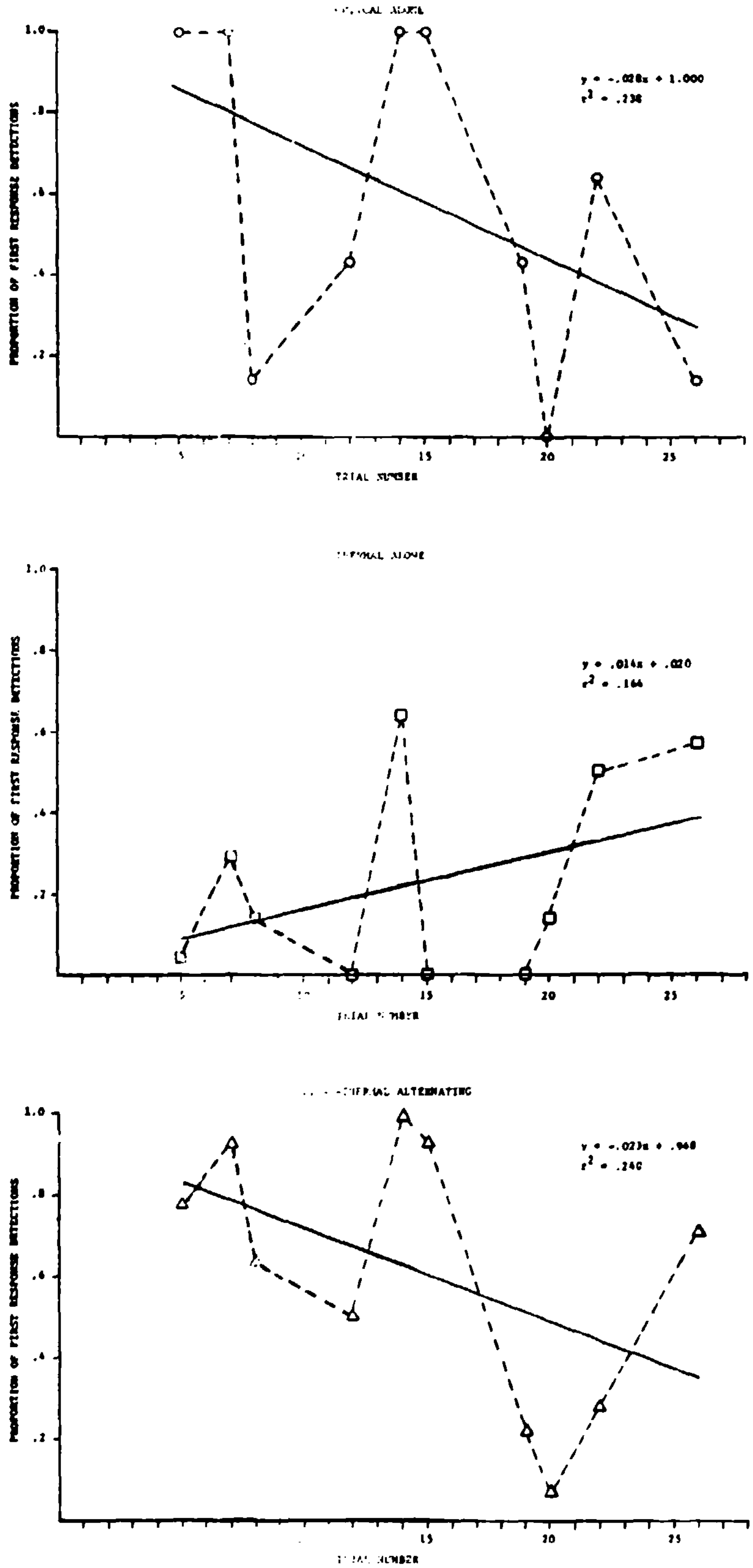


Figure 11. Proportion of first response detections over trials containing targets in open terrain for each sight condition.

