Technical Paper 300

THE EFFECTS OF WORK-REST, TARGET ACTIVITY, BACKGROUND NOISE, AND STRING SIZE ON OPERATOR INTERPRETATION OF UNATTENDED GROUND SENSOR RECORDS

Harold Martinek
Army Research Institute for the Behavioral and Social Sciences

and

Sterling Pilette and Billy Biggs
HRB-Singer, Inc.

BATTLEFIELD INFORMATION SYSTEMS TECHNICAL AREA

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W. C. MAUS
COL, GS
Commander

JOSEPH ZEIDNER
Technical Director (Designate)

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Requirement: To investigate the relationships between unattended ground sensor (UGS) operator performance and work/rest cycles, sensor string size, target activity levels, and noisy/quiet environments and to identify sources of operator error that can be eliminated through the use of new interpretation techniques, procedures, and training.

Procedure: Operators monitored UGS records for 8 hours of worktime under four different work/rest conditions: 2 hours works, 1 hour rest; 2 hours work, 15 minutes rest; 4 hours work, 1 hour rest; and 4 hours work, 15 minutes rest.

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The UGS records included counterbalanced variations of three string sizes (2, 3, and 4 sensors), 12 targets per hour or 6 targets per hour, and high and low "battle" noise.

~~Results:~~ The results were: For a contemplated 8 hours of monitoring, 2-hour work shifts interspersed with 1-hour or 15-minute rest periods are to be preferred over 4-hour work shifts interspersed with 1-hour or 15-minute rest periods. For heavy short-term monitoring requirements, for example, enemy attack requiring periods of concentrated monitoring, an operator can perform satisfactorily for one 4-hour shift but performance will deteriorate during a second 4-hour shift.

Performance was equal using 2, 3, or 4 sensor strings in the low-target-activity condition. However, during the high-target-activity condition, use of 3 or 4 sensor strings resulted in more target detections as compared to use of 2 sensor strings.

Operator performance during the high "battlefield" noise was equal to that during low noise. During the high-target-activity conditions the operators detected more targets than during the low-target-activity condition. However, they detected a higher percentage of targets during the low condition.

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

and

Sterling Pilette and Billy Biggs
HRB-Singer, Inc.

BATTLEFIELD INFORMATION SYSTEMS TECHNICAL AREA

Submitted as complete and technically accurate, by:

Edgar M. Johnson
Technical Area Chief

Approved By:

A.H. Birnbaum, Acting Director
ORGANIZATIONS AND SYSTEMS
RESEARCH LABORATORY

Joseph Zeidner
TECHNICAL DIRECTOR (Designate)

U.S. ARMY RESEARCH INSTITUTE FOR THE BEHAVIORAL AND SOCIAL SCIENCES
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Surveillance Systems

FOREWORD

The Battlefield Information Systems Technical Area is concerned with the demands of the future battlefield for increased man-machine complexity to acquire, transmit, process, disseminate, and use information. The research focuses on the interface problems and interactions within command and control centers in areas such as topographic products and procedures, tactical symbology, information management, user-oriented systems, staff operations and procedures, and sensor systems integration and utilization.

An area of special interest is that of human factors problems in the presentation and interpretation of surveillance and target acquisition information. One relatively new source of intelligence information is remote monitoring of the battlefield using seismic, acoustic, and magnetic unattended ground sensors. When these remote sensors are activated by enemy personnel or vehicle movement, a monitor display located behind our lines indicates the activity. The operator can derive from this display not only the presence of the enemy but such information as the direction and speed of convoys and personnel, the number of vehicles in a convoy, and the composition of the convoy, for example, armored or wheeled vehicles.

The present publication investigates the effect on operator performance of several variables of operational significance. Information on work/rest cycles, background noise, and target activity levels have implications for operator assignment doctrine and the intelligence analyst's reliability estimates of information derived from sensor reports. The results on string size indicate that sensor systems can be made more cost effective by using fewer sensors per string without loss of information. ARI Technical Papers 299 and 281 describe earlier research on unattended ground sensors.

Research in the area of sensor systems integration and utilization is conducted both in-house and by contract. The project reported here was conducted jointly by ARI and HRB-Singer, Inc. This research is responsive to requirements of Army Project 2Q662704A721 and to special requirements of the Assistant Chief of Staff for Intelligence. The cooperation and assistance of the participating operators and staff of the UGS USAIN school at Fort Huachuca, Ariz., is greatly appreciated.

JOSEPH ZEIDNER
Technical Director (Designate)

THE EFFECTS OF WORK/REST, TARGET ACTIVITY, BACKGROUND NOISE, AND STRING SIZE ON OPERATOR INTERPRETATION OF UNATTENDED GROUND SENSOR RECORDS

BRIEF

Requirement:

The experiment was designed to (1) investigate the relationships between unattended ground sensor (UGS) operator performance and various system-dependent and target-dependent parameters including work/rest cycle, number of sensors in a string, target activity level, and background noise; and (2) to identify sources of operator error that can be reduced through new interpretation techniques, procedures, and training.

Procedure:

Two 8-hour scenarios were compiled from a data bank of taped recordings of UGS activations during field tests by Modern Army Selected Systems Test, Evaluation, and Review (MASSTER) at Fort Hood, Tex. The tests were run under typical operational conditions using groups of personnel and wheeled and tracked vehicles as targets. Roughly 80% of the sensors were seismic, the remainder confirmatory. All sensors were deployed in typical string configurations. The scenarios included counterbalanced variations of strings of three different sizes (2, 3, and 4 sensors), high and low target activity, and high and low "battle" noise. The high-noise condition contained the same targets as the low but also included typical aircraft, artillery, and high background noise taped during the above field tests. Four work/rest cycles were used, each of which involved a total of 8 hours of work with work and rest periods of different durations: 2 hours work, 1 hour rest; 2 hours work, 15 minutes rest; 4 hours work, 1 hour rest; and 4 hours work, 15 minutes rest. Sixteen students at the U.S. Army Intelligence Center and School (Ground Sensor Department) at Fort Huachuca, Ariz., were given test procedure training and a 1-hour review consisting of instruction and practice in interpretation of seismic sensor records. They were also given a background questionnaire and a 30-minute pretest. Pretest results were used as the basis for assigning operators to the experimental groups. Each group was assigned one of four work/rest cycles the first test day and a different one the second test day. Subject performance was scored against the known target activity for correct detections, wrong detections, correct identifications, elapsed time, and confidence.

Findings:

For 8-hour monitoring shifts, 2-hour work shifts interspersed with 1-hour or 15-minute rest periods were better than 4-hour work shifts interspersed with 1-hour or 15-minute rest periods. For important short-term monitoring requirements, operator performance was satisfactory for the first 4-hour shift, but deteriorated during the second 4-hour shift.

Operator performance was equal using 2-, 3-, or 4-sensor strings in the low-target-activity condition. However, in the high-target-activity condition, use of 3- or 4-sensor strings resulted in more correct target detections than use of 2-sensor strings.

Operator performance during the high "battlefield" noise was equal to that during low noise.

During high-target-activity conditions, operators detected more targets than during low-target-activity conditions. They detected a higher percentage of targets during the low condition, however.

Sources of operator errors included the use of 2-sensor strings for the detection of targets in a high-target-activity condition, endpoint determination, measurement, arithmetic calculations, and use of confirming sensors.

Utilization of Findings:

The major findings regarding work/rest cycles can be used by all operational UGS commands and school units for assignment to duty cycles. Considering only operator performance and assuming high-sensor reliability, 2-sensor strings, rather than 3- or 4-sensor strings, can be used to reduce costs if only low-target activity is expected. If high activity is expected, 3-sensor strings can be used rather than 4 with no operator performance decrement. Operator problem areas identified should be used as the basis for a new training program. A UGS ruler should be developed for measuring sensor activation times directly on the display; a job aid (such as a nomograph) should be developed to simplify arithmetic computations and decimal point placement. A programed text for other operator errors should be developed and validated.

THE EFFECTS OF WORK/REST, TARGET ACTIVITY, BACKGROUND NOISE, AND STRING SIZE ON OPERATOR INTERPRETATION OF UNATTENDED GROUND SENSOR RECORDS

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THE EFFECTS OF WORK/REST, TARGET ACTIVITY, BACKGROUND NOISE, AND STRING SIZE ON OPERATOR INTERPRETATION OF UNATTENDED GROUND SENSOR RECORDS

BACKGROUND

Although significant technical achievements have been accomplished in the development of unattended ground sensor (UGS) systems, insufficient effort has been directed toward the study of the person who must operate and monitor the system and the interface of this operator and the equipment. Of major concern are interpretation errors on the part of the operator--errors of omission and errors of commission (false alarms). Depending upon field conditions, human error can be fairly substantial in attempting to isolate valid target activations.

Human factors studies have been conducted to investigate techniques of improving operator interpretation performance. One study (Cravens, 1972) investigated a limited automatic processing technique designed to suppress spurious activations and enhance meaningful activations. The intention was to provide a simplified display to the monitor by having the equipment identify continuous targetlike sequences using specified detection criteria. The technique caused no improvement in operation target detection performance and, in fact, increased the number of false detections.

The second study (Martinek, Hilligoss, & Lavicka, 1978) investigated the relative utility of a 1:25,000 situation map display and tape playback at eight times the normal speed of review (compressed time). The map covered small lights that showed the ground location of the sensors and blinked when the sensors were activated. Although the operators were able to determine the location of targets quickly because of the map presentation, they had difficulty separating target activations from nontarget activations. Because of the lack of a permanent record, it also was difficult to determine target speed and length of the column. The use of a compressed-time review was insufficient to compensate for lack of a permanent record.

The Remotely Monitored Battlefield Surveillance System (REMBASS) project focuses on providing support in conflict situations of middle and high intensity. In such situations, the UGS operators must be constantly alert to distinguish valid target activations from the many "false" activations produced by helicopters, low-flying fixed-wing aircraft, and artillery shell bursts, etc., in addition to nonmilitary and random false activations caused by wind, rain, small animals, and malfunctioning sensors. Operator errors from these and other sources cause the total system to have less than optimal reliability. An in-depth study of these sources of errors could be the basis for specialized training to enhance system reliability.

OBJECTIVES

The general objective of this effort was to develop information concerning the level of performance exhibited by trained UGS operators in interpreting display patterns (activations) obtained from sensors deployed in the field. More specifically, the objective was to investigate the relationship between operator performance and the following system-dependent and target-dependent parameters: work/rest (W/R) cycles, sensor string size, target activity level, and "noisy" versus quiet environments. An additional objective was to identify, by an analysis of the monitor errors, interpretation training techniques or procedures that could improve operational performance.

METHOD

Research Considerations

Variables considered for inclusion in the present study can be divided into two categories that present different requirements for the research design and procedure. In a monitoring situation, one group, the system-dependent variables, represents variables whose value is known or even sometimes controlled; for example, training and work/rest cycle. The second group, Target-Dependent variables, are variables whose values are always uncertain to the operator; for example, target type, target direction, and activity level. These variables are constantly changing during the course of an operational mission and their occurrence during an experiment must also change with no warning to the operator participating.

System-Dependent Variables

The primary System-Dependent variable investigated in the present study was the work/rest cycle. There is disagreement among operational personnel as to the optimal work/rest cycle. Most agree, however, with the conclusion of the Cavalry Troop Test Report (U.S. Army, January 1972) that work-shift length affects operator performance. During this field experiment, 12 operators worked in two shifts and manned six stations. The work shifts were 2 hours for the first week of the test and 4 hours for the second week. At the end of the experiment, the operators felt that the 2-hour shifts were fine but that the 4-hour shifts were too long. The conclusion regarding the shifts must be regarded as tentative because the work period was confounded with several other variables such as experience, target activity, and possible weather changes. Moreover, work/rest cycle as a function of other variables was not investigated.

