AD-A011 547

SEEKVAL PROJECT IA1: EFFECTS OF COLOR AND BRIGHTNESS CONTRAST ON TARGET ACQUISTION

Robert L. Hilgendorf, et al

Aerospace Medical Research Laboratory
Wright-Patterson Air Force Base, Ohio

July 1974

191096

ADA011547

AMRL-TR-74-55

SEEKVAL PROJECT IA1: EFFECTS OF COLOR AND BRIG... TARG...

ROBERT ...

AEROSPACE ...

BRADDO...

Approved for public release; distribution unlimited.

AEROSPACE MEDICAL RESEARCH LABORATORY
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT—PATTERSON AIR FORCE BASE, OHIO 45433

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AMRL-TR-74-55	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) SEEKVAL Project IA1: Effects of Brightness Contrast on Target Acquisition		5. TYPE OF REPORT & PERIOD COVERED Final Report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Robert L. Hilgendorf, Major, USAF John Milenski*		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Aerospace Medical Research Laboratory Aerospace Medical Division, AFSC Wright-Patterson Air Force Base, OH		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62202F; 7184; 718410; 71841013
11. CONTROLLING OFFICE NAME AND ADDRESS Aerospace Medical Research Laboratory Aerospace Medical Division, AFSC Wright-Patterson Air Force Base, OH		12. REPORT DATE July 1974 13. NUMBER OF PAGES ~~58~~ 74
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

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

18. SUPPLEMENTARY NOTES

*Braddock, Dunn and McDonald, Inc., El Paso, Texas

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

Vision
Target acquisition
Brightness contrast
Color

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

Report covers an experiment to determine the effects of target color and brightness contrast on visual detection performance by means of the unaided human eye. The data consist mainly of elapsed times between search initiation and correct detection of tank targets at a simulated slant range of about 1 mile. Statistical methods are employed to assess the effects of color (three levels of contrast factor, i.e., -0.6, -0.2, 0.6) on detection performance. Under the

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) extant experimental conditions, effects due to color and brightness contrast were each statistically significant; however, interaction effects between these two factors were not statistically significant. The effect of color tended to account for more variance than the effect of brightness contrast.

PREFACE

This report covers the third of a series of experiments for the Combat Air Support Target Acquisition Program (SEEKVAL) in response to SEEKVAL Project Plan IA1, July 1973. The following were key personnel in the accomplishment of this third experiment:

Jackie Douglas Colonel, USAF	Director, SEEKVAL Joint Test Force
K. Geiger Major, USAF	SEEKVAL Project Manager
R. L. Hilgendorf Major, USAF	Laboratory Project Manager
R. G. Searle SSgt, USAF	Laboratory Experimenter
H. Arenas A1C, USAF	Laboratory Project Technician
J. W. Milenski BDM, Inc.	Chief Analyst
J. S. Brackett BDM, Inc.	Analyst

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION AND PURPOSE

The overall purpose of this experimental series is to investigate the Aerospace Medical Research Laboratory's Tactical Response Facility's (TRF's) terrain model simulation methods in terms of evaluating direct visual target acquisition (TA) performance in the combat air support mission. It is planned to verify this methodology by field tests at a later date. This research is limited to TA from the air under daytime visual conditions in a Central European environment (SEEKVAL, 1973a).

The specific objective of the first two experiments was to examine the effects of number of tank targets (1, 3, or 9) and clutter density (defined as low, medium, or high numbers of trees in the immediate target area) on TA performance with remaining target and background factors fixed at nominal values as much as possible (SEEKVAL, 1973b). The first experiment (Hilgendorf *et al.*, AMRL-TR-74-4) dealt with the effects of these factors, target number and clutter, on dynamic target acquisition (i.e., with the subject moving). The second experiment (Hilgendorf and Milenski) dealt with the effects of these two factors on static target acquisition (i.e., with the subject stationary).

Generally, the results from the first two experiments indicated a significant main effect due to target number, but no consistent effect due to the clutter conditions. In other words, the effects of number of targets appeared to be more important than those of clutter on acquisition performance in both the static and dynamic modes, and there was no statistically significant interaction between the target and clutter factors.

The present experiment is concerned with the effects of color (green, brown, and gray) and brightness contrast (-0.6, -0.2, and 0.6) on TA. Brightness contrast as an experimental factor is defined as:

$$\text{Brightness Contrast} = \frac{B_T - B_B}{B_B}$$

Where: B_T = Brightness of the target

B_B = Brightness of the background

The other factor, color, includes some influences that have not been clear in the research literature. There is little or no information available concerning the effects of color (wavelength) on target acquisition with the brightness controlled. Further, there is not a large amount of information available to determine the capability of human observers to discriminate among stimuli on the basis of wavelength alone.

A recent paper by Hilz and Cavonius (1970) reported on the discrimination of wavelength differences using wavelength-modulated gratings as stimuli. Using square-wave gratings with the bars matched for brightness, the discriminations were measured over the range 480 to 660 nm. Wavelength-difference thresholds in all regions of the spectrum studied increased with the spatial frequency of the grating. Particularly with the lower spatial frequencies, the thresholds were smallest in the region of 600 nm.

An earlier effort by Bedford and Wyszecki (1958) had revealed that wavelength discrimination positions of relative maxima are in the ranges of 435-450 nm. and 510-540 nm. and positions of minima are in the ranges of 415-425 nm., 460-480 nm, and 570-595 nm. They measured wavelength discrimination by the method of least noticeable differences involving two halves of a visual field. Dimensions of the field were 1°, 12' and 1.5'. Brightness expressed in trolands, were 100 for the 1° field; 25, 100 and 500 for the 12' field; and 300, 900 and 2,000 for the 1.5' field.

The two studies discussed above are reasonably representative of the many research efforts on wavelength discrimination and the variables that influence it. Typically, one or two qualified observers are used with the methods of least noticeable difference or constant stimuli and attempts are made to look at such variables as field size, luminance, spectral bandwidths, and stimulus exposure time (Siegel, 1965). Concerning the latter, it has been found that wavelength discrimination improves as exposure time is increased. Despite the data available, there still remains some question concerning the ability of relatively large numbers of subjects to discriminate on the basis of color, particularly involving target acquisition in an applied experimental setting.

In a theoretical sense, if brightness contrast between target and background were zero, then if any discriminations were made, they would be based on wavelength primarily. The effect of wavelength, or color, on target acquisition has not been widely discussed in the target acquisition literature. Color is normally thought to lack importance since, at longer slant ranges, atmospheric attenuation appears to diminish its effects. However, at shorter ranges, this is probably not the case and this phenomenon has not been sufficiently investigated. This paper is an attempt to establish a beginning for filling this gap in the research literature.

METHOD

SUBJECTS

The subjects were 36 male college students or Air Force enlisted personnel with normal color vision and 20/20 visual acuity or better. All had served as subjects in one of the two earlier SEEKVAL experiments.

APPARATUS

The terrain model which was used as the background over which the subjects searched for the tank targets is on a scale of 1:1000 and represents a portrayal of Central European terrain. It measures 5 feet by 18 feet which represents a terrain of over three miles long by slightly less than one mile wide. It reasonably simulates the color and reflectance properties of the real world within the visible portion of the electromagnetic spectrum. A more detailed description of the terrain model and the model's configuration for the SEEKVAL experimental series are contained in the first report (Hilgendorf et al., AMRL-TR-74-4).

Three tanks were placed in each of the three target locations on the model for each trial. The tanks were deployed with spacing simulating approximately 50 meters between vehicles. An analysis of the scale tank dimensions is contained in the earlier report (Hilgendorf et al., AMRL-TR-74-4). The amount of clutter in each target area was held at "medium" (i.e., 20 trees in the area which simulated 200 meters in radius).

Since the two experimental factors were color (green, brown and gray) and brightness contrast (-0.6, -0.2 and 0.6), the main aspect of preparation for this experiment involved the development of the nine paint surfaces which represent the nine combinations of color and brightness (light, medium and dark). The medium (-0.2 brightness contrast) green is the color which was used in the two earlier experiments. Table 1 is a summary of the nine surface characteristics while Figures 1, 2 and 3 display the paint spectra.