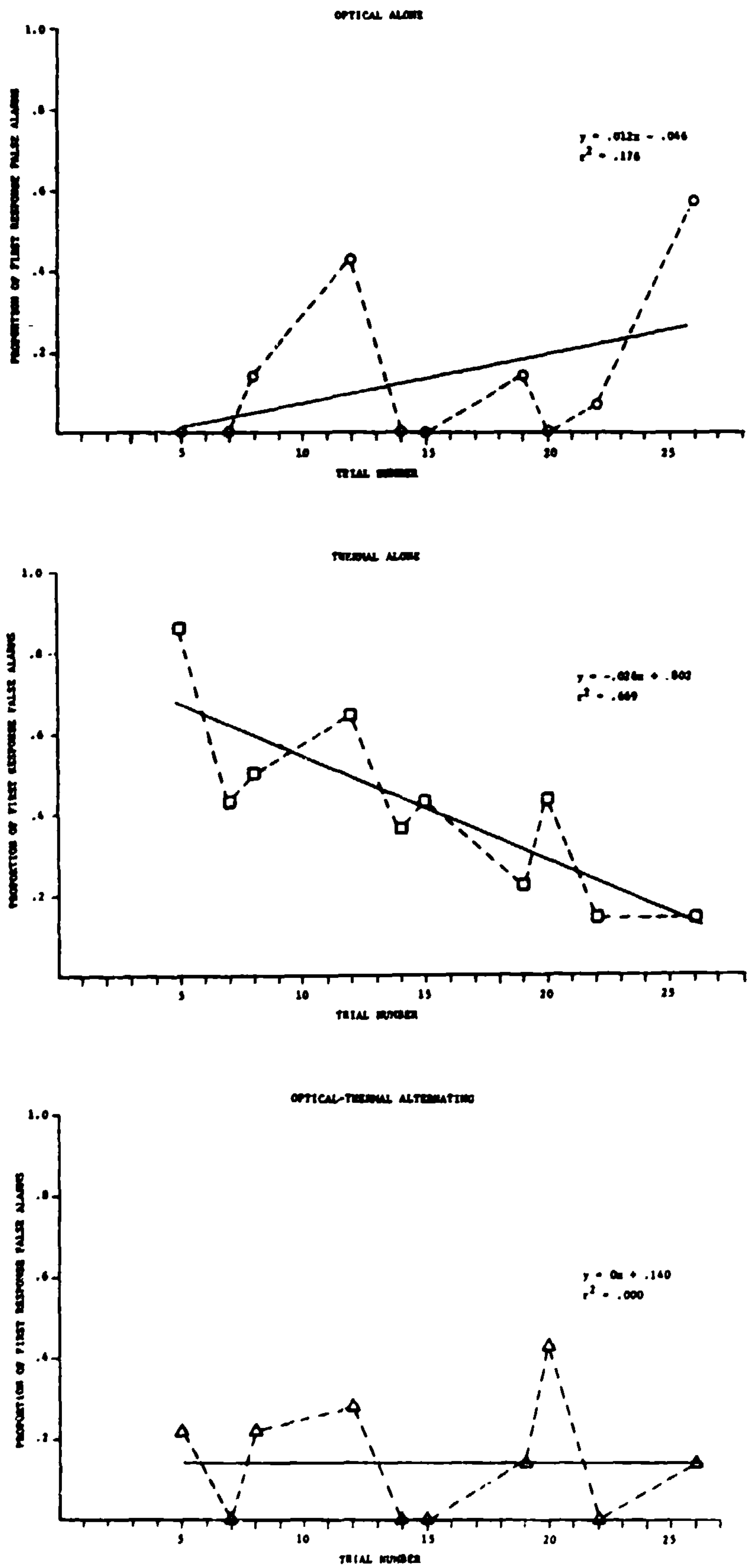


Figure 12. Proportion of first response false alarms over trials containing targets in open terrain for each sight condition.