On the basis of these results and discussion with operational personnel, a 1-hour work/rest cycle was eliminated from the present experiment. At the other extreme, it was felt that effects of a long work shift should be assessed, but probably one no longer than 8 hours. It was unreasonable to assume that a monitor would sit at a display for 8 hours and never leave the post. Therefore, it was decided to use a 4-hour shift with a 15-minute break. A 15-minute break might not have been sufficient, so a 1-hour break was also used. Because 2 hours is a typical length of worktime for a perceptual visual task (e.g., certain kinds of sentry duty) and was found acceptable in the above study, two work shifts were planned that contained 2-hour work periods. Rest periods were planned for 1 hour and for 15 minutes. Table 1 shows four work/rest cycles that were selected for study. For every work/rest cycle investigated, the total amount of worktime was 8 hours.

Table 1

Work/Rest Cycles Investigated

Periods	W/R I (in hours)	W/R II (in hours)	W/R III (in hours)	W/R IV (in hours)
Work	2	2	4	4
Rest	1	.25	1	.25
Work	2	2	4	4
Rest	1	.25		
Work	2	2		
Rest	1	.25		
Work	2	2		
Total work	8	8	8	8
Total rest	3	.75	1	.25
Total time	11	8.75	9	8.25

The second System-Dependent variable of concern was training. Although training was not varied as an experimental condition, the individual reports were analyzed with the intent of improving training.

During discussion with training personnel at Fort Huachuca, several points became evident:

1. Lecture-discussion and team training techniques are heavily used.

2. Practical exercises are typically based on ideal clearcut target activation patterns occurring in a relatively sanitized environment.

3. In the formulas used for computing speed, length of column, and number of units in a column, only the most essential factors are taught. Factors such as environmental effects are not considered part of the formulas.

Although the trainees were adequately prepared to detect, interpret, and compute target activations that appeared in orderly stairstep patterns, on-the-job experience may be required to cope with the more complex target environment of the real world, which includes unreliable sensors, radio masking, and other noise sources. In the last analysis, the value of UGS will be gaged by the quality of information it can provide under operational restraints. Thus, the scenarios used in the research contained activations that occurred during actual field conditions. The reports of these inexperienced operators could then be analyzed to find problem areas to revise training and develop improved interpretation techniques.

Target-Dependent Variables

After review of current Fort Huachuca training materials (U.S. Army, February 1971; U.S. Army, November 1972; U.S. Army, 1973; U.S. Army, December 1970; U.S. Army, September 1971), relevant research previously conducted (U.S. Army, December 1970; U.S. Army, May 1972; U.S. Army, June 1969), and consultation with knowledgeable personnel, nine Target-Dependent variables were identified. From these, three were selected for the present experiment: target activity level, sensor size, and background noise.

Target Activity. Target activity was defined as the number of sensor strings partially or completely activated during a given time segment. Two levels of activity were systematically assigned based on anticipated battle conditions. (These are consistent with target conditions as discussed in the DCPG Phase III Field Experiment Report, 1970.) Low target activity was designated as three target activations occurring within 30 minutes. High target activity was designated as six target activations occurring within 30 minutes (West, 1973). Because the targets were randomly assigned to the low- and high-activity conditions, equivalent target difficulty was assumed.

Sensor Size. The number of sensors in a string yielded different activation patterns and also had a potentially important effect on monitoring performance. Assuming the necessity of two working sensors for calculating speed and length of column, the question was asked, "How important are additional sensors to the complete reporting process from detection to dissemination?" Because there was a reasonable variation in the number of sensors per string, three string sizes (2, 3, and 4 sensors) were selected as levels of study.

Background Noise. UGS alone cannot distinguish between friend and foe, nor between natural and manmade disturbances. A false activation will produce the same result on the RO 376 event recorder as an activation made by a valid target. Generally, valid target activations differ from false activations in that valid target activations appear in distinguishable patterns. Even so, false activations can have a major effect on operator performance, and any analysis of performance should consider this. The level of false activations could be manipulated readily to either high- or low-noise conditions by carefully dubbing in or erasing battlefield noise. The presence of various noise types in the BASS and Project 1030 field data offered the necessary variability in readily manipulated form. The amount of noise inserted into high- and low-noise scenario segments was subjectively estimated.

The problem of estimating what noise to include was partially alleviated by using characteristic noise from five major noise sources: fixed-wing aircraft, helicopter, artillery shell bursts, weather activity, and radio interference. Noise could not be superimposed over target activity because of the characteristics of tape recorders. However, target activation patterns were not free of noise because noise did occur in the field during the original recording of the activations.

Population and Sample

The population of concern is the Army enlisted operator (MOS 17M20), school-trained at the U.S. Army Intelligence Center School, Fort Huachuca, Ariz. UGS classes were selected on the basis of class size as required by the experimental design and scheduling compatibility.

Research Design

The following independent variables and levels were included in the design: work/rest (4), sensor string size (3), target activity (2), and noise (2). The latter three variables and their levels were systematically presented in two matched scenarios. Each scenario was composed of 16 30-minute segments. Each 30-minute segment included one level of target activity and noise and all three levels of sensor string size.

Table 2 presents the schedule of administration showing the work/rest cycle and scenario assigned to each operator each day. The 16 operators were divided into groups of two on the basis of pretest scores. They were administered the two scenarios in a counterbalanced arrangement across the 2 days. On Day 1, half the operators took Scenario A and the other half took Scenario B. On Day 2, the groups switched scenarios, switching the work/rest cycles because Work/Rest Cycles I and IV were never paired with II and III. In the derivation of the analysis of variance, an intermediate sum of squares was included to correct for the partial confounding. The analysis of variance used a balanced incomplete-block design (Winer, 1962) with an embedded 3 x 2 x 2 factorial composed of the three Scenario variables. As shown in Table 2, the two highest operators became Group A and the two lowest became Group H. The operators were thus assigned to maximize homogeneity within the groups. Across the 2 test days, the matching technique provided a systematic balance of operator skill level across all of the work/rest cycles investigated.

Dependent Variables

Separate analyses of variance were planned for the following Dependent variables:

Correct Detections	If an operator reported an activation pattern resulting from a valid target, the response was classified as a correct detection. This variable is perfectly correlated with detection completeness except that completeness is a ratio of correct detections to total number of targets presented. Percentage completeness figures are given where they have special meaning.
False Alarms	If an operator reported an activation pattern resulting from other than a valid target, the response was classified as a false alarm.
Correct Identifications	If, in addition to detecting a valid target, the operator classified the target correctly by type (personnel or vehicle), the response was also classified as correct identification.

Two dependent measures were considered but were not statistically analyzed:

Table 2

Schedule of Administration

Operator pretest rank order	Matched groups	Day 1 Work/Rest Cycle	Day 1 Order of sections	Day 2 Work/Rest Cycle	Day 2 Order of sections
		Scenario A		Scenario B	
1,2	A	I (2 - 1)	I, II, III, IV	IV (4 - 1/4)	I + II, III + IV
3,4	B	II (2 - 1/4)	II, III, IV, I	III (4 - 1)	II + III, IV + I
5,6	C	III (4 - 1)	III + IV, I + II	II (2 - 1/4)	III, IV, I, II
7,8	D	IV (4 - 1/4)	IV + I, II + III	I (2 - 1)	IV, I, II, III
		Scenario B		Scenario A	
9,10	E	I (2 - 1)	I, II, III, IV	IV (4 - 1/4)	I + II, III + IV
11,12	F	II (2 - 1/4)	II, III, IV, I	III (4 - 1)	II + III, IV + I
13,14	G	III (4 - 1)	III + IV, I + II	II (2 - 1/4)	III, IV, I, II
15,16	H	IV (4 - 1/4)	IV + I, II + III	I (2 - 1)	IV, I, II, III

Elapsed Time	Time between target detection and completion of the report as written by the subject.
Confidence	The operator's confidence on a 4-point scale as to how confident he is that the activation pattern he has reported is a valid target.

A total of 72 target patterns were selected for the scenario tapes to satisfy the requirements of the research design. These patterns were divided into eight groups of nine targets each. Each group was included in 2 separate 30-minute segments. The operators were presented nine targets during each hour of monitoring. One 30-minute segment contained three targets. The other 30-minute segment contained six targets. Equal numbers of 2-, 3-, and 4-sensor string sizes were included within each 30-minute segment. Each scenario was composed of 16 of these 30-minute segments presented to the operator in four sections (I, II, III, and IV), lasting 2 hours each. The number of vehicles and personnel targets within each 2-hour section is shown in Table 3.

Upon completion of the scenario format, magnetic tapes were produced by splicing the appropriate segments of BASS III and UGS 1030 tapes together. These spliced tapes were used to produce four 2-hour scenarios on RO 376 plot paper. One copy of the scenarios remained as recorded, that is, under relatively low-noise conditions. The other copy was changed to be used for the high-noise conditions. Representative samples of noise were selected from the original BASS III and UGS 1030 data to complete the high noise conditions. Several kinds of field noise (artillery, fixed-wing aircraft, helicopters, radio activity, and random noise) were "burned in" on the high-noise portions of the scenarios. Thus, the actual targets in the low- and high-noise sections were identical. The scenarios were duplicated by using the training simulator at Fort Huachuca, Ariz. Additional information on scenario development is presented in Appendix A.

Development of the Implant Sketches. To simulate real world conditions, operators were given implant sketches. Implant sketches are made from topographical maps and are used as a quick reference to reveal the ground location of sensor strings and individual sensors being monitored. These sketches enable the monitor to visualize better the activity being reported by the sensors because the sketches do not include the often distracting information found on topographical maps.

The fact that the sensor activations used in this study were obtained from two separate field tests involving different terrain and scenarios eliminated use of the original field sketches. Consequently, it was necessary to construct implant sketches that presented appropriate portions of the original sensor fields integrated to simulate a realistic field situation. Because of several constraints under which the scenarios were developed, 8 different implant sketches were necessary, one for each low- and high-noise pair of 30-minute segments. (An example is given in Figure B-1.)

Table 3

Number of Personnel and Vehicle Targets[a] in Scenarios A and B[b]

	Total targets	Personnel targets	Vehicle targets
Scenario A			
Section I	18	6	12
Section II	18	4	14
Section III	18	6	12
Section IV	18	4	14
Scenario B			
Section I	18	4	14
Section II	18	4	14
Section III	18	4	14
Section IV	18	4	14
Total	144	36	108

[a]A target consists of from one to nine personnel or vehicles activating a sensor string.

[b]Scenarios A and B are each 8 hours long with four 2-hour sections shown above. Sections I and II were low noise and Sections III and IV were high noise and contained exactly the same targets.

Development of the School Solutions

The school solution to all records was based on standard computational procedures. A majority of the school solutions, however, did not correlate well with ground truth. In some cases, gross discrepancies existed--in speed or number of targets, for example. The poor correlation between the school solution and ground truth was probably due to lack of information concerning the actual detection range of the sensors and irregular activations.

Actual Detection Range. Because the actual detection ranges of the sensors were not known, manufacturers' specifications were used (U.S. Army, September 1971). Compounding this problem is the fact that the computational methods used by the Army do not integrate the effects of several additional important variables that influence detection range. For example, for calculating length of column, the detection range is required, but gain setting (whether high, medium, or low), soil type, and environmental effects usually cannot be considered even though it has been proved that they affect detection range.