The subject was positioned directly adjacent to each target array at a simulated altitude of 3500 feet. Annex A contains the detailed experimental geometry for the experiment. The subject was required to keep his head stationary and an NAC Eye-Mark Recorder was employed so that a video as well as audio tape could be recorded. One of the eyes was occluded because, at the actual ranges which were being simulated, there would be no stereoscopic distance/depth cues.

EXPERIMENTAL DESIGN

The experimental design was a partially confounded 3 x 3 x 3 factorial replicated four times which provided a total of 108 observations. There were three data points for each of the 30 subjects. The three factors refer to brightness contrast (the three levels of which are -0.6, -0.2 and +0.6), color (the three levels of which are green, brown and gray), and location (the three levels of which correspond to the position of the target arrays on the terrain model: right, center, and left). The development of the general experimental design is detailed in the first report (Hilgendorf *et al.*, AMRL-TR-74-4).

PROCEDURE

The test schedule is shown in Table 2. The instructions to the subject are contained in Annex B. The brightness contrast control procedure is described in Annex D.

TABLE 1

TANK SURFACE PROPERTIES

Colors	Paint Mixture	Chromaticity Coordinate X	Chromaticity Coordinate Y	Resulting Brightness Contrast
Green	3 parts CCL 756-561* 1 part White Acrylic Lacquer	.3360	.3641	0.6
Green	(See AMRL-TR-74-4)	.3672	.3928	-0.2
Green	1 part CCL 756-561* 1 part CCL 756-553*	.3109	.3333	-0.6
Brown	2 parts CCL 756-562* 1 part White Acrylic Lacquer	.3582	.3607	0.6
Brown	5 parts CCL 756-562* 2 parts White Acrylic Lacquer	.3675	.3605	-0.2
Brown	CCL 756-562*	.3554	.3634	-0.6
Gray	14 parts White Acrylic Lacquer 1 part Black Acrylic Lacquer	.2961	.3025	0.6
Gray	6 parts White Acrylic Lacquer 1 part Black Acrylic Lacquer	.2898	.2981	-0.2
Gray	3 parts White Acrylic Lacquer 1 part Black Acrylic Lacquer	.2828	.3021	-0.6