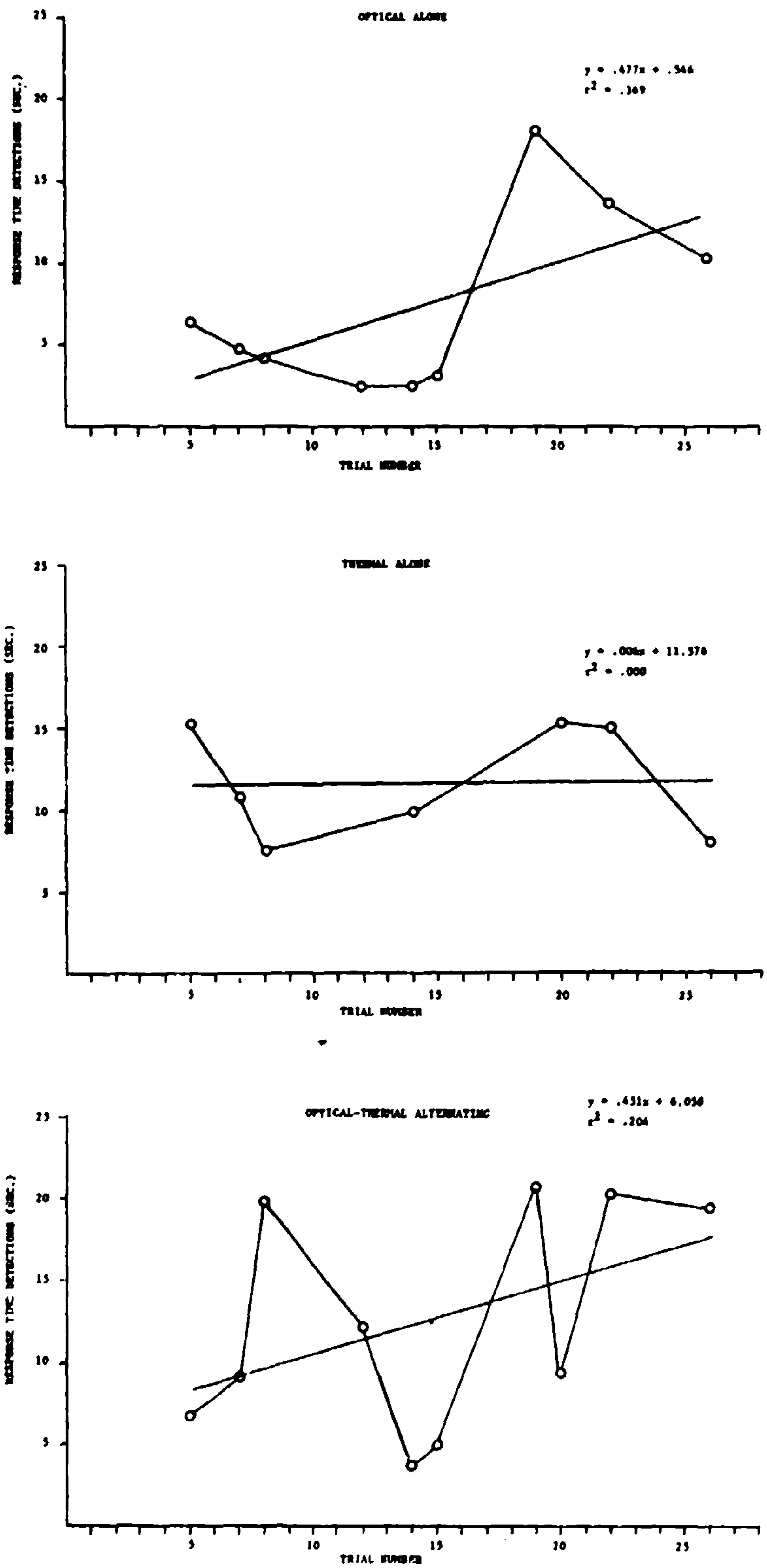


Figure 13. Response times for correct detections over trials containing targets in open terrain for each sight condition.