Irregular Activation. Irregular and inexplicable activations occurred in the target activations. These activations probably have simple explanations, but the information was not available and it was necessary to work around them. Where gross discrepancies existed between school solution and ground truth, it was necessary to make reasonable adjustments to some or all of the following parameters for a particular target: reported distance between sensors, detection range specifications as reported by manufacturers, and change of target type to use a different assumed distance between units. Troublesome school solutions were discussed with Fort Huachuca training personnel to safeguard against unreliable or invalid data from inaccurate school solutions.

Administration Procedure

Data were collected over a 2-1/2-day period. During the first half day, all operators were given test procedure training (Appendix B) that included a familiarization briefing in which a background (school and experience) questionnaire was completed. The operators were then given a 1-1/2-hour review of instruction and practice in interpreting seismic sensor records. During this time, questions were answered and operators were given the correct interpretations of the records. Finally, a 30-minute pretest was administered, scored, and used as the basis for matching the operators into homogeneous groups.

The scenarios were displayed by specially built training simulators identical in appearance to the operational RO 376 event recorder normally used in the field. The simulation of the display equipment was judged to be perfect with respect to operator display interface. The XT plots and the speed of presentation were identical to that found in the field. The only difference was that no sensor with associated electronic equipment was operating because the XT plots had been prepared earlier.

Operators were assigned work/rest cycles and a particular order for work/rest (W/R) cycles and scenario presentation. The testing schedule was conducted with the time schedules presented in Table 4. During the testing, the two experimenters continually insured that each operator was using the proper implant sketch (Fig. B-1) and sensor program record (Table B-2) for each 30-minute segment. The program record contained the following information: pen number, string/field number, sensor type, and detection radius.

Table 4

Time Schedule of Work/Rest Cycles

	W/R Cycle I (2-1)	W/R Cycle II (2-1/4)
Briefing	7:20 - 7:30 a.m.	7:20 - 7:30 a.m.
Work	7:30 - 9:30	7:30 - 9:30
Finish[a]	9:30 - 9:35	9:30 - 9:35
Rest	9:35 - 10:35	9:35 - 9:50
Work	10:35 - 12:35 p.m.	9:50 - 11:50
Finish[a]	12:35 - 12:40	11:50 - 11:55
Lunch	12:40 - 1:40	11:55 - 12:10 p.m.
Work	1:40 - 3:40	12:10 - 2:10
Finish[a]	3:40 - 3:45	2:10 - 2:15
Rest	3:45 - 4:45	2:15 - 2:30
Work	4:45 - 6:45	2:30 - 4:30
Finish[a]	6:45 - 6:50	4:30 - 4:35
Secure	6:50 - 7:00	4:35 - 4:45

	W/R Cycle III (4-1)	W/R Cycle IV (4-1/4)
Briefing	7:20 - 7:30 a.m.	7:20 - 7:30 a.m.
Work	7:30 - 11:30	7:30 - 11:30
Finish	11:30 - 11:35	11:30 - 11:35
Lunch	11:35 - 12:35 p.m.	11:35 - 11:50
Work	12:35 - 4:35	11:50 - 3:50 p.m.
Finish	4:35 - 4:40	3:50 - 3:55
Secure	4:40 - 4:50	3:55 - 4:05

[a]Five minutes were allowed to finish calculations on targets already annotated because some targets appeared very near the end of the work period.

During data collection, the operator annotated the scenario plot by drawing a circle around each potential target pattern and numbering these circles consecutively as they were drawn. The operator recorded each potential target on the sensor target log report (Table B-1). After recording the pattern number, the operator recorded the pen number associated with each pattern, the approximate time, and the operator's confidence using a 4-point scale (4 = low, 3 = 50-50, 2 = high, and 1 = positive).

The operator then determined and recorded target direction, speed, and target type, and number of units in the target (quantity).

RESULTS AND DISCUSSION

Correct Detections

Table 5 presents the analysis of variance (ANOVA) results for correct detections. Of primary interest is the nonsignificant result for the work/rest (W/R) cycle variable. The ANOVA indicates that there were no differences in number of correct detections as a function of work/rest cycles.

It is equally important, however, to determine if there is a trend over the 8-hour work shifts, whether due to learning or fatigue or a combination of the two. Because each 8-hour test scenario consisted of four 2-hour sections counterbalanced in order of presentation, it was possible to analyze performance over the four sections without scenario effects confounding the results. Because of the significant difference between the two scenarios (Table 5), each scenario had to be considered individually at the beginning of a trend analysis for each work/rest cycle. Tables 6 through 9 present correct detection data by work/rest cycle, scenario, and time period.

A graph presenting the same data is shown in Figures 1 through 4. The first two figures indicate a possible slight positive trend in Work/Rest Cycles I and II; the second two figures indicate a moderate negative trend in Work/Rest Cycles III and IV, perhaps due to fatigue. Within each cycle, the general trend pattern appears to be similar for the two scenarios. In other words, although the number of correct detections in any time period may depend on which scenario was used, the trend pattern is generally the same.

Figure 5 indicates the overall trend in each of the four work/rest cycles for both scenarios combined. Components of linear, quadratic, and cubic trends were analyzed. A discussion of the computational details of the analysis is given in Winer (1962). As shown in Table 10, none of the trend components was statistically significant for any individual W/R cycle.

Table 5

Analysis of Variance Table for Target Detection

Source of variation	df	SS	MSS	F	Significance level
Work/rest cycles	3	7.344	2.488	1.94	NS
Days	1	.010	.010	.01	NS
String size	2	206.646	103.323	80.53	.01
Noise	1	1.260	1.260	.98	NS
Target activity	1	283.594	283.594	221.04	.01
Groups	6	148.562	24.760	19.30	.01
Scenarios	1	6.510	6.510	5.09	.05
Days x string size	2	.584	.294	.23	NS
Days x noise	1	.095	.095	.07	NS
Days x target activity	1	6.511	6.511	5.07	.05
String size x noise	2	2.522	1.261	.98	NS
String size x target activity	2	216.063	108.032	84.21	.01
String size x scenarios	2	24.144	12.072	9.41	.01
Noise x target activity	1	.511	.511	.40	NS
Noise x scenarios	1	2.910	2.910	2.27	NS
Target activity x scenarios	1	23.006	23.006	17.93	.01
Days x string size x noise	2	5.803	2.902	2.26	NS
Days x string size x target activity	2	.642	.321	.25	NS
Days x noise x target activity	1	.259	.259	.20	NS
String size x target activity	2	1.582	.791	.62	NS
String size x noise x scenarios	2	7.568	3.784	2.95	NS
String size x target activity x scenarios	2	61.577	30.789	24.00	.01
Noise x target activity x scenarios	1	4.600	4.600	3.58	NS
Residual	151	276.249	1.829	1.43	
Error	192	246.500	1.283		
Total	383	1386.490			

Table 6

Detection Rights for Work/Rest Cycle I (2-1)[a]

2-hour periods	1	2	3	4	Total
Scenario A	30	39	35	38	142
Scenario B	40	41	33	43	157
Total	70	80	68	81	299

[a]Four-hour work periods separated by 1-hour rest periods for a total of 8 hours' work.

Table 7

Detection Rights for Work/Rest Cycle II (2-1/4)[a]

2-hour periods	1	2	3	4	Total
Scenario A	34	34	32	42	142
Scenario B	41	44	42	43	170
Total	75	78	74	85	312

[a]Two-hour work periods separated by 15-minute rest periods for a total of 8 hours' work.

Table 8

Detection Rights for Work/Rest Cycle III (4-1)[a]

2-hour periods	1	2	3	4	Total
Scenario A	46	48	46	38	178
Scenario B	43	43	39	33	158
Total	89	91	85	71	336

[a]Two-hour work periods separated by 1-hour rest periods for a total of 8 hours' work.

Table 9

Detection Rights for Work/Rest Cycle IV (4-1/4)[a]

2-hour periods	1	2	3	4	Total
Scenario A	42	37	39	26	144
Scenario B	46	41	45	39	171
Total	88	78	84	65	315

[a]Four-hour work periods separated by 15-minute rest periods for a total of 8 hours' work.

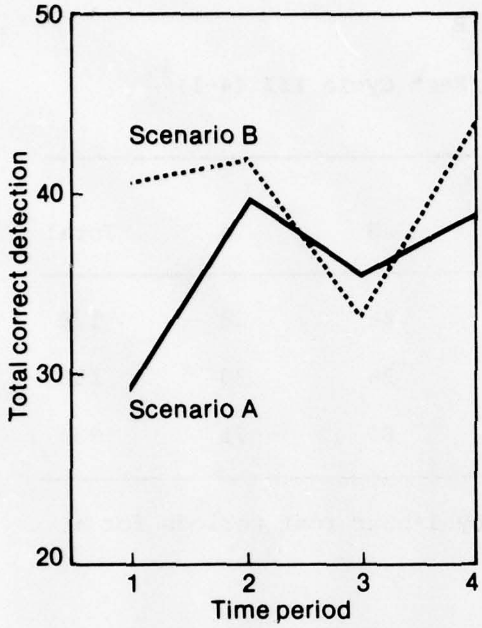

Figure 1. Correct detections for Work/Rest Cycle I.

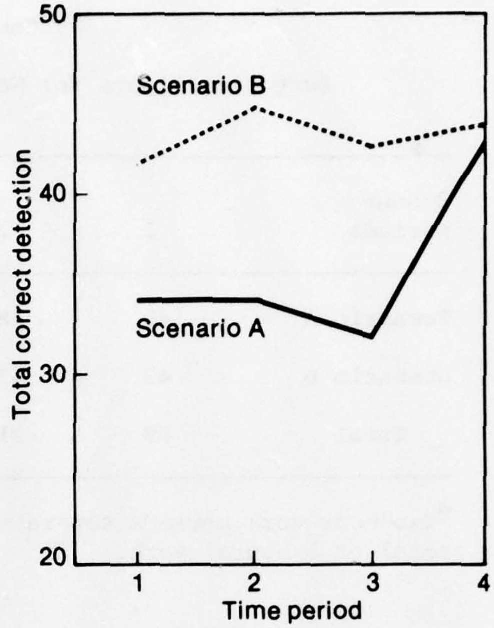

Figure 2. Correct detections for Work/Rest Cycle II.

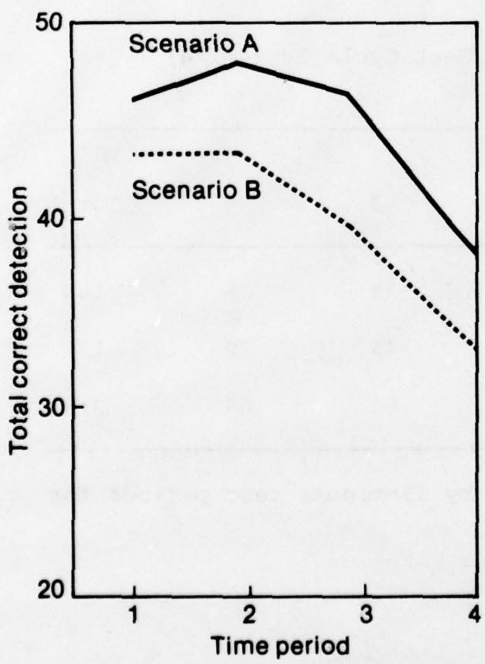

Figure 3. Correct detections for Work/Rest Cycle III.