* Supplied by the Aberdeen Proving Ground, Maryland

GREEN COLORS FOR EXPERIMENT III

FIGURE 1

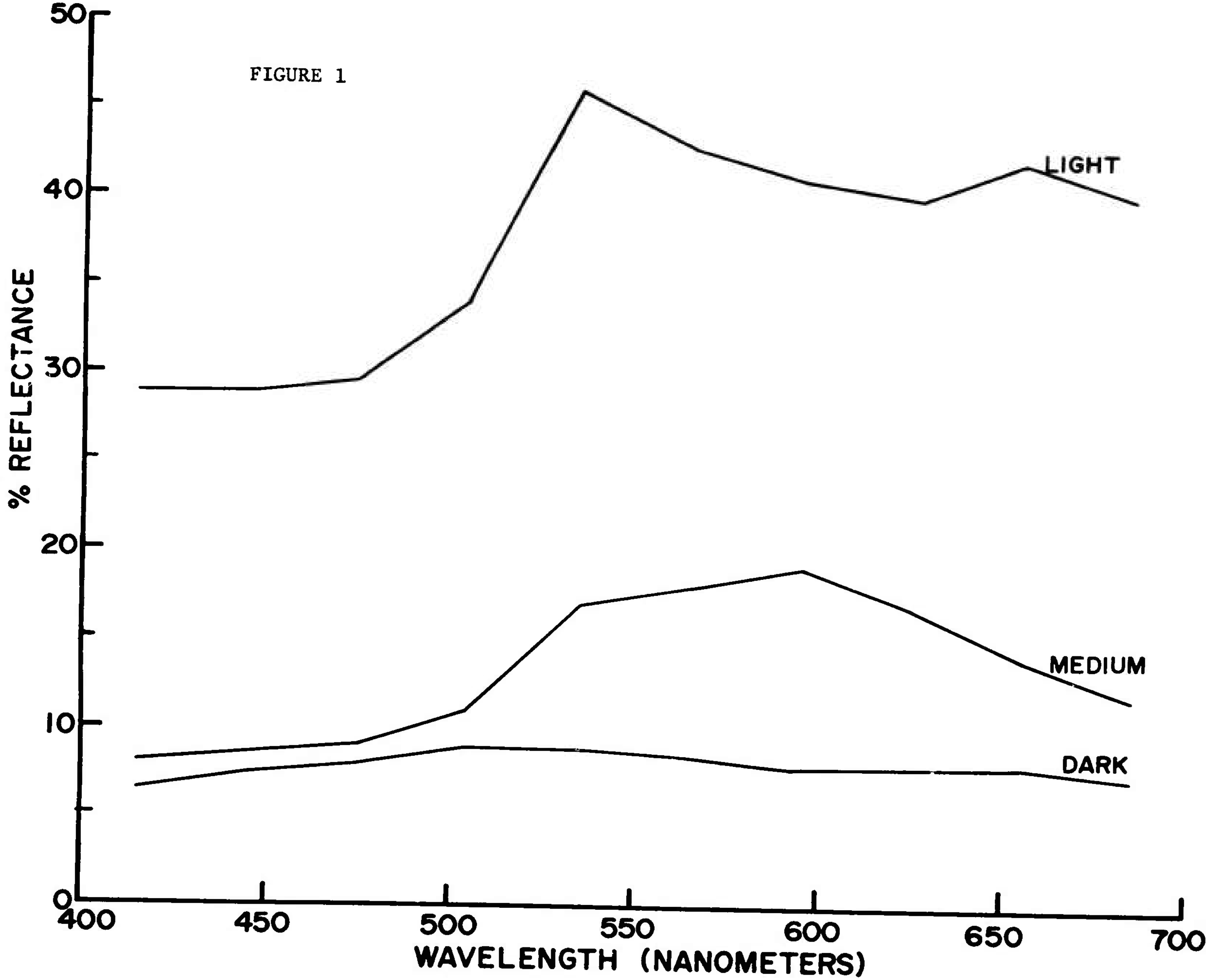


FIGURE 2

BROWN COLORS FOR EXPERIMENT III

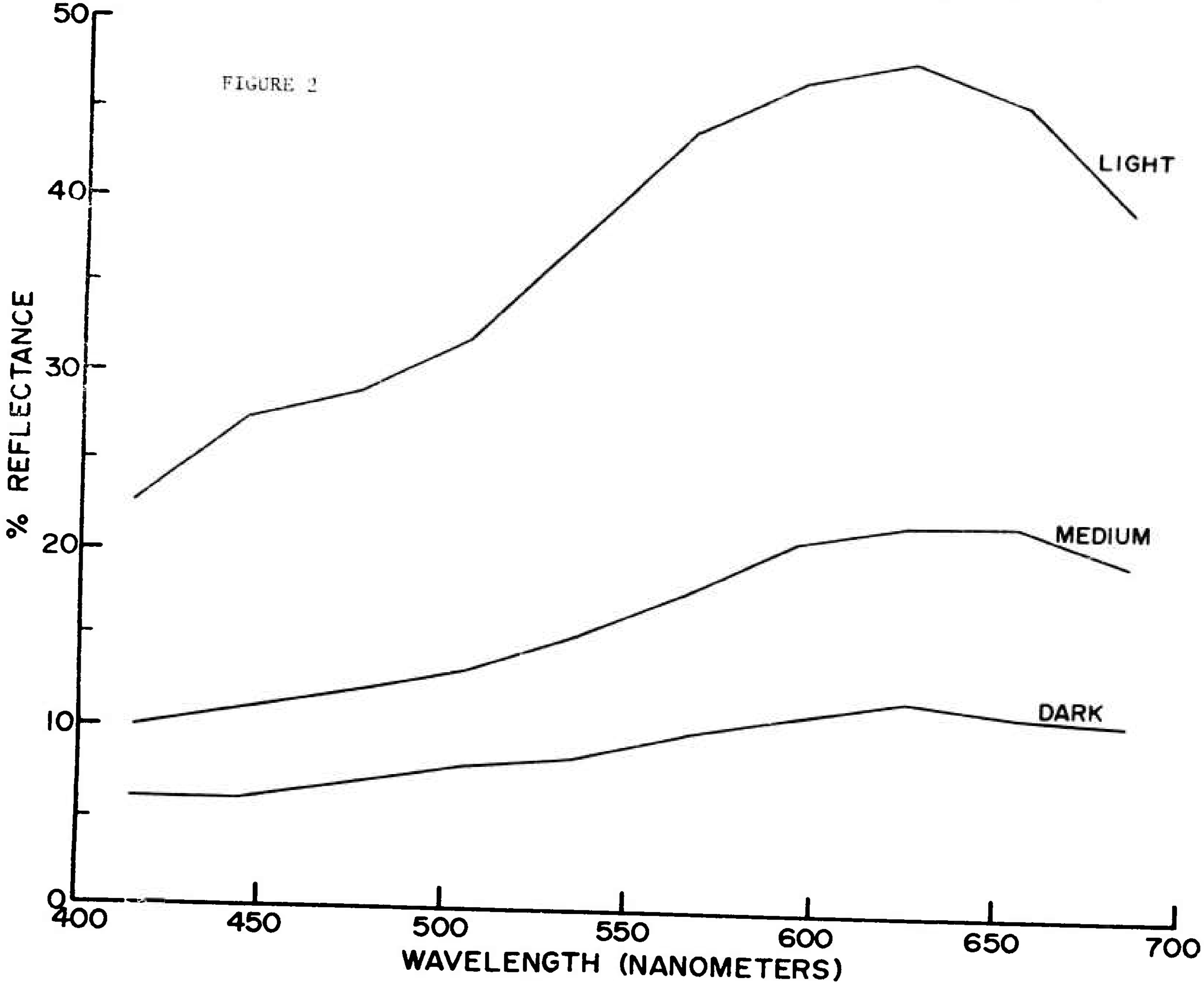


FIGURE 3

GRAY COLORS FOR EXPERIMENT III

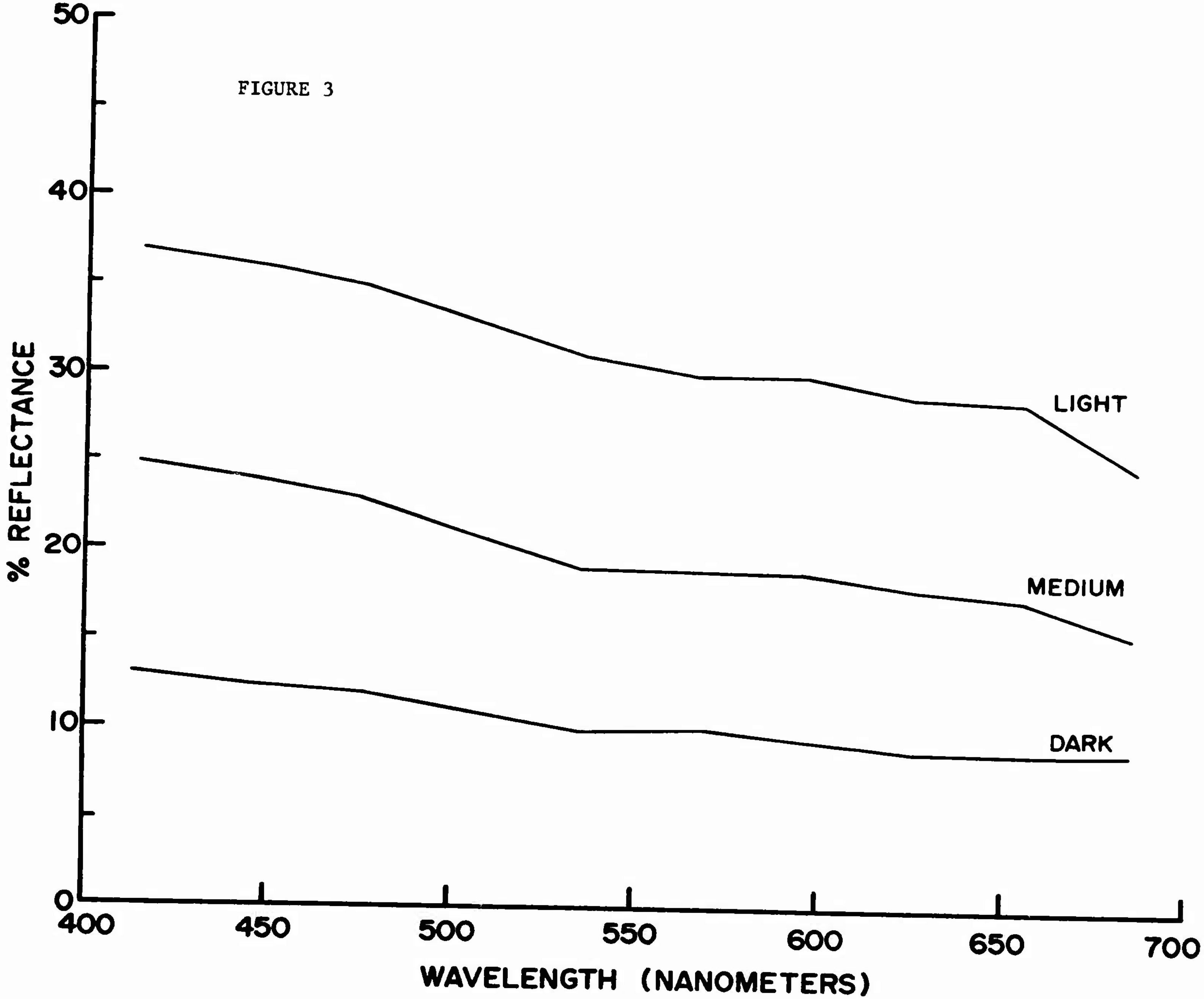


Table 2. Test Schedule for Third Experiment

Observer	*Location 1*	*Location 2*	*Location 3*
1 (29)	Gy, +0.6	Bn, 0.6	Gn, -0.2
2 (23)	Bn, 0.6	Gy, +0.6	Gn, -0.2
3 (32)	Bn, -0.6	Gn, 0.2	Gy, +0.6
4 (20)	Gy, +0.6	Gn, -0.2	Bn, -0.6
5 (35)	Gn, -0.2	Gy, +0.6	Bn, -0.6
6 (26)	Gn, -0.2	Bn, -0.6	Gy, +0.6
7 (6)	Gn, -0.2	Bn, +0.6	Gy, -0.6
8 (15)	Gn, -0.2	Gy, 0.6	Bn, +0.6
9 (9)	Gy, -0.6	Gn, 0.2	Bn, +0.6
10 (12)	Bn, +0.6	Gn, 0.2	Gy, -0.6
11 (3)	Bn, +0.6	Gy, 0.6	Gn, -0.2
12 (18)	Gy, -0.6	Bn, +0.6	Gn, -0.2
13 (19)	Gn, 0.6	Bn, +0.6	Gy, -0.2
14 (31)	Gy, 0.2	Bn, +0.6	Gn, 0.6
15 (25)	Bn, +0.6	Gy, 0.2	Gn, -0.6
16 (34)	Bn, 0.6	Gn, 0.6	Gy, -0.2
17 (22)	Gy, -0.2	Gn, 0.6	Bn, +0.6
18 (28)	Gn, 0.6	Gy, 0.2	Bn, +0.6
19 (5)	Bn, 0.6	Gy, 0.2	Gn, +0.6
20 (14)	Bn, 0.6	Gn, +0.6	Gy, -0.2
21 (8)	Gn, +0.6	Bn, 0.6	Gy, 0.2
22 (11)	Gy, -0.2	Bn, 0.6	Gn, +0.6
23 (2)	Gy, 0.2	Gn, +0.6	Bn, 0.6
24 (17)	Gn, +0.6	Gy, -0.2	Bn, -0.6
25 (24)	Gn, +0.6	Bn, -0.2	Gy, -0.6
26 (30)	Bn, -0.2	Gn, +0.6	Gy, -0.6
27 (21)	Bn, -0.2	Gy, 0.6	Gn, +0.6
28 (33)	Gn, +0.6	Gy, -0.6	Bn, -0.2
29 (27)	Gy, 0.6	Gn, +0.6	Bn, -0.2
30 (36)	Gy, 0.6	Bn, 0.2	Gn, +0.6
31 (1)	Gn, -0.6	Bn, 0.2	Gy, +0.6
32 (16)	Bn, 0.2	Gn, 0.6	Gy, +0.6
33 (7)	Bn, 0.2	Gy, +0.6	Gn, 0.6
34 (10)	Gn, 0.6	Gy, +0.6	Bn, -0.2
35 (4)	Gy, +0.6	Gn, 0.6	Bn, -0.2
36 (13)	Gy, +0.6	Bn, 0.2	Gn, 0.6

Gy, Bn, Gn, Gray, Brown, Green tank color.