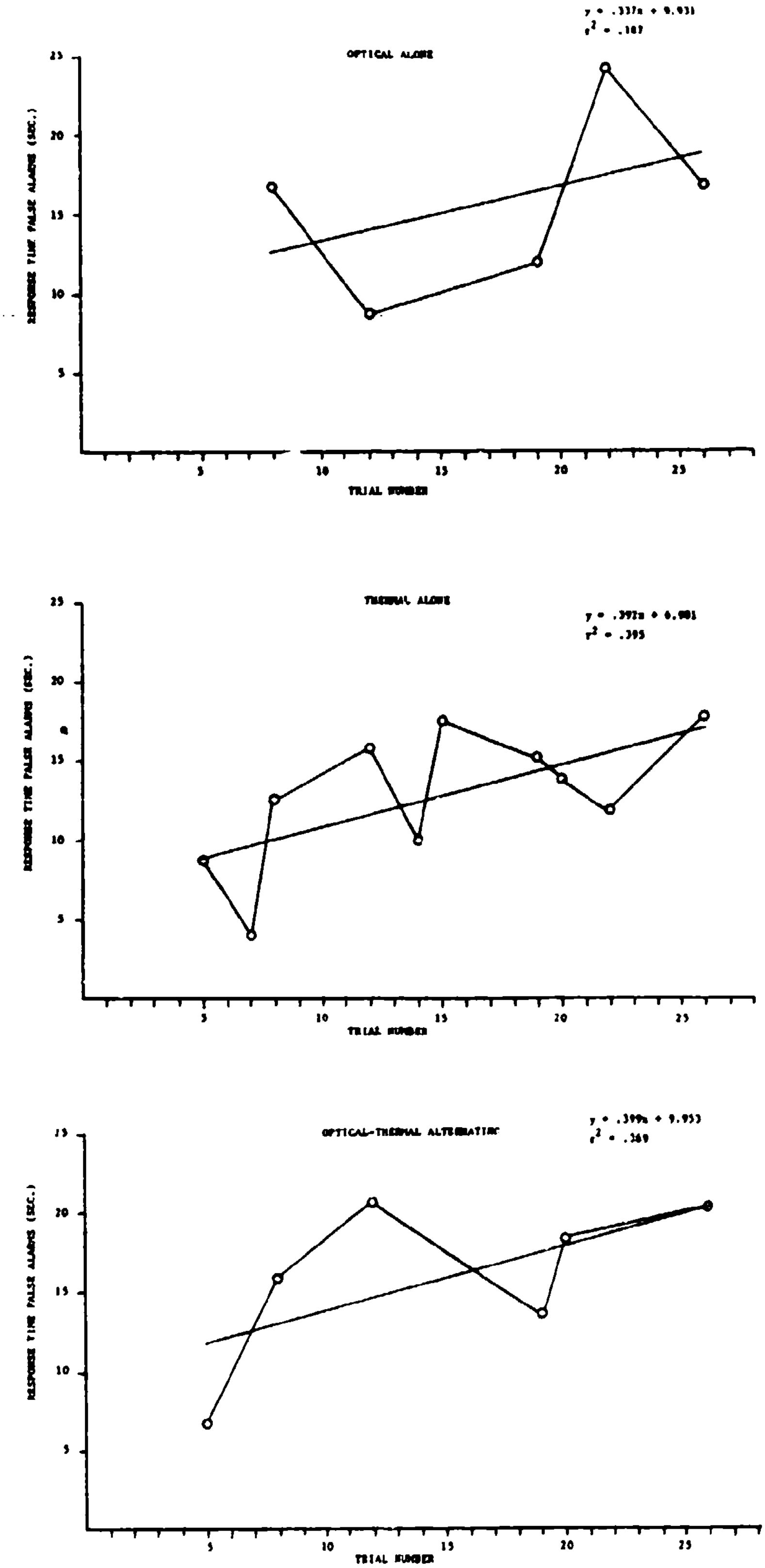


Figure 14. Response times for false alarms over trials containing targets in open terrain for each sight condition.

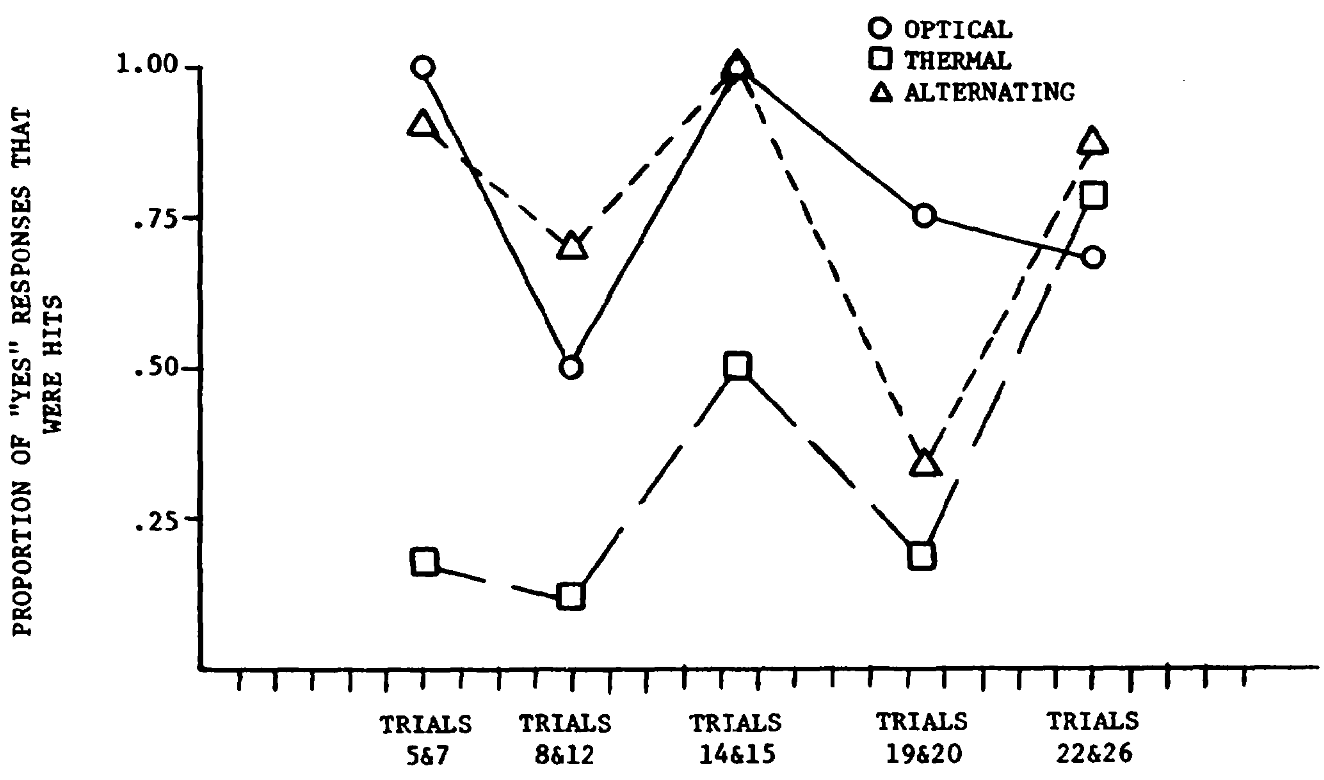


Figure 15. Proportion of "yes" responses that were correct across pairs of trials in open terrain.