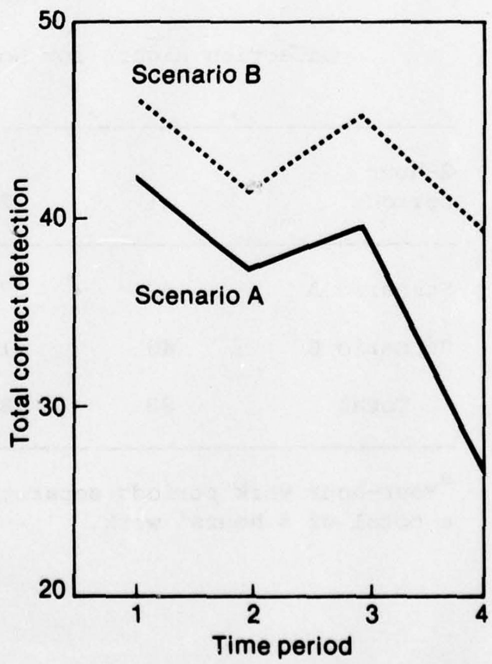

Figure 4. Correct detections for Work/Rest Cycle IV.

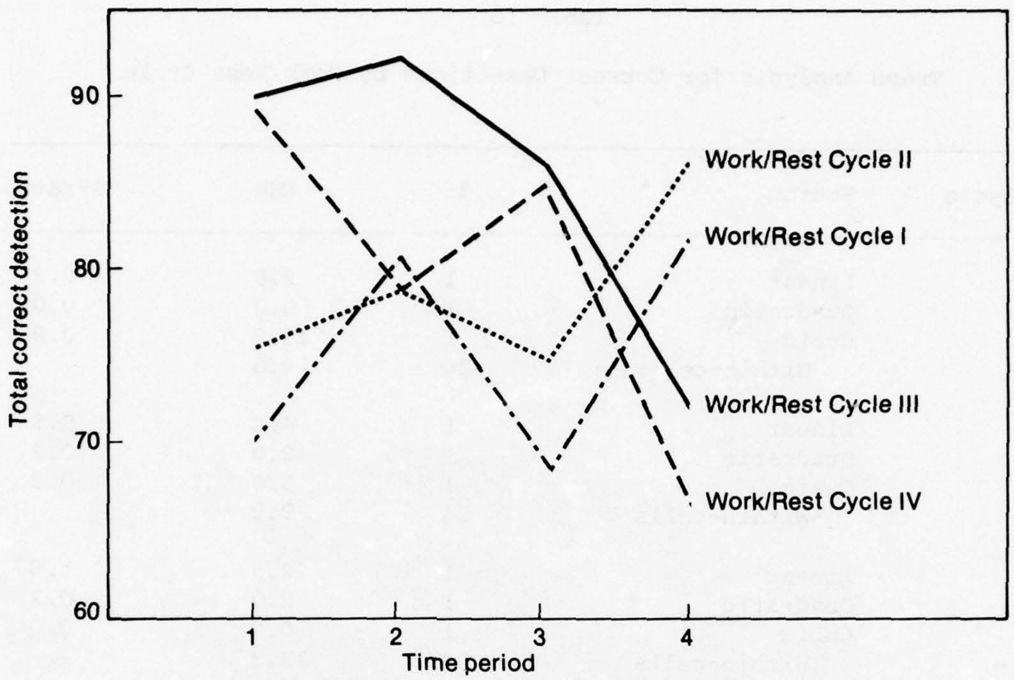

Figure 5. Total correct detections for each Work/Rest Cycle.

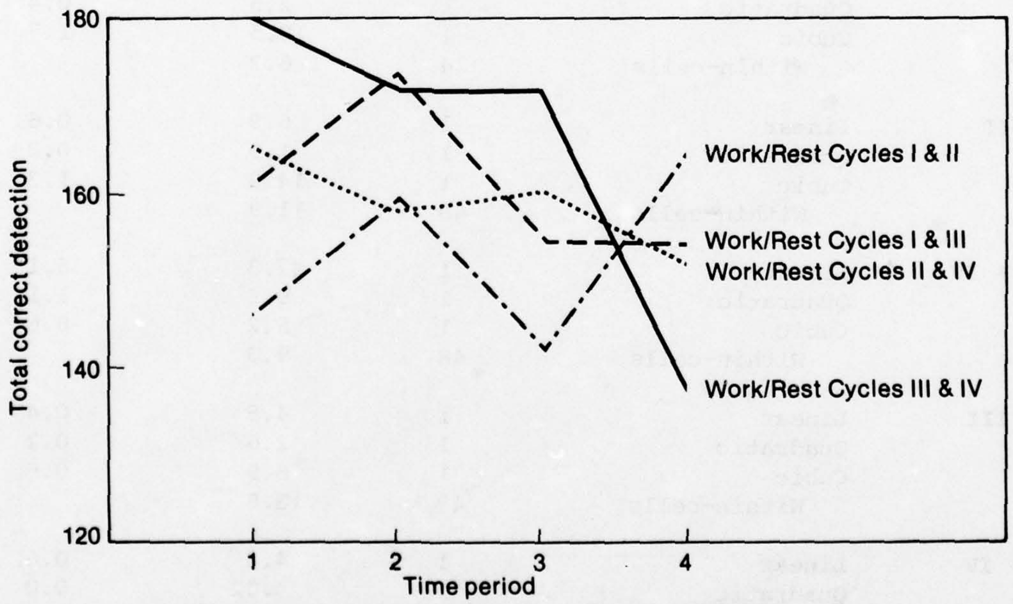

Figure 6. Total correct detections for Work/Rest Cycle pairs.

Table 10

Trend Analysis for Correct Detections by Work/Rest Cycle

W/R Cycle	Source	df	MSS	F-ratio
I	Linear	1	2.8	0.2
	Quadratic	1	0.3	0.0
	Cubic	1	13.8	0.9
	Within-cells	24	14.6	
II	Linear	1	4.2	0.5
	Quadratic	1	2.0	0.2
	Cubic	1	3.0	0.3
	Within-cells	24	9.2	
III	Linear	1	22.5	1.8
	Quadratic	1	8.0	0.7
	Cubic	1	0.0	0.0
	Within-cells	24	12.3	
IV	Linear	1	24.8	4.0
	Quadratic	1	2.5	0.4
	Cubic	1	10.5	1.7
	Within-cells	24	6.2	
I + II	Linear	1	6.9	0.6
	Quadratic	1	1.9	0.2
	Cubic	1	14.9	1.3
	Within-cells	48	11.9	
III + IV	Linear	1	47.3	5.1*
	Quadratic	1	9.8	1.1
	Cubic	1	5.2	0.6
	Within-cells	48	9.3	
I + III	Linear	1	4.8	0.4
	Quadratic	1	2.6	0.2
	Cubic	1	6.9	0.6
	Within-cells	48	13.5	
II + IV	Linear	1	4.3	0.6
	Quadratic	1	.02	0.0
	Cubic	1	1.1	0.1
	Within-cells	48	7.7	

*$p < .05$.

In addition to the trend analyses of the individual cycles, trend analyses were conducted by combining the data of the cycles into the following logical pairs: I and II, III and IV, I and III, and II and IV. This procedure provides a more powerful test for trend by increasing the number of observations on which it is based. Figure 6 presents the graph of overall performance for each cycle pair. The corresponding analysis and testing of trend components is given in Table 10.

From the F-tests indicated in Table 10, it can be seen that only Work/Rest Cycles III and IV combined have a significant linear trend. From Figure 6, it is evident that this trend is negative, implying that a degradation in performance occurs over the time periods.

As indicated in Figure 6, the downward trend of Cycles III and IV is accentuated by the fact that they started noticeably higher than Cycles I and II. It is possible that this initial high performance is an artifact of the experimental procedure. This beginning spurt may have been the result of a positive motivational reaction by the operators due to the realization that they would be finishing sooner than operators on Cycles I and II. Perhaps even more likely, the operators may have felt they were selected for the hardest job and were willing to work harder because the operators knew they would be monitoring 4 straight hours without a break.

The data and trends of the Work/Rest Cycle results suggest that for a contemplated 8 hours of monitoring, 2-hour work shifts interspersed with 1-hour or 15-minute rest periods are preferred over 4-hour work shifts interspersed with 1-hour or 15-minute rest periods.

As indicated in Table 5, the Days variable is nonsignificant. This outcome indicates that any fatigue, learning, or boredom effects from the first day's testing were not carried over to the second day's testing.

The String-Size variable is significant at the .01 level. Out of 24 possible detections the average operator could have made in 1 day for each string size, the 2-sensor strings resulted in 9.1 detections, a significantly lower figure than the 15.4 detections for the 3-sensor strings and the 15.1 detections for the 4-sensor strings. At least two factors could account for this result: The orientation of the USAICS places less emphasis on 2-sensor interpretation during training, and the targets in the 2-sensor string condition could be more difficult than those in the 3- and 4-sensor string condition because they included more personnel targets.

The Noise variable was nonsignificant, indicating that the high-noise level had no effect on detection performance. The low-noise scenario sections resulted in 40 correct detections, as compared to 39 in the high-noise scenario sections.

The Target Activity variable is significant at the .01 level. The low-target-activity condition resulted in an average 29.2 correct detections (out of a possible 48 for both scenarios); the high-target-activity condition had an average 49.7 correct detections (out of a possible 96 for both scenarios). The high-target-activity condition, however, contained twice as many targets as the low-target-activity condition. A statistical test of completeness (correct detections divided by total targets presented) resulted in a significant difference ($t = 6.31$, $df = 15$, $p < .01$). This outcome shows that the low-activity condition resulted in significantly higher completeness (61% versus 52%).

The Groups variable is significant at the .01 level. The operators in the eight groups were selected to minimize within-subjects variability for the purpose of increasing the power of the statistical test. The inclusion of a main effect for groups permitted this source of variability to be subtracted out of the error term, thus increasing the power of the statistical tests for other main effects.

The Scenario variable is significant at the .05 level. On the average, operators detected 37.9 targets on Scenario A and 41 targets on Scenario B (out of a possible 72 for each scenario). As with the Groups variable, control of this variable was necessary to increase the sensitivity of the statistical analysis and eliminate confounding.

The differences in the low- and high-target-activity conditions by scenario are shown in Table 11. The significant interaction between scenario and target activity indicates noticeably lower performance (22.6) in the high-target-activity condition of Scenario A than in the high-target-activity condition of Scenario B (27). The data in Table 11 also suggest that the difference in completeness between the high and low activity conditions occurred mainly in Scenario A.

Table 11

Mean Number of Correct Detections and Completeness by Target Activity and Scenario

	Scenario A	Scenario B	Sum
Low-Target Activity	15.3 (64%)	13.9 (58%)	29.2
High-Target Activity	22.6 (47%)	27.0 (57%)	49.7
Average	19.0	20.5	

The target activity by days interaction (Table 12) is significant at the .05 level. The cause of this interaction is difficult to identify because there is a decrement in performance for the low-target-activity condition.

Table 12

Mean Number of Correct Detections
by Target Activity and Days

Day	Low Target	High Target	Sum
Day 1	15.3	24.1	39.4
Day 2	13.8	25.7	39.5
Average	14.6	24.9	

The string size by target activity interaction presented in Table 13 is significant at the .01 level. This interaction is due to the substantially fewer correct detections in the high activity, 2-sensor string condition than in the 3- and 4-sensor string conditions. Equally informative is the completeness score of 26%, which is far below all other string-size and target activity level combinations shown in the table. This result suggests that 2-sensor strings could be used in areas where target activity is expected to be low with no loss in performance and with a reduction in system costs.

Table 13

Mean Number of Correct Detections and Completeness
by Target Activity and String Size

	2-sensor	3-sensor	4-sensor	Sum
Low-Target Activity	9.8 (61%)	10.4 (65%)	8.9 (56%)	29.1
High-Target Activity	8.3 (26%)	20.3 (63%)	21.2 (66%)	49.8
Average	9.1	15.4	15.1	

The string size by scenario interaction (Table 14) was significant at the .01 level, indicating that the number of correct detections using 2-sensor, 3-sensor, and 4-sensor string sizes differed, depending upon whether the scenario was A or B.