0.6, 0.2, +0.6 Contrast between tanks and background.

Numbers in parentheses refer to the observer sequence required for analysis of variance.

RESULTS AND DISCUSSION

BASIC PERFORMANCE DATA

Observer response times for correct detections together with target color and brightness contrast at each of the three array locations are presented in Table 3. Response times contained in this table are measured relative to the time of search initiation. A correct detection response time is associated with each opportunity of acquisition since observers were allowed to search until correct detection and acquisition had occurred. Consecutive observer numbers in the first column identify the order of observers in actual conduct of the experiment. The observer numbers in parentheses are the required observer sequence numbers necessary to conduct an analysis of variance (Annex E).

As in the first two SEEKVAL terrain model experiments (Hilgendorf et al., AMRL-TR-74-4; Hilgendorf and Milenski), a number of false targets was reported by experimental observers. False target detection data are presented in Table 4. Individual false targets are identified by capital letters in Table 4. A detailed description of each false target together with its location is contained in Annex C of this report.

ANALYSIS OF TIME REQUIRED TO DETECT

The main objectives of this experiment are to examine the effects of variations on color and brightness contrast on detection performance. In order to quantitatively assess the effects of these two factors and the effect of the inherent target location factor on detection performance,

TABLE 3. CORRECT DETECTION PERFORMANCE DATA

Observer Number	Target Color, Contrast Configuration			Time Response (seconds) for Correct Detection		
	Loc. #1	Loc. #2	Loc. #3	Loc. #1	Loc. #2	Loc. #3
1 (29)	Gy,+0.6	Bn,-0.6	Gn,-0.2	1.5	108.0	81.0
2 (23)	Bn,-0.6	Gy,+0.6	Gn,-0.2	2.7	2.1	7.8
3 (23)	Bn,-0.6	Gn,-0.2	Gy,+0.6	6.9	6.0	2.4
4 (20)	Gy,+0.6	Gn,-0.2	Bn,-0.6	1.2	1.8	14.4
5 (35)	Gn,-0.2	Gy,+0.6	Bn,-0.6	22.8	1.8	176.4
6 (26)	Gn,-0.2	Bn,-0.6	Gy,+0.6	9.6	76.8	9.9
7 (6)	Gn,-0.2	Bn,+0.6	Gy,-0.6	3.0	3.0	2.7
8 (15)	Gn,-0.2	Gy,-0.6	Bn,+0.6	20.1	8.7	2.4
9 (9)	Gy,-0.6	Gn,-0.2	Bn,+0.6	3.0	7.8	14.1
10 (12)	Bn,+0.6	Gn,-0.2	Gy,-0.6	4.8	58.2	2.4
11 (3)	Bn,+0.6	Gy,-0.6	Gn,-0.2	3.9	12.9	7.5
12 (18)	Gy,-0.6	Bn,+0.6	Gn,-0.2	3.0	12.0	13.2
13 (19)	Gn,-0.6	Bn,+0.6	Gy,-0.2	2.1	1.8	1.8
14 (31)	Gy,-0.2	Bn,+0.6	Gn,-0.6	3.0	71.1	75.6
15 (25)	Bn,+0.6	Gy,-0.2	Gn,-0.6	2.4	2.4	2.7
16 (34)	Bn,+0.6	Gn,-0.6	Gy,-0.2	13.8	3.0	1.5
17 (22)	Gy,-0.2	Gn,-0.6	Bn,+0.6	3.0	4.8	7.2
18 (28)	Gn,-0.6	Gy,-0.2	Bn,+0.6	3.0	11.1	2.7

Gy, Bn, Gn, = Gray, Brown, Green tank color.

-0.6, -0.2, +0.6 = Contrast between tanks and background.

Numbers in parentheses refer to the observer sequence required for analysis of variance.

TABLE 3. CORRECT DETECTION PERFORMANCE DATA (CONT'D)

Observer Number	Target Color, Contrast Configuration			Time Response (seconds) for Correct Detection		
	Loc. #1	Loc. #2	Loc. #3	Loc. #1	Loc. #2	Loc. #3
19 (5)	Bn,-0.6	Gy,-0.2	Gn,+0.6	6.0	3.6	3.6
20 (14)	Bn,-0.6	Gn,+0.6	Gy,-0.2	13.8	5.1	9.0
21 (8)	Gn,+0.6	Bn,-0.6	Gy,-0.2	4.5	12.9	6.3
22 (11)	Gy,-0.2	Bn,-0.6	Gn,+0.6	1.5	9.3	1.5
23 (2)	Gy,-0.2	Gn,+0.6	Bn,-0.6	3.6	2.1	60.0
24 (17)	Gn,+0.6	Gy,-0.2	Bn,-0.6	2.1	2.4	2.1
25 (24)	Gn,+0.6	Bn,-0.2	Gy,-0.6	1.5	35.7	4.5
26 (30)	Bn,-0.2	Gn,+0.6	Gy,-0.6	2.1	50.4	1.2
27 (21)	Bn,-0.2	Gy,-0.6	Gn,+0.6	7.2	6.9	3.3
28 (33)	Gn,+0.6	Gy,-0.6	Bn,-0.2	1.5	10.8	9.9
29 (27)	Gy,-0.6	Gn,+0.6	Bn,-0.2	1.2	2.4	2.4
30 (36)	Gy,-0.6	Bn,-0.2	Gn,+0.6	5.1	1.5	1.5
31 (1)	Gn,-0.6	Bn,-0.2	Gy,+0.6	64.8	63.9	2.4
32 (16)	Bn,-0.2	Gn,-0.6	Gy,+0.6	3.0	45.0	2.7
33 (7)	Bn,-0.2	Gy,+0.6	Gn,-0.6	1.8	1.5	1.8
34 (10)	Gn,-0.6	Gy,+0.6	Bn,-0.2	32.4	1.8	9.6
35 (4)	Gy,+0.6	Gn,-0.6	Bn,-0.2	3.6	4.5	9.6
36 (13)	Gy,+0.6	Bn,-0.2	Gn,-0.6	1.5	69.6	3.6

Gy, Bn, Gn, = Gray, Brown, Green tank color.

-0.6, -0.2, +0.6 = Contrast between tanks and background.

Numbers in parentheses refer to the observer sequence required for analysis of variance.

TABLE 4. FALSE TARGET DETECTION DATA

Observer Number	False Tgt I.D.*	Observer Opposite Location No.	Time of False Target Detection (sec)
5 (35)	G	3	158.4
8 (15)	A	1	10.5
10 (12)	C	2	7.5
10 (12)	D	2	18.6
23 (2)	G	3	12.6
26 (30)	G	2	15.6
26 (30)	E	2	22.2
26 (30)	F	2	34.2
26 (30)	B	2	44.7
36 (13)	C	2	41.1

* Annex C presents false target locations and descriptions.

an analysis of variance was conducted on correct detection response times. (Computational procedures required for the analysis of variance are presented in Annex E). Subsequently, Newman-Keuls tests were conducted to assess the significance of factor levels for those factors determined to be significant as the result of the analysis of variance.

Results of the analysis of variance are summarized in Table 5. Examination of the analysis of variance (ANOVA) table indicates that detection performance was significantly affected by color (Factor a) and by brightness contrast (Factor b). Color was significant at the 0.01 level and brightness contrast at the 0.05 level. Further examination of the ANOVA table reveals that effects due to location (Factor c) and the two and three factor interactions were not statistically significant.