TABLE 4
AVERAGE RESPONSE PROPORTIONS AND RESPONSE TIMES FOR TARGETS
IN MIXED TERRAIN (MISSING RESPONSE TIMES ESTIMATED BY LINEAR REGRESSION)

PERFORMANCE	SIGHT CONDITION		
	Optical	Thermal	Alternating
ACCURACY (PROPORTION OF TRIALS)			
FIRST RESPONSE DETECTIONS	.58	.24	.61
FIRST RESPONSE FALSE ALARMS	.14	.41	.14
AVERAGE DETECTION TIMES (SEC.)			
DETECTIONS	8.18	11.72	13.78
FALSE ALARMS	14.92	12.87	15.85

Targets on slides containing mixed terrain were located in open areas and around the edges of treelines and clumps of trees. Based on the results reported here, it seems clear that the optical sight is the sight of choice in terms of speed and accuracy when searching in such areas during daylight.

One important question is why the best sight to use seems to be different for the two kinds of terrain. It is possible that the detection superiority produced by alternating the thermal and optical sights in dense vegetation is a product of at least two factors. First since thermal sights operate by detecting temperature differences, one would expect hot vehicles to show up in cool, shady areas quite well during the day. While vegetation conceals targets optically, it shades the terrain and produces large temperature differences during the day, which effectively enhances target detection. The Alternating sight condition is probably effective under these circumstances because the optical view allows observers to reject patches of earth between vegetation that have been heated by the sun and look much like targets through the thermal sight, avoiding many false alarms. On bare terrain or around the edges of woodlines, however, the sun quickly heats the ground (especially with high ambient temperatures, as there were when the slides for this research were taken), and the bases of targets tend to blend into the hot ground. This perceptually disrupts the figure-ground relationship between the target and the ground on which it stands, producing a difficult target detection task. This effect makes targets phenomenally difficult to distinguish and merits consideration in future investigations of performance with the thermal sight in open terrain.

Theoretical Considerations

A point of less immediate interest for practical application involves the quantitative aspects of the Alternating optical and thermal condition versus the Optical or Thermal condition. Expected detection performance when optical and thermal views were alternated was greater than the average expected performance of the other two conditions, and was greater by a factor of approximately $\sqrt{2}$. This is the result one would expect from the summation of detection probability from two independent channels, analogous to the $\sqrt{2}$-increase in detection performance provided by input from two independent observers. This is also consistent with the conclusion in Swets et al. (1964) that target detectability increases as the square root of the number of observations (here, the number of different sight displays). In the same way, one would expect a reduction in the probability of false alarms by a factor of approximately $1/\sqrt{2}$ as information from two independent channels is combined. Table 5 shows values along the regression lines for the Alternating sight condition, as well as along the regression line of the average performance with the other two sights. While further research must be done before attempting to use these data to estimate parameters in any large-scale modeling of combat, performance when thermal and optical sight pictures are alternated while searching dense vegetation can be expected to exceed the performance yielded when independent optical and thermal performances are averaged.

TABLE 5

AVERAGE PERFORMANCE OF ALTERNATING SIGHT CONDITION AND AVERAGE PERFORMANCE OF OPTICAL AND THERMAL CONDITIONS IN DENSE VEGETATION AND MIXED TERRAIN

PERFORMANCE	TRIAL BLOCK				
	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	Mean
Dense Vegetation					
First Response Hits					
Alternating Optical/Thermal	.58	.54	.51	.47	.52
Predicted (Average X $\cdot$ $\sqrt{2}$)	.51	.50	.49	.48	.50
First Response False Alarms					
Alternating Optical/Thermal	.18	.16	.15	.13	.16
Predicted (Average X $\div$ $\sqrt{2}$)	.16	.17	.18	.20	.18
Mixed Terrain					
First Response Hits					
Alternating Optical/Thermal	.87	.71	.55	.38	.63
Predicted (Average X $\cdot$ $\sqrt{2}$)	.69	.62	.55	.48	.58
First Response False Alarms					
Alternating Optical/Thermal	.14	.14	.14	.14	.14
Predicted (Average X $\div$ $\sqrt{2}$)	.25	.22	.18	.15	.20

Note. Figures express the proportion of trials in each category.