Table 14

Mean Number of Correct Detections by Scenario and String Size

	2-sensor	3-sensor	4-sensor	Sum
Scenario A	7.7	16.3	14.1	38.1
Scenario B	10.4	14.5	16.1	41.0
Average	9.1	15.3	15.1	

The three-way interaction of string size by target activity by scenario was significant at the .01 level. The raw scores and completeness values are shown in Table 15. Notice the exceptionally poor performance for both scenarios in the 2-sensor, high-target-activity condition.

Table 15

Mean Number of Correct Detections by String Size, Target Activity, and Scenario

String size	Low-Target Activity		High-Target Activity	
	Scenario A	Scenario B	Scenario A	Scenario B
2-sensor	3.9 (48%)	5.9 (73%)	3.7 (23%)	4.6 (28%)
3-sensor	5.8 (73%)	4.6 (58%)	10.4 (65%)	9.9 (62%)
4-sensor	5.7 (70%)	3.4 (42%)	8.5 (53%)	12.7 (79%)

The remaining interactions in Table 15 were all nonsignificant and are not discussed. Higher order interactions (i.e., beyond three-way interactions) were not analyzed because they would serve no useful purpose in this study.

False Alarms

Of particular interest to the present problem is the small number of false alarms reported by the operators. Only 11 false alarms were reported across both days of testing, a number insufficient for statistical analysis and relatively unimportant operationally. Also, the false alarms were distributed in a random fashion across 10 operators, who achieved a very high target reporting accuracy (better than 95%).

Correct Identifications

Table 16 presents the analysis of variance results for correct identifications. The Work/Rest Cycle variable was nonsignificant, as with correct detections. The same analyses were used to assess trends in correct identifications as in assessment of trends in correct detections.

Tables 17 to 20 present the correct identification data by work/rest scenario and time period. Figures 7 to 12 indicate that large fluctuations are apparent, both between the two scenarios and also in a comparison of one W/R cycle with another. Figure 11 indicates the overall trends in each of the four work/rest cycles for both scenarios combined. Cycles I and II showed no overall improvement or loss in performance across the four time periods. A trend analysis (Table 21) of these data detected no significant trends.

In contrast to the curves for Cycles I and II in Figure 11, the curves for Cycles III and IV present a downward trend. The trend analyses conducted across the four time periods for these data show a significant cubic trend only for Cycle IV. The practical portion of this cubic trend is the rapid decline in operator performance from period 3 to period 4 from a performance plateau across periods 1, 2, and 3.

Trend analyses conducted on pairs of the work/rest data are reported in Table 21. From the F-tests shown, it can be seen that Cycles III and IV combined resulted in a significant linear trend. This result parallels the decrease over time periods found for correct detections.

The Days variable was nonsignificant (Table 16). As with detection performance, Day 2 identification performance was not affected by Day 1 test activity.

Table 16

Analysis of Variance Table for Target Identification

Source of variation	df	SS	MSS	F
Work/rest cycles	3	.864	.288	.257
Days	1	.666	.666	.595
String size	2	163.734	81.867	73.160*
Noise	1	2.041	2.041	1.823
Target activity	1	219.010	210.010	195.719*
Groups	6	107.875	17.979	16.067*
Scenarios	1	7.593	7.593	6.786*
Days x string size	2	1.286	.643	.574
Days x noise	1	.843	.843	.753
Days x target activity	1	4.166	4.166	3.723
String size x noise	2	.223	.111	.99
String size x target activity	2	186.098	93.049	83.153*
String size x scenarios	2	14.828	7.414	6.625*
Noise x target activity	1	3.375	3.375	3.016
Noise x scenarios	1	1.041	1.041	.930
Target activity x scenarios	1	31.510	31.510	28.159*
Days x string size x noise	2	5.171	2.585	2.310
Days x string size x target activity	2	6.317	3.158	2.822
Days x noise x target activity	1	.843	.843	.753
String size x noise x target activity	2	1.421	.710	.634
String size x noise x scenarios	2	.255	.127	.113
String size x target activity x scenarios	2	20.067	10.033	8.966*
Noise x target activity x scenarios	1	.374	.374	.334
Residual	151	3352.555	22.202	19.841*
Error	192	215.000	1.119	
Total	383	4347.156		

*p < .01.

Table 17

Correct Identifications for Work/Rest Cycle I (2-1)[a]

2-hour periods	1	2	3	4	Total
Scenario A	28	35	24	31	118
Scenario B	31	37	27	37	132
Total	59	72	51	68	250

[a]Two-hour work periods separated by 1-hour rest periods for a total of 8 hours of work.

Table 18

Correct Identifications for Work/Rest Cycle II (2-1/4)

2-hour periods	1	2	3	4	Total
Scenario A	29	27	27	34	117
Scenario B	32	32	31	28	123
Total	61	59	58	62	240

Table 19

Correct Identifications for Work/Rest Cycle III (4-1)

2-hour periods	1	2	3	4	Total
Scenario A	37	34	33	31	135
Scenario B	30	30	32	21	113
Total	67	64	65	52	248

Table 20

Correct Identifications for Work/Rest Cycle IV (4-1/4)

2-hour periods	1	2	3	4	Total
Scenario A	26	25	23	18	92
Scenario B	42	37	40	29	148
Total	68	62	63	47	240

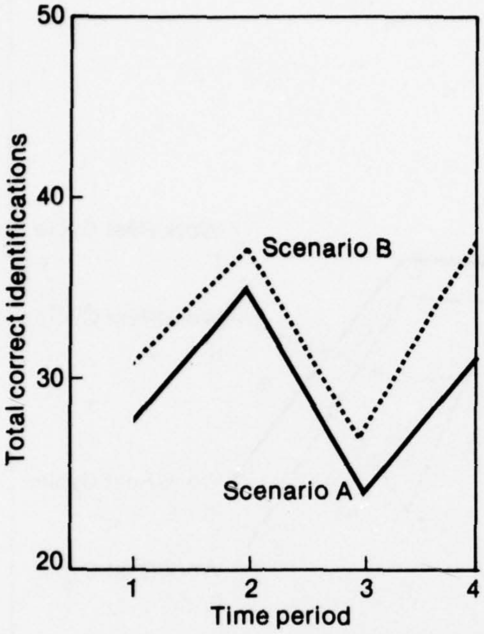

Figure 7. Correct identifications for Work/Rest Cycle I.

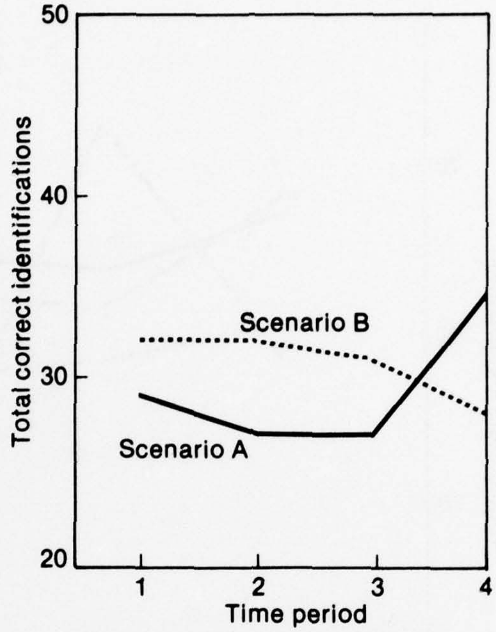

Figure 8. Correct identifications for Work/Rest Cycle II.

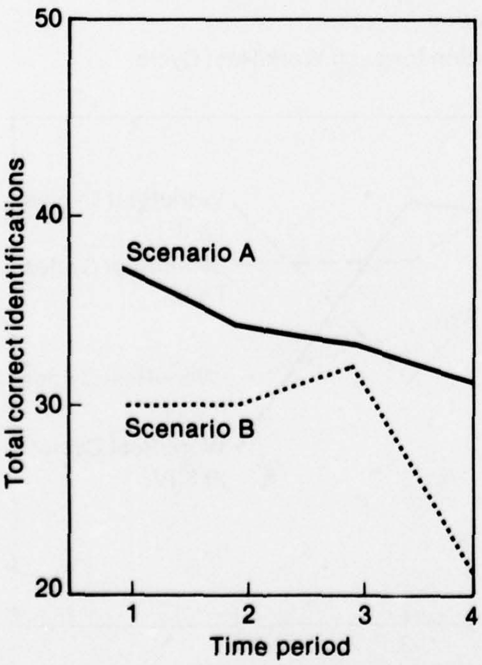

Figure 9. Correct identifications for Work/Rest Cycle III.

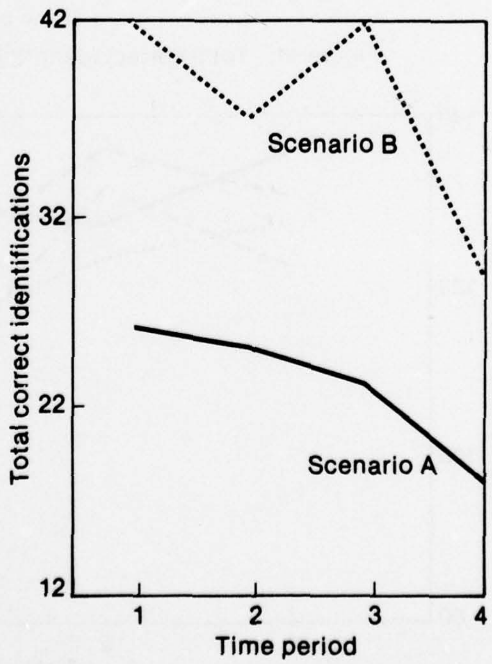

Figure 10. Correct identifications for Work/Rest Cycle IV.

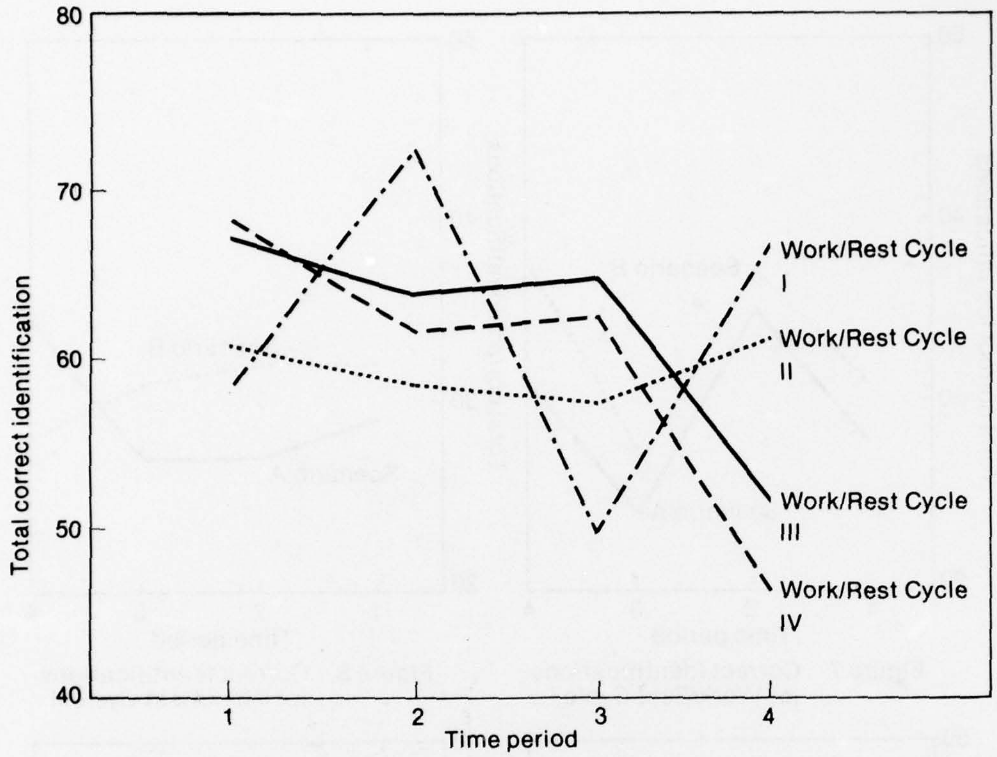

Figure 11. Total correct identification for each Work/Rest Cycle.