Although the analysis of variance tests have shown that significant main effects were due to both color and contrast, the analysis of variance does not allow an assessment of significance to be made among individual factor levels. This assessment can be made by conducting direct tests on main effects since all interactions are not statistically significant. The Newman-Keuls method is well suited for these direct tests following a significant F ratio, because it is necessary to employ only the means of the time response measurements at the given factor levels together with a modified range statistic q_m. This modified range statistic depends upon increasing order ranking of measurement means and the standard error of these means together with the degrees of freedom associated with experimental error or residual. Comparison of the

TABLE 5. ANALYSIS OF VARIANCE TABLE FOR CORRECT DETECTION TIMES

SOURCE OF VARIATION			DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
MEAN			1	22,256.853		
BETWEEN BLOCKS			35	29,901.327		
	Replications		3	4,396.907	1,465.636	
	Blocks within Replications		32	25,504.420	797.013	
WITHIN BLOCKS			72	45,156.660		
Main Effects	Effect A (Color)		2	6,904.747	3,452.374	7.43
	Effect B (Contrast)		2	4,115.222	2,057.611	4.43
	Effect C (Location)		2	2,964.502	1,482.251	3.19
Two-Factor Interactions	AXB		4	2,642.353	660.588	1.42
	AB (1,2)	½ Info	2	9.310		
	AB^2(3,4)		2	2,633.043		
	AXC		4	1,446.826	361.707	0.78
	AC (1,3)	½ Info	2	889.373		
	AC^2(2,4)		2	557.453		
	BXC		4	2,102.273	525.568	1.13
	BC (1,4)	½ Info	2	1,411.690		
	BC^2(2,3)		2	690.583		
Three-Factor Interaction	AXBXC		8	3,611.178	451.397	0.97
	ABC (2,3,4)	¾ Info	2	1,642.889		
	ABC^2(1,3,4)		2	468.187		
	AB^2C(1,2,4)		2	862.282		
	AB^2C^2(1,2,3)		2	637.820		
RESIDUAL			46	21,369.559	464.556	
TOTAL			108	97,314.840		

difference between all possible pairs of ordered means and the modified range statistic q_m then allows an inference to be made among factor levels since these factor levels are indexed according to ranking of measurement means.

Table 6 presents the Newman-Keuls test procedure on ordered pairs of mean response times according to color factor levels. This table shows that mean performance concerning colors green (a_o) and brown (a_1) are each statistically different from mean performance concerning color gray (a_2) at the 0.05 level of significance; however, there is no significant difference between mean performance on color green (a_o) and mean performance on color brown (a_1) at the 0.05 level of significance.

The Newman-Keuls test procedure on ordered pairs of mean response times according to brightness contrast factor levels is presented as Table 7. This table reveals that only one pair of means possess a statistically significant difference at the 0.05 level of significance. Mean performance on contrast -0.6 (b_o) is statistically different from mean performance on contrast +0.6 (b_2). Mean performance on contrast -0.2 (b_1) is not significantly different from mean performance on contrast -0.6 (b_o) or on contrast +0.6 (b_2).

The analysis of variance table has shown that a significant F ratio is not clearly associated with the effects of target location (Factor c). Hence, no direct tests on target location factor levels (i.e., c_o, c_1, c_2) appear to be warranted.

Since the effect of target location factor on detection performance was not significant and also since there were no significant two and three

TABLE 6. NEWMAN-KEULS TEST PROCEDURE TABLE ON ORDERED PAIRS OF MEAN RESPONSE TIMES ACCORDING TO EXPERIMENT TARGET COLOR FACTOR LEVELS

Order of factor levels		1	2	3
Factor and level		a_2	a_0	a_1
Ordered means		4.00	15.60	23.47
		a_2	a_0	a_1
	a_2	-	11.60	19.47
Differences between pairs	a_0		-	7.87
	a_1			-
Truncated range r			2	3
$q_{.95}$ (r,46)			2.85	3.43
$q_m = q_{.95}(r,46)\sqrt{MS_{res}/n}$			10.23	12.31 ($n=36, MS_{res}=464.56$)
		a_2	a_0	a_1
Pairs of means with statistically significant differences	a_2		*	*
	a_0			-
	a_1			

SUMMARY: Mean performance on colors green (a_o) and brown (a_1) are each statistically different from mean performance on color gray (a_2), but there is no statistically significant difference between mean performance on color green (a_0) and mean performance on color brown (a_1). (All comparisons at 0.05 level)

TABLE 7. NEWMAN-KEULS TEST PROCEDURE TABLE ON ORDERED PAIRS OF MEAN RESPONSE TIMES ACCORDING TO EXPERIMENT TARGET CONTRAST FACTOR LEVELS

Order of factor levels		1	2	3
Factor and level		b_2	b_1	b_0
Ordered means		6.97	14.01	22.08
		b_2	b_1	b_0
	b_2	-	7.04	15.11
Differences between pairs	b_1		-	8.07
	b_0			-
Truncated range r			2	3
$q_{.95}(r,46)$			2.85	3.43
$q_m = q_{.95}(r,46)\sqrt{MS_{res}/n}$			10.23	12.31 ($n=36, MS_{res}=464,56$)
		b_2	b_1	b_0
Pairs of means with statistically significant differences	b_2		-	*
	b_1			-
	b_0			

SUMMARY: Mean performance on contrast -0.6 (b_0) is statistically different from mean performance on contrast +0.6 (b_2), no other mean performance differences are statistically significant. (All comparisons at 0.05 level.)

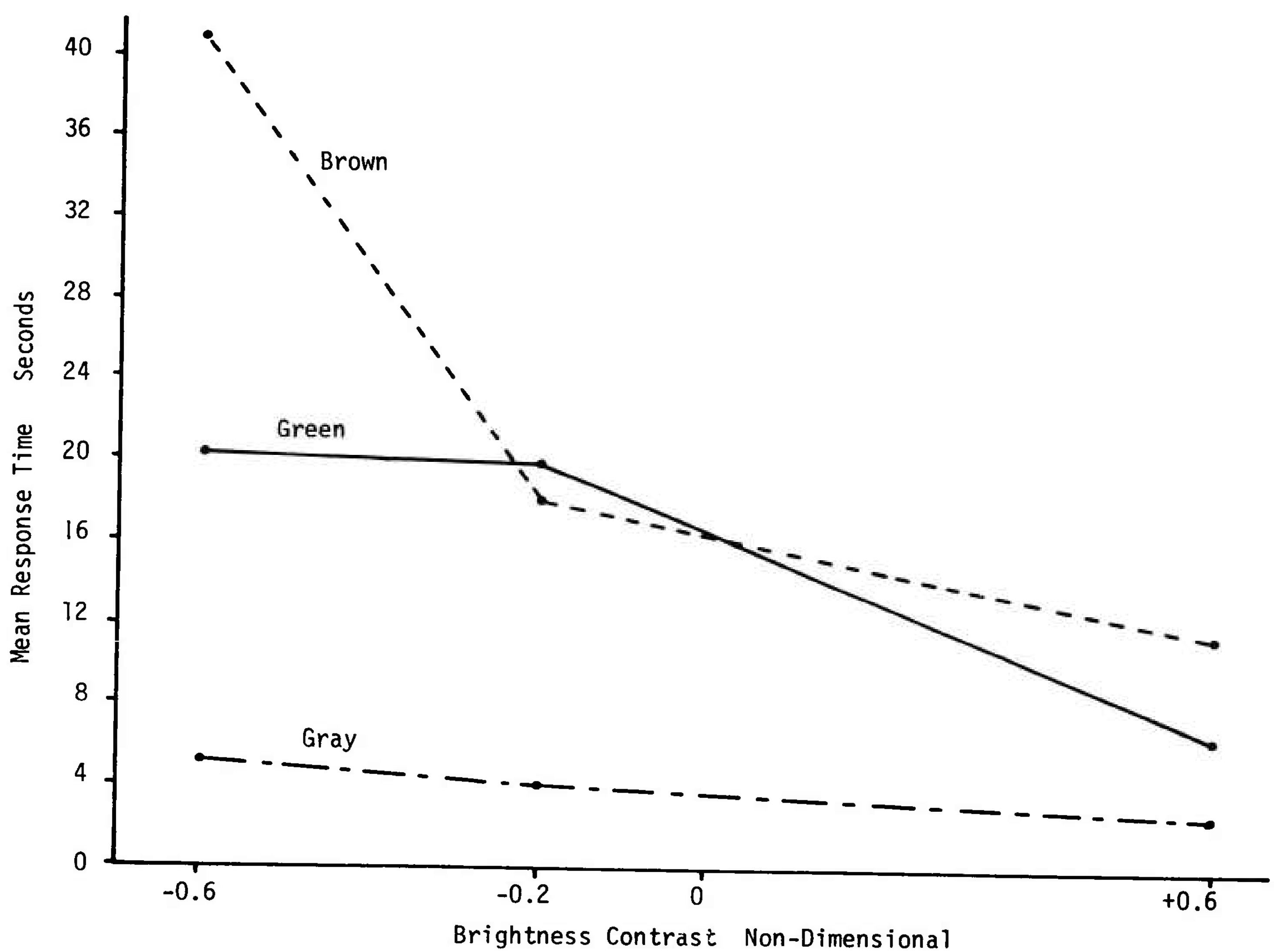
factor interactions (which are partially confounded with block effects), the unadjusted color, contrast cell mean response times could be obtained. These are graphically depicted in Figure 4. Each of the 9 descriptive means in this figure results from the averaging of 12 observer response times. Although these cell means are entirely descriptive in nature, they clearly evidence that it was more difficult for observers to detect targets with negative brightness contrasts (targets darker than background) as opposed to targets with positive brightness contrasts (targets lighter than background) regardless of color. These means also show that it was always much easier for observers to detect the gray targets than either the green or brown targets, regardless of brightness contrast. At the extreme values of contrast (± 0.6), it was harder to detect brown targets than green targets; however, at the intermediate contrast (-0.2), green targets were slightly more difficult to detect than were the brown targets.