Overall, performance when alternating between thermal and optical sights exceeded performance with either sight alone by a factor of $\sqrt{2}$. This result agrees with the results of Swets et al. (1964), with Garner's (1962) observation that an increase in stimulus dimensionality increases total information transmission, and with research by Mulligan and Shaw (1980) indicating that observers make independent decisions on a multimodal detection task and then combine the results of these independent decisions to produce a final judgment. That the redundant information contained in the correlated displays of the thermal and optical sights aided detection performance is also consistent with the observation of Teichner and Mocharnuk (1979) that redundancy aids discrimination under conditions of reduced or difficult discriminability, but not when stimulus features are clear and easily discriminable. Stimulus features in detecting vehicles on the battlefield will seldom be clear and easily discriminable.

CONCLUSIONS

Alternating between optical and thermal sights provided an increased ability to detect targets over all terrain during daylight hours relative to using either sight alone, but allowed increased detection at the expense of time. When searching densely vegetated terrain, alternating between optical and thermal sights provided the highest performance in detecting targets (although there was some indication that detection time may be fastest with the optical sight alone). In contrast, when searching terrain with bare or grassy areas and searching the edges of woodlines, optical sights produced the best target detection performance with respect to speed and accuracy during daylight. One should keep in mind that these results are likely to depend on the relative magnification of the two sights, target vehicle temperature, and weather conditions. Systematic research must be done to evaluate the effects of these variables on operational performance in order to provide the best possible guidance to personnel who must operate weapon systems with both thermal and optical sights.

An important point to consider is that observers' performance with the thermal sight increased over all trials. It is unclear whether the increase in performance in the Thermal condition was due to an increase in observers' perceptual ability to discriminate targets from nontargets or whether observers simply began to learn which spots on the terrain containing the targets were hot spots that looked much like targets. Since the target area was restricted when the slides were taken, most of the slides containing mixed terrain were taken in the same general area; with the feedback provided over trials, observers almost certainly learned something about which spots on the terrain were not targets. This statement gains some support from the casual observation that thermal performance in dense vegetation did not increase nearly as much over trials as it did in mixed terrain, perhaps because there were no readily recognizable terrain features to use as landmarks in dense vegetation, and hence no hot spots that could readily be located and immediately discarded as targets on every trial. Yet another hypothesis for the increased thermal performance is that a combination of learning about the terrain and learning to discriminate targets from nontargets was responsible for the increase in thermal target detection performance. However, further research is definitely needed to assess the relative contributions of these two factors.

Regardless of contributing factors, a major conclusion to be drawn from the thermal data over both kinds of terrain is that detecting targets using thermal sights is not automatic. False alarms occurred quite frequently, especially on early trials. Performance increased with practice. Based on these data, it appears that simply allowing someone to use a thermal sight with no training will fail to produce acceptable levels of target detection performance.

Since the output of the thermal sight is a video display, the prospects are favorable for development of training methods producing effective and transferable performance based on use of currently available and inexpensive technology in a classroom setting. Because people may be able to learn which hot spots are not targets if presented with the same terrain several times, the target scenes used should have varied backgrounds to allow observers to discriminate targets from places on the terrain that falsely appear somewhat target-like.

An immediately relevant point of this research for combat, given the likelihood of terrain-specific learning, is that when setting up in a defensive position, TCs and gunners should examine the terrain through the thermal sight to locate hot spots. By taking advantage of the opportunity to compare thoroughly optical and thermal scenes before the battle, the gunner should be able to reduce markedly the chances of costly detection errors during both daylight and night conditions.