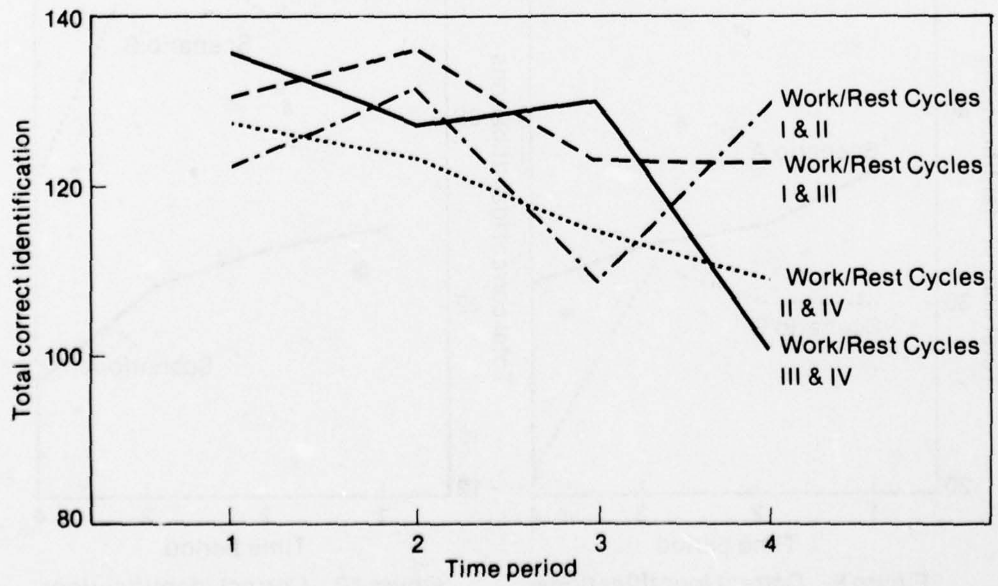

Figure 12. Total correct identification for each Work/Rest Cycle.

Table 21

Trend Analysis for Each Work/Rest Cycle Identification Score

Work/Rest Cycle	Source	df	MSS	F-ratio
I	Linear	1	0.2	0.2
	Quadratic	1	0.5	0.0
	Cubic	1	32.4	2.6
	Within-cells	24	12.4	
II	Linear	1	0.0	0.0
	Quadratic	1	1.1	0.1
	Cubic	1	4.6	0.5
	Within-cells	4	9.5	
III	Linear	1	12.1	1.4
	Quadratic	1	3.1	0.4
	Cubic	1	2.0	0.2
	Within-cells	24	8.4	
IV	Linear	1	24.0	3.3
	Quadratic	1	3.1	0.4
	Cubic	1	36.1	4.9*
	Within-cells	24	7.3	
I + II	Linear	1	39.2	3.7
	Quadratic	1	4.5	0.4
	Cubic	1	2.3	0.2
	Within-cells	24	11.0	
III + IV	Linear	1	35.1	4.5*
	Quadratic	1	6.3	0.8
	Cubic	1	5.5	0.7
	Within-cells	24	7.8	
I + III	Linear	1	4.5	0.4
	Quadratic	1	0.6	0.1
	Cubic	1	9.1	0.8
	Within-cells	48	10.4	
II + IV	Linear	1	11.3	1.3
	Quadratic	1	0.3	.0
	Cubic	1	1.3	0.1
	Within-cells	48	8.4	

*$p < .05$.

The String-Size variable was significant at the .01 level. Of the 24 targets for each of the three string sizes, an average of 7 were correctly identified for the 2-sensor strings, 12 for the 3-sensor strings, and 12 for the 4-sensor strings. This result, however, was due to the fewer targets detected with 2-sensor strings. Of the total number of targets detected with the 2-sensor strings, 72% were identified; of the total detected by 4-sensor strings, 81% were identified. These latter results may indicate that string size was not a factor in determining whether the target was vehicular or personnel.

The remaining identification results in Table 16 are similar to the detection results in Table 5. Of the main effects, the Scenario, Group, and Target Activity variables were significant at the .01 level, whereas Days and Noise were not. For the Target Activity variables, the identification completeness values (taking into consideration the unequal number of targets in each of the activity conditions) were also significant ($t = 2.73$, $df = 15$, $p < .02$), the low-activity condition having the higher mean.

Most of the significant interactions in the detection analysis were also significant in this analysis: string size x target activity, string size x scenario target activity. The significant residual means that one or more of the higher level interactions (i.e., beyond the three-way interactions) were significant but were not considered important to the objectives of the study. All of the remaining interactions are nonsignificant. Table 22 presents the confidence and elapsed time results broken down by W/R cycle, operator, and day. Tests of statistical significance for confidence were not conducted for several reasons. Posttest interviews revealed that some operators were not giving confidence with respect to the target detection as instructed, but with respect to the entire target report, including speed and length of the column. Of more importance, the absence of false alarms prevented an analysis of the variable, average confidence in correct detection minus average confidence in false alarms.

During the testing, irregularities were noticed with regard to the operators' handling of the variable, Elapsed Time. On many occasions it was observed that some operators were not reporting the clock time when they first detected a target as instructed but at some time during the target analysis. Even though frequent reminders were given, some operators would begin filling out the target information sheet without recording the time at which they had detected the target, or they would record the time only after they were positive that they had detected a valid target, usually long past the time of detection. The elapsed time data, therefore, contains considerable error variation, and for this reason a statistical analysis of this variable was not conducted.

Table 22

Average Confidence and Elapsed Time Results

Work/Rest Cycle	Day 1 Operator	Day 1 Confidence detection	Day 1 Elapsed time (min)	Day 2 Operator	Day 2 Confidence detection	Day 2 Elapsed time (min)
I	S1	2.9	3.0	S7	2.8	2.8
	S2	2.3	5.3	S8	1.0	5.0
	S9	1.4	5.7	S15	2.1	5.0
	S10	1.2	5.8	S16	1.5	3.4
Average		2.0	5.0		1.9	4.1
II	S3	2.9	4.9	S5	1.4	2.3
	S4	1.2	5.0	S6	1.2	5.3
	S11	1.0	2.6	S13	1.9	5.3
	S12	1.7	3.7	S14	3.0	2.3
Average		1.7	4.1		1.9	3.8
III	S5	1.2	3.0	S3	2.4	5.0
	S6	1.1	6.8	S4	1.0	6.4
	S13	1.7	5.2	S11	1.0	2.3
	S14	3.0	2.9	S12	1.5	2.9
Average		1.8	4.5		1.5	4.2
IV	S7	2.3	4.5	S1	2.7	2.7
	S8	1.5	3.9	S2	2.5	2.6
	S15	1.9	4.2	S9	1.7	7.5
	S16	1.9	3.4	S10	1.2	5.9
Average		1.9	4.0		2.0	4.7
Total		1.8	4.4		1.8	4.2

Error Analysis

During the test procedure it became apparent that almost half of the operators were having difficulty in using the column-length formula (Appendix B) and interpreting its results. This formula is used to determine target speed, length of column, and number of targets, three important types of information for target acquisition and intelligence estimates.

During posttest interviews, it was discovered that the operators were rejecting target detections if calculations of the column-length formula yielded negative answers or zero. Theoretically, these answers are impossible if a valid target is involved. However, they are completely reasonable in the real world considering the inaccuracies that could exist in the formula substitution values and the errors that can be made by an operator.

In the case of inaccuracies existing in the real world, an operator may be confronted with inaccurate sensor detection ranges, incorrect distances between sensors, wrong sensor types, and other inconsistencies. Some of these errors were present in the data given to the operators. The operators, however, were accustomed to working with more clear-cut, easily solved problems and tended to reject targets and target calculations that did not compute and yield expected answers.

In the case of errors that can be made by an operator, data analysis of the target log information revealed the following errors directly connected with the column-length formula:

1. Incorrect placement of the endpoints of sensor activation patterns for measuring TT_1 and T_M (time estimates).

2. Inaccurate estimations of TT_1 and T_M measurements even if the activations endpoints are not ambiguous.

3. Arithmetic errors in multiplication, division, and decimal point placement.

4. Confusion in computing the detection range (DR) value and in deciding what arithmetic function to use with it.

It was also discovered during data analysis that the nonseismic sensors (Electromagnetic Intrusion Detector (EMID), Magnetic Intrusion Detector (MAGID), and Directional Infrared Intrusion Detector (DIRID)) were not optimally used, especially when the column-length formula failed to work. For example, when sensor strings resulted in zero or negative number after computation of the column-length formula, the activation pattern was discarded as a true target instead of the nonseismic or confirmatory sensor being analyzed for the target information.

CONCLUSIONS AND RECOMMENDATIONS

Summary of Results

Correct Detections. Independently considered, none of the four work/rest cycles investigated showed any statistically significant advantage in operator detection performance.

When analyzed together, the two 4-hour work shifts (W/R III and IV, with rest periods of 1 hour and 15 minutes, respectively) resulted in a significant linear trend toward detection performance deterioration.

When analyzed together, the two 2-hour work shifts (W/R I and II with three rest periods of 1 hour or 15 minutes respectively) did not result in any significant changes in performance.

Time effects resulting from Day 1 testing had no appreciable effect on Day 2 performance.

The "battle noise" activations in the high-noise condition did not affect monitor performance when compared with the low-noise condition. This is interpreted to mean that the Army operators are receiving at least sufficient training in differentiating "noise" activations from "target" activations.

Detection completeness was significantly lower in the high-target-activity condition than in the low-target-activity condition when 2-sensor strings were used. This is a definite source of operator error.

False Alarms. The number of false alarms was negligible. The subjects showed high target reporting accuracy (in excess of 95%) but at the expense of relatively low completeness of target reporting (55%).

Correct Identification. Independently considered, only Cycle IV (4 hours work, 15 minutes rest, 4 hours work) showed any statistically significant trend. Cycle IV resulted in an increasing decline in operator performance over time.

When analyzed together, the two 4-hour work shifts (Cycles III and IV) showed a significant linear decline in performance.

Approximately four out of every five targets detected were identified correctly. The remaining targets were not identified correctly because of various operator errors, including inaccurate measurement of the target activation patterns and errors in arithmetic in the use of the column-length formula.

Time effects resulting from Day 1 testing had no appreciable effect on Day 2 performance.

The high-noise condition did not affect operator performance.

Operator identification completeness under the high-activity level was significantly lower when a 2-sensor string was used than when the 3- and 4-sensor strings were used. This is a definite source of operator error but is largely attributable to the poorer detection rate found when 2-sensor strings were used.

Column-Length Formula. The column-length formula provides an estimated target speed and length-of-column measurement and is typically computed for each detection that the operator feels is a valid target. In the process of determining why some targets were not detected, were detected but later scratched out, or were detected but incorrectly identified, the following operator procedural and arithmetic errors were noted:

1. Incorrect placement of the endpoints of sensor activation patterns for measuring TT_1 and T_M.
2. Inaccurate estimations of TT_1 and T_M measurements even if the activation endpoints are not ambiguous.
3. Arithmetic error in multiplication, division, and decimal point placement.
4. Confusion in computing the combined detection range (CDR) value and in deciding what arithmetic function to use with it.
5. Seismic and confirmatory sensors--EMID, MAGID, and DIRID were not used to full advantage.