DISCUSSION OF RESULTS

The results of this experiment indicate that the effects of color may have more impact on target detection performance than was traditionally thought. In addition, a significant difference between performance at the -0.6 brightness contrast level and performance at the +0.6 brightness contrast level was evident; however, there was no significant difference in performance between the -0.2 contrast level and the ± 0.6 contrast levels.

The possibility that color effects were of more importance than those of brightness contrast in the applied experimental setting may be

Figure 4. Unadjusted Color, Contrast Cell
Mean Detection Response Times



somewhat surprising. Color or chromatic effects have generally been regarded as being of lesser importance than effects of brightness or luminance contrast in virtually all endeavors to mathematically model the visual target detection/acquisition process. In fact, a recent and thorough review by Greening (1973, p. 94) discloses that only one of a number of widely employed visual target acquisition models provides for color or chromatic contrast considerations. Reasons for not including the effects of color contrast are not enumerated by Greening. Rationale for exclusion of color contrast in a model formulated by Bradford (1966) followed from the comments by Duntley (1964, p. 552) regarding simplification and collation of experimental data ". . . . The experimental result that color contrasts have an almost negligible effect on the detectability of an optical signal, although they affect the noticeability of suprathreshold objects constitutes yet another important simplification of visual properties. . . ."

Middleton (1952, Chap. 8) provides a theoretical treatment on the alteration of color of distant objects by the atmosphere. His treatment shows that effects of the atmosphere are to act as a neutral filter on light from a colored object and to add white light to it resulting in an apparent achromatic object at distant ranges of observation. However, Middleton's treatment also shows that at extremely small slant ranges, the apparent chromaticity of colored objects is virtually unaltered by the atmosphere.

For the experiment conducted, physical slant ranges from observers to targets were on the order of 6 feet. At these extremely small ranges, atmospheric effects were totally negligible and true color vision by the observers was accordingly preserved, and under the levels of experimental factors considered, the effects of color predominated over those of brightness contrast.

Although the bulk of modeling efforts associated with visual target acquisition have tended to ignore (for whatever reasons) the effects of color, the results of this experiment indicate that color can be quite important under certain conditions. Greening (1973, p. 122) makes an observation regarding the exclusion of color or chromatic effects ". . . . This is probably not a serious limitation for many military targets at extreme acquisition ranges, but could be a severe limitation in other cases." Greening's observation is consistent with the findings of this experiment.

The strong tendency for mean response times to monotonically decrease with increasing brightness contrast and the statistically significant difference between mean response times at the -0.6 and +0.6 levels of contrast are results which also may be somewhat surprising. Jones *et al*. (1973, p. 64), in reviewing contrast thresholds, point out that frequently a distinction is not made between targets brighter than the background and targets darker than the background since little difference has been found between them in terms of detection thresholds; the only exception is for large targets with very low background luminance levels. Duntley (1964, p. 552), in discussing human visual properties, remarks ". . . The fact that under virtually all circumstances *geometrically identical objects are equally detectable if their universal contrasts are equal in magnitude even if opposite in sign* is perhaps the most important of the first-order experimental generalizations..." From the review of visual target detection/acquisition models by Greening (1973), it is evident that none of the models provide for the visual observer to make a distinction between targets brighter than their backgrounds and targets darker than their backgrounds; in fact, target/background contrasts are generally forced to be positive by use of absolute values or some other mathematical artifice. In these models, positive apparent contrasts of target/background are combined with visual observer threshold contrasts to formulate probability of detection and/or acquisition.

Although no distinction is usually made between targets darker or lighter than the background when characterizing observer detection thresholds, it is noted that detection thresholds are based on highly stylized and restricted laboratory experiments. Typically, these experiments involve uniformly luminous targets against uniformly luminous backgrounds. The time of target occurrence and in certain instances, the target location itself are known to observers who are forced to report within a given time whether or not they detected the presented target.

The present experiment has addressed the much harder task of free search and detection of targets in a highly complex experimental setting. Target backgrounds possessed severe luminance and color gradients. The background surroundings were structured with natural clutter elements and also contained non-uniform surface vegetation and terrain features. Targets were high-fidelity three-dimensional scale models and, as a consequence, target shadows comprised part of the immediate background.

In addition, luminance gradients existed across the projected target areas because of the directional reflectance of light incident upon the high-fidelity three-dimensional surfaces. These differences in experimental conditions from those associated with threshold investigations may relate to the surprising performance associated with contrast levels. Shadows and the generally mottled green and brown target backgrounds could be major factors affecting search and detection performance.

CONCLUSIONS

The general tendency to assume that color has an almost negligble effect on the detectability of targets is not supported by data from this experiment. In this experiment, color effects were significant and accounted for a greater proportion of the total variance than did the effects of brightness contrast.

The additional general tendency to assume that identical targets are equally detectable if their brightness contrasts are equal in magnitude, regardless of sign, is also not supported by data from this experiment. This experiment, conducted in an applied setting, evidences that targets darker than their backgrounds are more difficult to detect than targets lighter than their backgrounds.

It would appear that these findings could have a significant impact on the military target acquisition community, particularly in the areas of field experiment design and mathematical modelling. However, it should be emphasized that findings of this experiment are based on only three responses per each of thirty-six untrained subjects. It is recommended that additional experiments, also in applied settings, be conducted to further examine the effects of target/background color and contrast on visual search and detection performance.

REFERENCES

SEEKVAL Joint Test Project Plan of Combat Air Support Target Acquisition Program Phase I, July 1973a.

SEEKVAL Joint Test Project Plan of Combat Air Support Target Acquisition Program Project Plan IA1 Direct Visual Terrain Table Experiments, July 1973b.

Hilgendorf, Robert L., Milenski, John and Hart, Robert S., SEEKVAL Project IA1: Effects of Target Number and Clutter on Dynamic Target Acquisition. Aerospace Medical Research Laboratory Technical Report, AMRL-TR-74-4. In editing.

Hilgendorf, Robert L., Milenski, John, SEEKVAL Project IA1: Effects of Target Number and Clutter on Static Target Acquisition. Aerospace Medical Research Laboratory Report. In editing. (AMRL-TR-74-14).