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APPENDIX A

SKETCH OF TARGET AREA SHOWING TARGET LOCATIONS

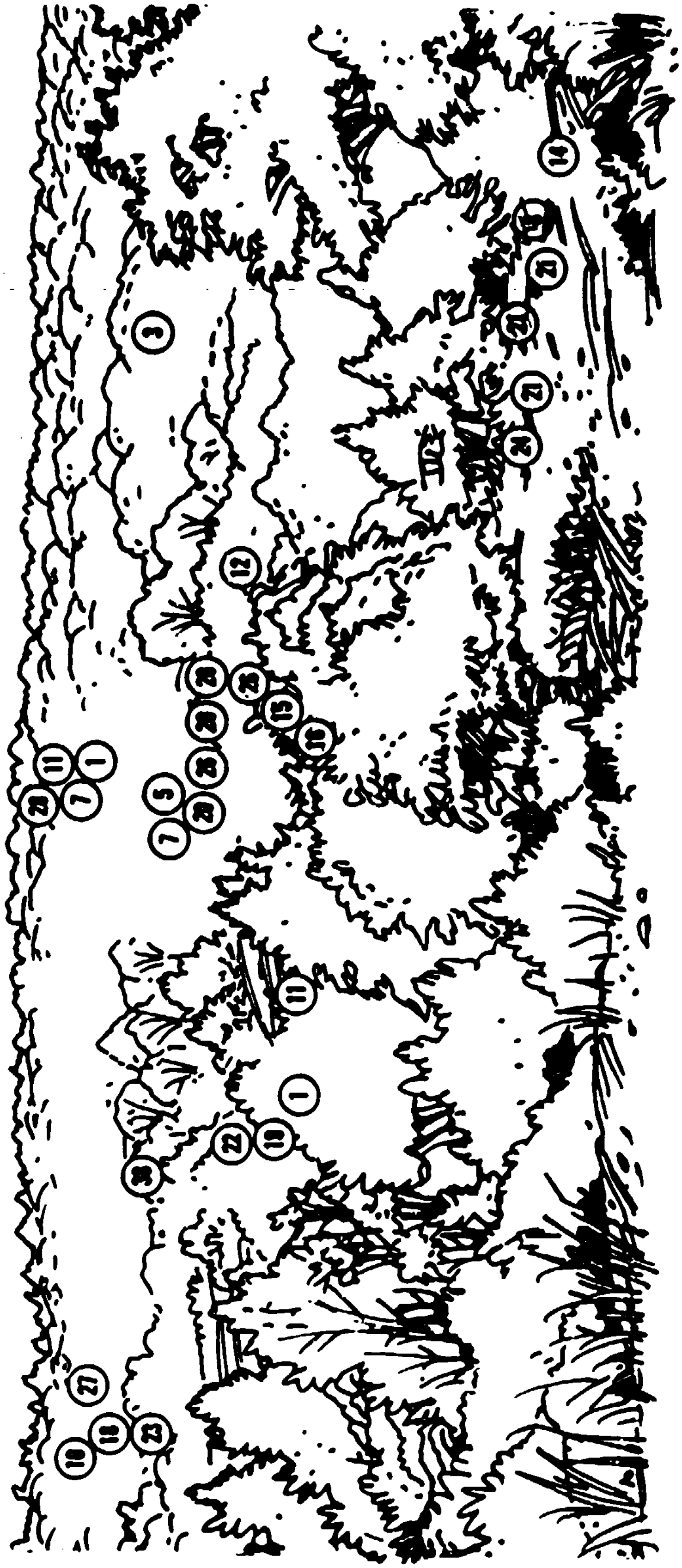

TABLE A-1
STIMULUS PRESENTATION SEQUENCE

TRIAL NR.	NR. OF TARGETS	RANGE CATEGORY OF NEAREST TARGET	OPTICAL TARGET TO BACKGROUND CONTRAST	TARGET DESCRIPTION
1	2	MEDIUM	.50	Frontal tank, Frontal panel
2	0	N/A	X	Control slide - terrain without targets
3	1	FAR	.20	Frontal panel
4	0	N/A	X	Control slide - terrain without targets
5	1	MEDIUM	.30	Flank jeep
6	0	N/A	X	Control slide - terrain without targets
7	2	MEDIUM	.50	Frontal tank, Frontal panel
8	1	NEAR	.80	Frontal tank
9	0	N/A	X	Control slide - terrain without targets
10	1	FAR	.10	Frontal panel
11	2	MEDIUM	.40	Flank tank, Frontal panel
12	1	MEDIUM	.50	Frontal jeep
13	0	N/A	X	Control slide - terrain without targets
14	1	NEAR	.75	Frontal tank
15	1	MEDIUM	.10	Frontal jeep
16	1	MEDIUM	NOT RECORDED	Frontal jeep
17	0	N/A	X	Control slide - terrain without targets
18	1	FAR	.10	Flank jeep
19	1	MEDIUM	.35	Frontal jeep
20	3	MEDIUM	.40	Flank jeep, Two frontal panels
21	3	NEAR	NOT RECORDED	Frontal panels
22	1	MEDIUM	.30	Frontal tank
23	1	FAR	.15	Frontal tank
24	1	NEAR	NOT RECORDED	Flank jeep
25	0	N/A	X	Control slide - terrain without targets
26	2	MEDIUM	.25	Frontal panels
27	1	FAR	.10	Frontal tank
28	2	FAR	.20	Frontal tank, Frontal panel