Recommendations for Operational Application

1. For monitoring schedules over extended periods of time, 2-hour work shifts interspersed with 1-hour or 15-minute rest periods are to be preferred over 4-hour work shifts interspersed with 1-hour or 15-minute rest periods. The size of the rest periods did not seem to have an appreciable impact on operator performance.

2. The use of 2-sensor strings is advantageous from the convenience and cost factor point of view and results in no decrement in performance if target activity is low (3 targets per 30 minutes) and sensors are reliable. Use of 2-sensor strings in an operational situation should be considered, dependent on local conditions.

3. For operations similar to those in this study, use of 3-sensor strings results in the same operator performance as use of 4-sensor strings.

4. Scenario differences must be controlled for testing and research in this area.

Training Recommendations

1. Training programs should be oriented toward improving operator performance in areas found to be deficient in this investigation. The major sources of operator error were (1) detection and identification performance of those targets associated with 2-sensor strings in high-target-activity conditions, (2) column-length formula calculations, and (3) utilization of nonseismic and confirmatory sensors.

2. To perform accurate time measurements directly from the RO 376 tactical data, it would be advantageous to develop a small, easily used ruler accurate to 0.1 minute. To perform arithmetic calculations and decimal point placement, it would be advantageous to develop a job aid in the form of a nomograph.

3. The present-day training for target detection during "battle noise" conditions should be continued.

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APPENDIX A

DEVELOPMENT OF THE SCENARIOS

The development of two realistic and equivalent performance measures (Scenarios A and B) was accomplished in a series of phases. Each phase was followed by reevaluation and revision.

The initial phase of development consisted of review of pertinent literature, and detailed studies of all BASS III and UGS 1030 field data. Target activations from this field data were used in the scenarios. Emphasis was placed on the requirements of the Target-Dependent Independent variables.

Additional detailed summary tables containing all relevant information found in the field data were constructed. These tables included information on sensor type, sensor configuration, radio frequency, sensor ID number, target type, number of targets, field study number, troop scenario number, field run number, dates, times, amounts of noise, and judged difficulty levels (subjectively determined) of the target activations.

Recordings of activations and records of target activity of two MASSTER field tests were available. Field test UGS 1030 involved wheeled and tracked vehicles as targets in groups of from 1 to 9 traveling at different predetermined speeds. BASS III involved personnel as targets in groups of 1 to 20. All target groups traveled on predetermined paths according to a time schedule.

Both the BASS III and UGS 1030 field data had been collected on eight radio frequencies (RF). It was necessary to select 2 RF's from each of the studies because of electronic recording constraints. Those which were selected (790 and 1,690 from BASS III and 190 and 1,150 from UGS 1030) contained the greatest amount of usable data. The data from these four frequencies were further analyzed in an attempt to determine which specific sensor ID and sensor strings provided the largest amount of quality data. A total of 60 sensor ID's were chosen to be used in the scenarios.

With the usable data then reduced to 4 frequencies and 60 ID's, the specific targets were selected. The criteria applied to target selection were the following:

1. Activations involving strings composed of 2, 3, or 4 sensors

2. Activations within a 30-minute segment covering a range of difficulty

3. Balance between number of vehicular and personnel targets

4. The presence of at least a minimal amount of staircase patterning in each target.

APPENDIX B

OPERATOR INSTRUCTIONS

A. Test Procedure Training

Before the operators entered the testing room the following preparations were made:

1. Placed two tables and four chairs in each corner of the test room with two X-T event recorders on each table.
2. Checked to see that the event recorders were in proper running condition. Checked recorder operation when driven by a master recorder or independently.
3. Loaded pretest tape into each event processor and checked operation when carriage was lifted out.

MONITOR: Read the following instructions (15 minutes):

As you already know, you have been selected to participate in a research effort to study UGS performance under various conditions as they might exist in the field. We have been contracted by the Department of the Army and this school to administer this exercise to you, to collect performance data, to analyze the results, and to submit a report. I want to make it clear at the outset that our objective is not to isolate each of you and attach a proficiency score to each of you. Our objective is to determine the total capability of the UGS information potential as it combines both the man (you) and the machine output (the UGS record). However, part of your performance will be scored and given to the school for its use.

To summarize the entire exercise, you will be given UGS sensor records (XT plots) to interpret. These plots, for the most part, are target activations that have been collected under various field exercises primarily in the Fort Hood area. Involved in these exercises were varying numbers of tanks, APCs, and personnel. These tests also contain noise activations which are typical of wartime operation, such as fixed-wing and helicopter activity, malfunctioning and unreliable sensors, radio interference, weather/wind activity, and artillery-shell bursts. All we ask is that you interpret the X-T plots to the best of your ability and try to make sense out of what sometimes might appear to you to be rather difficult. Let me stress that we have tried to make these records as realistic as we could.

You will interpret these X-T plots under periods of work and rest similar to those under battlefield conditions. You will probably become tired and fatigued because of the workload. However, in wartime it might be a lot worse. You wouldn't slow down then because your life might depend on how well you do your job. There is a great need for the Army to find out how typical UGS specialists will be able to function under battlefield conditions. The results of this test should give them an idea.

You are important because you, as a group, represent the hundreds of specialists who have graduated and will graduate from the UGS School for a long time to come. Army deployment plans for UGS equipment and personnel will be partly influenced by what you can do under various workload conditions.

Since we will be repeating this exercise with other UGS operators, I will read the instructions to you so that all groups will get the same information. However, you may ask questions at any time.

At this time we will pass out the test packets which contain all the materials you will need today. Take out all the materials carefully. The first sheet should be a questionnaire. Complete this questionnaire at this time. Feel free to ask questions.

MONITOR: Pass out packets and administer and collect questionnaires (10 minutes). Discuss Target Log Sheet (30 minutes).

The next sheet should be a TARGET LOG (see Table B-1). On this sheet you will record most of the target information you would regularly record on a SENSOR ACTIVATION SPOT REPORT plus additional information. Note the first column of the target log. This is the pattern log number. For activation patterns on the chart paper that you think are targets we want you to circle the target on the chart paper and number it. Record the number in the first column. Each target that you detect always number and record on your target log. If you detect a target but later feel it is not a target do not erase what you have written but simply write "No Target" and start recording the next target on the space below. Number all your targets consecutively in sequence.

In column 2 record the clock time that you made a target detection and round it off to the nearest minute. You can use your wristwatch but be sure it is synchronized with the wall clock.

In column 3 record the pen numbers of the sensor string.

In column 4 record how confident you are that what you think is a target really is a target. Use the terms of confidence that are shown at the bottom of the target log sheet: positive, high, 50/50, and low. Tell us how confident you are that the activation pattern you are looking at really is a target. Assuming that you will be sending this information to your company commander during a battle situation. He knows you are doing your best but he wants to know how confident you are in

Table B-1

Target Log

Name ____________________

1 Pattern number	2 Clock time detected	3 Pen numbers	4 Confi- dence	5 Direc- tion	6 Speed (S) = D/T_M	7 Target type	8 Column length $L_C = S(TT_1) - D_R$	9 Quantity	10 Clock time finished

*Confidence ratings: Positive, high, 50/50, low.

the information you are sending to him. If you are not confident in your information then he will place a higher weight on the information being supplied to him by other intelligence sources such as real-time IR reconnaissance, radar, or electronic intelligence. The confidence estimate should relate only to your detection of a target and not necessarily to any of the following information.

In column 5 record the direction of movement of the target. Use the terms NW, NE, SW, and SE.

In column 6 compute the speed of the target using the formula,

$$\text{Speed (S)} = D/T_M$$

where D = distance between sensors
T_M = mean time of activations from center of the first sensor activation to the center of the second sensor pattern.

Show your calculations for speed in the space provided. Round off your speed to the nearest meters/minutes.

In column 7 record the target type whether personnel or vehicular. If the speed is less than 150 meters/minutes, call the target "personnel" and write P. If the target is greater than 150 meters/minutes call the target "vehicles" and write V.

In column 8 compute the length of the target column using the formula,

$$L_C = S\ (TT_1) - D_R,$$

where S = speed calculated and recorded in column 6
TT_1 = total time the first sensor was activated
D_R = detection range which is the detection radius of the first sensor plus the detection radius of the second sensor added. In this test the detection radius of all sensors in a string is the same.

Substitute the values in the formula in the spaces provided and show your work. Do your actual multiplication on scratch paper. Round off your numbers where appropriate.

MONITOR: Find out what they have been taught in UGS school for rounding numbers.

In column 9 record the quantity or number of units in the target. If the target is personnel, divide the length of the column by 5 meters to determine the number of personnel. If the target is vehicles, divide the length of the column by 50 meters to determine the number of vehicles.

In column 10 record the clock time in which you are finished with the target and are ready to send the information to your company commander.

The sequence of the information required on the target leg was planned and we want you to try to use this sequence. Does anyone have any reservations about this sequence? If another sequence works better for you let us know so everyone can try it.

MONITOR: Discuss the Implant Sketch (Field I). (10 minutes)

Remove your target log and place it aside. The next sheet should be an implant sketch (see Figure B-1) which is marked on the upper right-hand side Pretest, Part I. As you know, implant sketches show the location of the sensor strings.

During the next couple of days, you will be using implant sketches very similar to this one. The implant sketches will show the location of the sensors along the roads and trails, give the pen number for each sensor, the string number, and the distance between the sensors.

As you can see, the spatial relationships between the sensors are not drawn to scale. This is the case with all the implant sketches you will be given during this entire exercise. The purpose of this implant sketch is merely to present you with the information that you will need. There will also be times in which you may disagree as to the placement of the sensor strings in the various deployment patterns. Although certain string deployments may differ from what you feel or have been taught, accept the deployments presented, keeping in mind that in operational situations there are many factors involved in deploying sensors. The sensor string deployments are the ones used in the Fort Hood tests and are adequate for purposes of this exercise.

The implant sketches will also provide you with information as to whether the string contains a MAGID, ACOUSID, EMID, or DIRID sensor. In this implant sketch (Pretest, Field I) there are three MAGIDs.

MONITOR: Discuss the Sensor Program Record.