Hilz, R., and Cavonis, C. R., Wavelength Discrimination Measured with Square-Wave Gratings, Journal of the Optical Society of America, 1970, 60, 273-277.

Bedford, R. D. and Wyzecki, G. W., Wavelength Discrimination for Point Sources, Journal of the Optical Society of America, 1958, 48, 129-135.

Siegal, M. H., Color Discrimination as a Function of Exposure Time. Journal of the Optical Society of America, 1965, 55, 566-568.

Greening, Charles P., Target Acquisition Model Evaluation, Final Summary Report. Naval Weapons Center Technical Publication NWC TP-5536, June 1973.

Bradford, W. H., A Mathematical Model for Determining the Probability of Visual Acquisition of Ground Targets by Observers in Low-Level, High-Speed Aircraft. Sandia Corporation Technical Memorandum SC-TM-66-54, Feb 1966.

Duntley, S. Q., Visibility. Applied Optics, Volume 3, Number 5, May 1964.

Middleton, W. E. K., Vision Through the Atmosphere, Canada, University of Toronto Press, 1952.

Jones, D. B., Collyer, S. C., Freitag, M., and Leonard, K. W., A Source Book for Air-to-Ground Target Acquisition, Final Report. Martin Marietta Report OR 12, 470, April 1973.

Winer, B. J., Statistical Principles in Experimental Design, New York, McGraw-Hill, 1962.

Winer, B. J., Statistical Principles in Experimental Design, Second Ed., New York, McGraw-Hill, 1971.

ANNEX A

TARGET LOCATION AREAS AND EXPERIMENTAL GEOMETRY

1. GENERAL. Figure 5 depicts the three target location areas and observer geometry directly opposite the target array centerline. Contained within each of these areas were three tank targets and clutter elements in the form of twenty scale model trees. The boundary of each target area was a circle twenty centimeters in radius simulating a real world radius of two hundred meters.

2. TARGET AREA DESCRIPTIONS.

a. Location #1. This area is very nearly flat at a level of three inches above the point of river termination on the near edge of the model. Color of the area is essentially a mottled combination of dark green and brown or tan. Disregarding the twenty clutter elements, the area is almost totally void of vegetation. However, dense foliage of trees and bushes border most of the area. A road running parallel to the model's major dimension is tangent to the twenty centimeter radius circle.

b. Location #2. The target area at this location is flat in an overall sense at a level of 0.5 inches above the point of river termination. This area is traversed by a narrow road running down a ridge on the far righthand side of the location and terminating at the river. This road almost passes through the center of the area boundary circle, running from two o'clock to eight o'clock. A shallow gully or wash emptying into the river at six o'clock is partially contained within the area boundary. The area coloration is basically a mixture of light greens and brown; however,

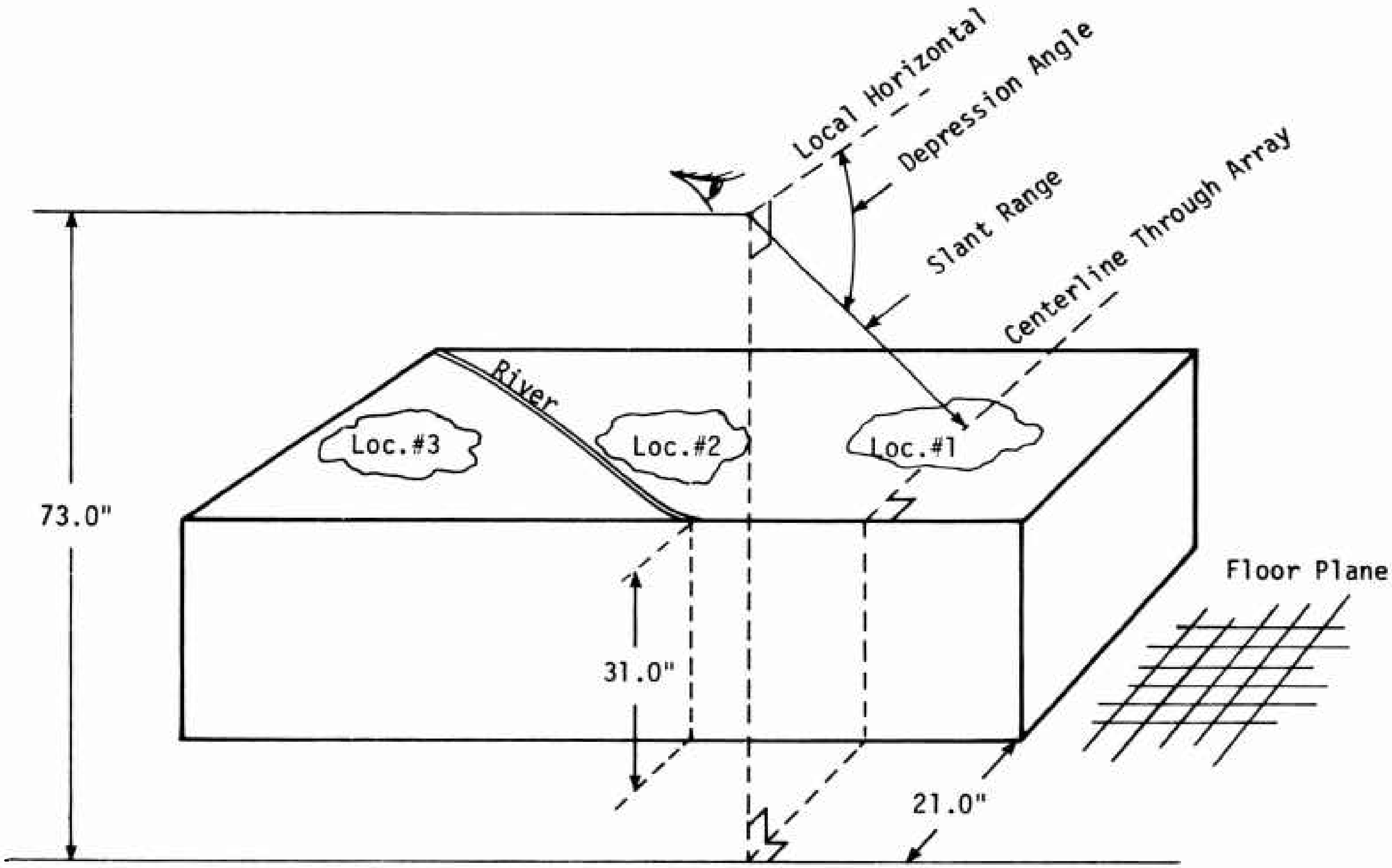


Figure 5. Observer Geometry Directly Opposite Target Array Location
(Location #1 Depicted)

dark green surface vegetation lines road edges and banks of the shallow wash.

c. Location #3. Unlike the other two target areas, this area is not flat. Small knolls and hummocks are within much of the boundary confines. Average slope of the area is approximately ten degrees, increasing from the river to the model's near edge. Crests of knolls are barren and coloration of these crests is a mixture of light green, gray and brown. Shallow depression areas among knolls and hummocks contain very dark green "patches" of vegetation. Ground areas surrounding these patches are light green, brown and tan in color.

3. EXPERIMENTAL GEOMETRY.

a. Altitude and Floor Range Constraints. The point of river termination on the near edge of the model is considered to be zero altitude for the terrain model. The point of termination is 31.0 inches above the floor. A simulated altitude of 3500 feet above the model zero reference level was required for the experiment. Since the model scale is 1 to 1000, the observer's eye was required to be positioned 73 inches (42" + 31") above the floor. Ground or floor range from the leading edge of the model to the observer's eye was constrained to be 21.0 inches since the platform was repositioned laterally along rails running parallel to the model's major dimension. Altitude and floor range constraints together with target array center positions relative to a reference point on the model allow determination of observer line-of-sight slant range and depression angle to the center of any array.

b. Target Array Locations. Table 8 gives the position of the center of each target array/clutter area relative to the near right hand corner of the model with zero altitude taken with respect to point of river termination.