TABLE A-1 (Continued

TRIAL NR.	CONDITION OBSERVERS 1,6,11,16, 21,26,31	OBSERVERS 2,7,12,17, 22,27,32	OBSERVERS 3,8,13,18, 23,28,33	OBSERVERS 4,9,14,19, 24,29,34	OBSERVERS 5,10,15,20, 25,30,35
1	O&B	O	B	W	O&W
2	W	O&W	O&B	O	B
3	O	B	W	O&W	O&B
4	O&B	O	B	W	O&W
5	O&W	O&B	O	B	W
6	O&W	O&B	O	B	W
7	O&B	O	O&B	O	B
8	O	B	W	O&W	O&B
9	O	W	O	W	O&W
10	O&W	O&B	O	B	W
11	O	O&W	W	O&W	O
12	O&B	O	B	W	O&W
13	O&B	O	B	W	O&W
14	W	O&W	W	O&W	O
15	O&B	O	O&B	O	B
16	B	W	O&W	O&B	O
17	W	O&W	O&B	O	B
18	B	O&B	B	O&B	O
19	W	O&W	O&B	O	B
20	W	O&W	O&B	O	B
21	O&W	O&B	O	B	W
22	O	B	O	B	O&B
23	O	B	W	O&W	O&B
24	B	W	O&W	O&B	O
25	B	W	O&W	O&B	O
26	O	B	W	O&W	O&B
27	O	W	O	W	O&W
28	B	W	O&W	O&B	O

Note. O = Optical; B = Black Hot Thermal; W = White Hot Thermal.

APPENDIX B

ANALYSIS OF VARIANCE SUMMARY TABLES

TABLE B-1
SIGHT CONDITION PERFORMANCE
(PROPORTION OF CORRECT DETECTIONS DIVIDED BY THE TOTAL NUMBER OF "TARGET" RESPONSES)
OVER ALL TRIALS

SOURCE	ss	df	ms	F	P
Total	6.63	53	--	--	--
Trials	2.03	17	--	--	--
Sight condition	1.17	2	.58	5.8	<.01
Error	3.43	34	.10	--	--

TABLE B-2
CORRECT DETECTION TIMES OVER ALL TRIALS

SOURCE	ss	df	ms	F	P
Total	1564.14	53	--	--	--
Trials	559.94	17	--	--	--
Sight condition	315.61	2	157.81	7.79	<.005
Error	688.59	34	20.25	--	--

TABLE B-3
FALSE ALARM TIMES OVER ALL TRIALS

SOURCE	ss	df	ms	F	P
Total	1071.14	53	--	--	--
Trials	416.25	17	--	--	--
Sight condition	40.46	2	20.23	1.12	7.20
Error	614.43	34	18.07	--	--

TABLE B-4
SIGHT CONDITION PERFORMANCE
(PROPORTION OF CORRECT DETECTIONS DIVIDED
BY THE TOTAL NUMBER OF "TARGET" RESPONSES)
FOR TARGETS IN DENSE VEGETATION

SOURCE	ss	df	ms	F	P
Total	2.65	23	--	--	--
Trials	.50	7	--	--	--
Sight condition	.99	2	.50	6.25	<.025
Error	1.16	14	.08	--	--

TABLE B-5
CORRECT DETECTION TIMES
FOR TARGETS IN DENSE VEGETATION

SOURCE	ss	df	ms	F	P
Total	838.85	23	--	--	--
Trials	197.49	7	--	--	--
Sight condition	181.61	2	90.80	2.76	<.10
Error	459.75	14	32.84	--	--

TABLE B-6
FALSE ALARM TIMES
IN DENSE VEGETATION

SOURCE	ss	df	ms	F	P
Total	544.41	23	--	--	--
Trials	177.25	7	--	--	--
Sight condition	11.03	2	5.52	<1	NS
Error	356.13	14	25.44	--	--

TABLE B-7
SIGHT CONDITION PERFORMANCE
(PROPORTION OF CORRECT DETECTIONS DIVIDED
BY THE TOTAL NUMBER OF "TARGET" RESPONSES)
FOR TARGETS IN MIXED TERRAIN

SOURCE	ss	df	ms	F	P
Total	3.97	29	--	--	--
Trials	1.52	9	--	--	--
Sight condition	.81	2	.40	4.44	<.025
Error	1.64	18	.09	--	--

TABLE B-8
CORRECT DETECTION TIMES
FOR TARGETS IN MIXED TERRAIN

SOURCE	ss	df	ms	F	P
Total	839.52	29	--	--	--
Trials	347.74	9	--	--	--
Sight condition	160.36	2	80.18	4.36	<.05
Error	331.42	18	18.41	--	--

TABLE B-9
FALSE ALARM TIMES
IN MIXED TERRAIN

SOURCE	ss	df	ms	F	P
Total	530.27	29	--	--	--
Trials	269.28	9	--	--	--
Sight condition	49.63	2	24.82	2.11	NS
Error	211.36	18	11.74		