Put the implant sketch aside. The next sheet should be a SENSOR PROGRAM RECORD (see Table B-2). This sheet provides the string number and field designation, sensor type and detection ranges of the various sensors. It contains four sections to provide this information for four different sensor fields. On this sheet three sensor fields are shown: I, II, and III. Right now we will be concerned with only the first sensor field labeled roman numeral I. The sensor record or readout sheets you are probably using to work with contain a great deal more information including geographical coordinates, sensor ID, sensor frequency,

Table A-3

Example Implant Sketch Part II

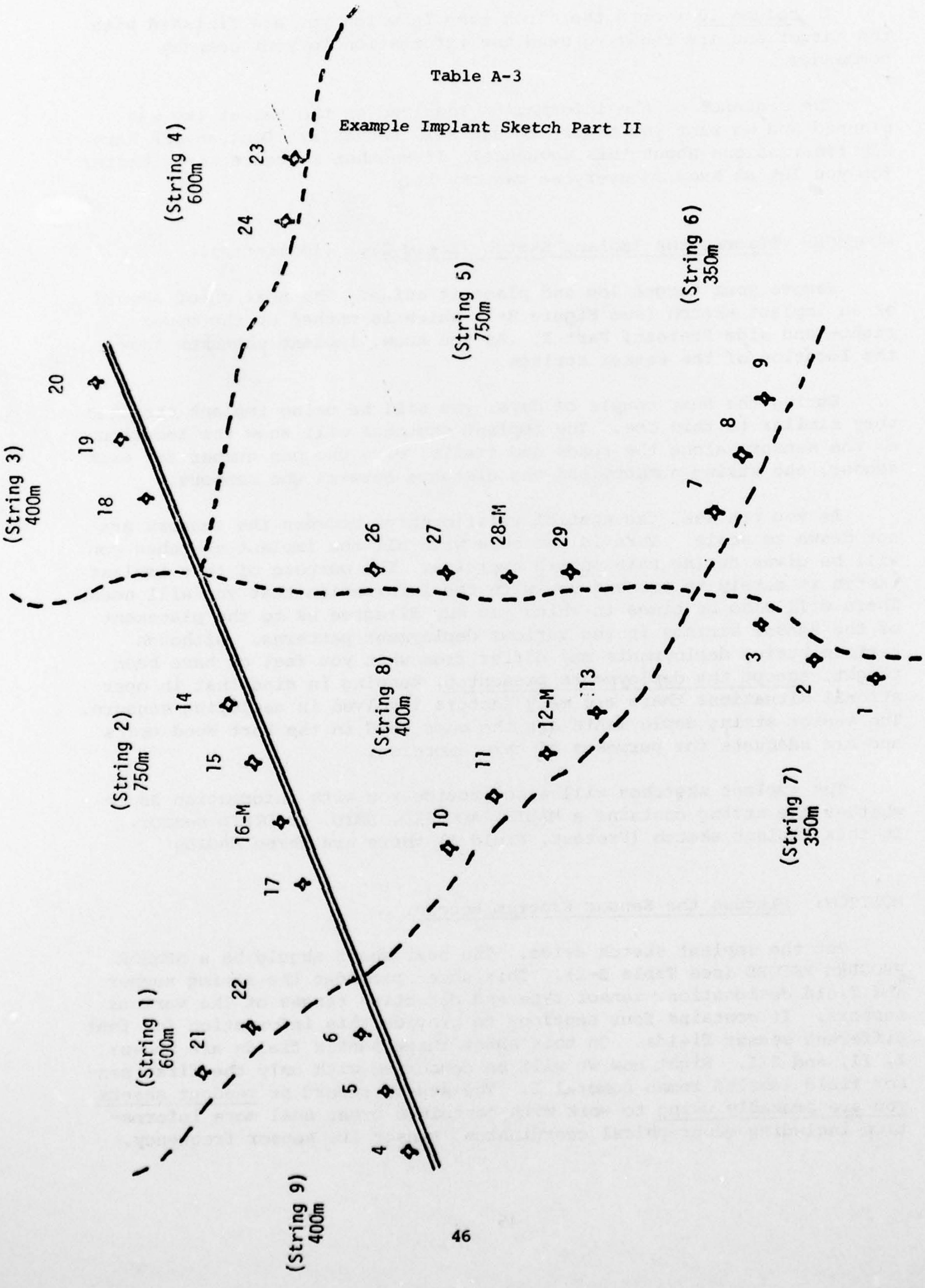

Table B-2

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Sensor Program Record

Pen #	String/ field	Type sensor	Detection radius Per	Veh	Pen #	String/ field	Type sensor	Detection radius Per	Veh	Pen #	String/ field	Type sensor	Detection radius Per	Veh
1	6	DSID	30	300	1	8	ADSID	30	300	1	1	ADSID	30	300
2	6	DSID	30	300	2	8	ADSID	30	300	2	1	ADSID	30	300
3	6	DSID			3	8	ASID			3	1	ADISD		
4	5	DSID	30	300	4	10	DSID	30	300	4	1	ACOUSTIC	SEISMIC	
5	6	DSID	30	300	5	10	DSID	30	300	5	1	ADSID		
6	5	DSID			6	10	DSID			6	1	ADSID		
7	-				7	7	MINISID	30	100	7	2	MINISID	30	100
8	-				8	7	MINISID	30	100	8	2	MINISID	30	100
9	Malfunction				9	7	MAGID	MAGNETIC		9	-			
10	4	MINISID	30	75	10	9	MINISID			10	3	MINISID	40	500
11	4	MINISID	30	75	11	9	MINISID			11	3	MINISID	40	500
12	4	MAGID	MAGNETIC		12	9	MAGID	MAGNETIC		12	3	MAGID	SEISMIC	
13	4	MINISID			13	9	MINISID			13	3	MINISID		
14	2	ADSID	30	300	14	2	DSID	30	300	14	-			
15	2	ASID	30	300	15	2	DSID	30	300	15	-			
16	2	ADSID			16	2	ACOUSID	SEISMIC		16	-			
17	2	ADSID			17	2	DSID			17	-			
18	-				18	3	MINISID	50	600	18	6	MINISID	30	100
19	-				19	3	MINISID	50	600	19	6	MINISID	30	100
20	-				20	3	ACOUSID	SEISMIC		20	6	MINISID		
21	-				21	1				21	4	DSID	30	300
22	-				22	1				22	4	DSID	30	300
23					23	5	ADSID	30	300	23	4	DSID		
24	3	MINISID	30	100	24	5	ADSID	30	300	24	4	DSID		
25	3	MINISID	30	100	25	-				25	-			
26	3	MAGID	SEISMIC		26	6	MINISID	30	100	26	5	MINISID	30	775
27	1	MINISID	30	100	27	6	MINISID	30	100	27	5	MINISID	30	775
28	1	MINISID	30	100	28	6	MAGID	MAGNETIC		28	5	MAGID	MAGNETIC	
29	1	MAGID	MAGNETIC		29	6	MINISID			29	5	MINISID		
30	-				30	-				30				
							Field II					Field III		

mode, and inhibit times. The ones we will work with are simplified for purposes of this exercise.

Notice that for detection radius, a value is given for vehicles and for personnel. Detection radius varies greatly for vehicles and personnel depending upon the sensor type, soil type, and gain setting. The detection radius of the first two sensors of every string will always be given since you will always determine the time between the midpoints of the first two activations in a string used to determine target speed.

MONITOR: Administer Pretest, Part I.

Place your target log, implant sketch, and sensor record in a convenient place near your event processor which is already loaded with our X-T chart paper. Put your packet aside. We will work through a 30-minute practical exercise, in which we will use the materials we have just discussed. Fill out your target log and use your implant sketch and sensor record. Please do not write on the implant sketches or the sensor record. As you detect patterns that you think are targets, circle the pattern on the chart with your pencil and place the number of the target next to the circle. Then fill out your target log by first recording this number in column 1. Are you ready? Start monitoring.

MONITOR: Turn on Event Processors.

Check each man to be sure he is working with proper materials. When the first group of noise activations has completely appeared, find out if anyone called them targets. When the first, second, and third targets have each appeared (in different time frames) find out who did not detect them as targets and assist these people. For the first target, work out the calculations on the blackboard if necessary. Find out how this class is performing and give assistance individually or for the entire class as required. Emphasize aspects of the procedure that are not being performed. Check each man to be sure he is properly filling in all the information blanks on the target log.

At the end of the 30-minute period turn off the event processors no more than one-half inch above the line separating the 30-minute periods and review procedures where appropriate.

MONITOR: Read the Following:

During the next several days, you will be monitoring various 30-minute chart preparations. After each 30-minute period you will use a new implant sketch. We will begin the next 30-minute period shortly. Get your packets and take out the implant sketch marked Pretest, Part II, in the upper right-hand corner. Do you have any questions concerning this one? Remember, you are numbering your targets consecutively in sequence so if you need additional target logs let us know and we will supply them. Again, do not write on the implant sketches or the sensor record sheets. Be sure you are working with the appropriate sensor record. For the next 30-minute segment you will be working with the sensor record, labeled Pretest II. Are there any questions before we begin the next 30-minute segment? All right, we will now start.

MONITOR: Turn the Equipment on and Administer Pretest, Part II.

Conduct Pretest, Part II, in a manner similar to Part I, with somewhat less involvement of the monitors during the test. Check what procedural problems are still occurring. At the end of the 30 minutes, turn off the equipment not more than one-half inch below the line indicating the next 30-minute segment. Address the entire class on procedural problems and reiterate where necessary.

MONITOR: Read the Following:

The next 30-minute segment, Pretest, Part III, will be the last one this afternoon. Get your packet and take out the implant sketch marked Pretest, Part III, and place your old one at the rear of the event processor. Do you have any questions concerning this new implant sketch? Take your sensor record and if you desire, place a piece of paper over sensor field II so you will not confuse it with the next sensor field which is roman numeral III. You may write on the target log, but do not write on the implant sketch and sensor record sheets. During this next 30-minute period we will let you work quietly and discuss any problems afterwards. If you are going to use your wristwatch, synchronize it with the wall clock. Are there any questions before we begin? All right, we will start now.

MONITOR: Turn the Equipment on and Administer Pretest, Part III.

Since the results of this 30-minute segment will be used as the basis for subject placement into homogeneous groups, there should be little or no interplay between personnel. At the end of this segment ask the subjects to roll up their chart paper, tape it, and place it on top of the event processor. Review any final procedural problems.

MONITOR: Read the Following:

Thank you for your cooperation today. Today's activities were geared to teaching you the procedures that will be used during the next 2 days. You will be monitoring 30-minute segments tomorrow but we will not stop you after each one as we did today. You will continue to work through the 30-minute segments for different periods of time and you will receive a different implant sketch for each 30-minute segment. The implant sketches you will be working with during the next 2 days are similar to the ones you worked with today.

Tomorrow, you will be interpreting UGS tapes during different periods of work and rest. Some of you will be working longer tomorrow and some of you will be receiving longer rest periods and lunch breaks than others. However, these differences will equalize the second day so that everyone will have worked and rested approximately an equal amount of time. Tomorrow, take the same seats at 7:30 to start.

B. Test Administration

MONITOR: Do the Following Before Operators Arrive:

Based upon the pretest scores, rank-order the operators and place them in matched groups. On a class roster place the appropriate operator number next to each name. On each operator-numbered test packet write the appropriate name and place the packets and target logs on the tables as per the administration plan.

As each operator enters the test room, have him find his own packet or assist him. Each event processor must be fully loaded with the appropriate work/rest cycle X-T scenario. Check to see that operators have a pencil and X-T plot. Begin the testing promptly at 7:30 and try to maintain the testing schedule.

MONITOR: Read the Following:

Take the material out of your test packets. The first two sheets will be a sensor record sheet and the implant sketch for your first 30-minute period. All the implant sketches and sensor record sheets that you will use today and tomorrow are the same as those you studied yesterday. Remember that you will not stop working after each 30-minute segment but will continue to work until you have completed your work shift. All of you will be given a lunch break and some of you will get several rest periods. You will be told as a group when your rest period will occur. Depending upon which group you are a member of, you will receive different periods of work and rest. However, as I said yesterday, total work and rest across the 2 days will be equal for all of you.

I would like to remind you that the wall clock is right there (point to it) to get the times required on the target log. If you are going to use your wristwatch, set it with the wall clock now. We will not be assisting you in any way with respect to your target analysis. We will, however, be assisting you to make sure you are looking at the right sensor record and implant sketch throughout the exercise. If you have any questions with regard to whether or not you are using the proper sensor record or implant sketch please do not hesitate to ask. Be sure to circle the activation patterns that you think are targets. Number these patterns consecutively and record in the first column of the target log. Are you ready? Begin.

MONITOR: Turn the Equipment On.

Check to see that all the equipment is running satisfactorily. Every 30 minutes each monitor will supervise the changing of the implant sketches for two groups of four subjects. The monitor will be sure that each operator is using the proper implant sketch and sensor record.

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