TABLE 8. POSITIONS TO CENTER OF TARGET ARRAYS

Target Array Location	Position to Center of Array		
	Left (inches)	Forward (inches)	Altitude (inches)
#1	22.5	35.0	3.0
#2	125.5	26.5	0.5
#3	188.5	35.5	1.0

c. Slant Ranges and Depression Angles. Geometric considerations and requisite numerical values allow the slant range and depression angle from observer to center of each array to be determined. These are presented in Table 9 .

TABLE 9. SLANT RANGES AND DEPRESSION ANGLES

Target Array Location	Slant Range to Center of Array		LOS Depression Angle (degrees)
	Actual (inches)	Simulated (feet)	
#1	68.24	5,687	34.86
#2	63.08	5,257	41.14
#3	69.81	5,818	35.97

4. PROJECTED TARGET AREAS AND TARGET ANGULAR SIZES.

a. Projected Target Areas. The projected area of any single tank perpendicular to observer line-of-sight is dependent upon observer location relative to tank together with actual tank size and shape. If a tank is considered to be a "shoebox", located at the center of the array, with its longitudinal axis perpendicular to a line parallel to the model's major dimension and its horizontal plane to be elevated to the mean local slope over the array, then it is possible to determine the projected area directly opposite the array center. Table 10 presents the projected tank areas and the radii of equivalent circular tanks. These areas and corresponding radii are based upon mean "shoebox" tank dimensions of: width = 0.155", length = 0.328", height = 0.133" (Hilgendorf et al., AMRL-TR-74-4); the depression angles given in Table 10; mean local array slopes of 0^{o}, 0^{o}, 10^{o} at Locations #1, #2, #3 respectively.

TABLE 10. PROJECTED TANK AREAS AND RADII OF EQUIVALENT CIRCULAR TANKS

Target Array Location	Area (sq. inches)	Radius (inches)
#1	0.04597	0.1210
#2	0.04897	0.1249
#3	0.04080	0.1140

b. Angular Size of Targets. A quantity which is commonly employed to characterize target size is the angular subtense of the target expressed in minutes of arc. This quantity is directly proportional to the diameter of the equivalent circular target perpendicular to the observer's line-of-sight and inversly proportional to slant range between observer and target. Table 11 presents angular sizes of targets based on slant ranges of Table 9 and radii of Table 10.

TABLE 11. ANGULAR SIZE OF TANKS

Target Array Location	Angular Size (min. of arc)
#1	12.19
#2	13.61
#3	11.23
Ave. over Locations	12.34

ANNEX B

EXPERIMENTAL CONDUCT

1. SUBJECTS. The subjects were Air Force enlisted personnel or male college students who had previously participated in one experiment utilizing the terrain model. To insure that subjects still possessed 20/20 or better visual acuity and normal color vision, they were again tested with the Ortho-Rater and color vision plates.

2. QUESTIONNAIRE. Each subject completed a personal questionnaire. This questionnaire is contained in Appendix 1 to this annex. The purpose of this questionnaire was to obtain personal data which may possibly be related to observer performance during the experiment.

3. GENERAL BRIEFING. A general verbal briefing was given to each subject or observer subsequent to completion of the personal questionnaire. The purpose of this briefing was to appraise the observer of the objectives of the experiment, measures of performance, and overall general conduct. This briefing was given by the chief experimenter in a room adjacent to the actual experimentation room and a small briefing model (3' x 4') was employed during the course of this briefing. The observer was shown nine model tanks (three colors, three brightness contrasts per color) placed on the small briefing model. He was instructed to study these models very carefully in order to become familiar with model tank size, shape and colors as might be observed on the experimentation scale terrain

model. The observer was also advised of the eye mark recorder, seating platform and chin rest. He was told that tanks could be located at any position on the model and may or may not be grouped together.

4. EXPERIMENTATION ROOM PROCEDURES.

a. Fitting of eye mark recorder. After the observer had been briefed and shown the model tanks, he was brought into the experimentation room and seated in the platform which was locked in position directly opposite the center of Location #1. He was prevented from viewing any portion of the model during the course of seating by means of a sliding curtain running along the entire length of the model. Subsequent to seating of the observer, he was fitted with the eye mark recorder and this device initially adjusted and aligned so that the eye mark itself was positioned on the same reference point as the observer's viewing eye.

b. Altitude control. After preliminary alignment of the eye mark recorder, the viewing platform was hydraulically elevated to initially position the observer's eye level to the required height. His chin was then placed in the platform chin rest and the chin rest vernier adjustment screw rotated to position the pupil of the observer's eye to the required height with respect to the floor of the experimentation room. A last adjustment and alignment of the eye mark was then performed.

c. Final instructions. Prior to the actual detection and acquisition attempt itself at Location #1, final tasking instructions were given to the observer. These tasking instructions consisted of an audio playback from a cassette recorder unit. A transcript of these taped instructions is presented in Appendix Z to this annex.

d. Location #1 acquisition attempts. After the observer had received tasking instructions, all instrumentation was activated and underwent a final checkout. A masking or blocking board was held in place between the observer and curtain by an assistant experimenter, the curtain was then drawn open by the chief experimenter. After the curtain was drawn open, the chief experimenter commenced a countdown. At the end of countdown, the masking board was quickly removed by the assistant experimenter. Countdown and the observer's verbal responses were recorded on the audio channels of a video/audio recorder. By real time monitoring of the recorder video display (which contained the eye mark "vee" superimposed on the observer's view) and by simultaneously monitoring the observer's verbal response, the chief experimenter easily determined when a correct detection had occurred. No time limit was imposed for detection and acquisition of targets (i.e., the observer was allowed to search until he had detected and acquired true targets even though true detection could be preceded by one or more FALSE detections). After correct detection and acquisition, instrumentation was deactivated and the observer tasked to point out false targets so that their descriptions and locations could be recorded.

e. Acquisition attempts at Locations #2 and #3. Experimental conduct procedures at these two locations were identical to those at Location #1.

5. DEBRIEFING. Upon completion of an experimental trial, the observer was given a debriefing questionnaire. The debriefing questionnaire is presented in Appendix 3 to this annex. Debriefing was conducted mainly in the form of interview questioning by the chief experimenter. The intent of debriefing was to obtain additional information which could possibly be related to detection and acquisition performance.

6. CLUTTER CONTROL. Clutter in the form of 20 trees at each of the three target array locations was positively controlled by the use of a clutter template. Positioning of scale trees was such that none of the tank targets was masked by clutter elements.

7. DATA COLLECTION AND REDUCTION.

a. Data collection. An instrumentation data collection and recording system consisting of an eye mark recorder, video camera, video/audio recorder and video monitor was employed during the experiment. Details concerning the functioning of this system are contained in an earlier report (Hilgendorf et al., AMRL-TR-74-4)

b. Data reduction. Data reduction consisted mainly of recording the times of detection (true and false target detection) obtained by playback of video/audio records and utilization of a stopwatch. Additional data reduction involving false target identification was conducted immediately after every acquisition attempt by each individual observer.

8. PHOTOGRAPHIC DOCUMENTATION. A total of twenty-seven 35 mm color slides was generated for documentary purposes. These slides depict each distinct target color, contrast configuration at each location.

APPENDIX 1

ANNEX B

OBSERVER QUESTIONNAIRE

SUBJECT NAME:____________________ RANK:________________ DATE:______________

SUBJECT NUMBER:__________________ TIME:________________

1. AGE:______________

2. SEX: M, F

3. MARITAL STATUS: MARRIED, DIVORCED, SINGLE, SEPARATED

4. EDUCATION: YEARS HIGH SCHOOL______________________________

   YEARS UNDERGRADUATE STUDIES______________________

   YEARS GRADUATE STUDIES__________________________

5. COLLEGE MAJOR:____

6. NUMBER OF COLLEGE PSYCHOLOGY COURSES TAKEN: (UNDERGRADUATE)____________

7. NUMBER OF CIGARETTES SMOKED PER DAY (CIRCLE YOUR ANSWER)

   a. None
   b. Half a pack
   c. Pack
   d. One and one half packs
   e. Two or more packs

8. AMOUNT OF SLEEP (IN HOURS) YOU NORMALLY GET AT NIGHT:____________________

9. AMOUNT OF SLEEP (IN HOURS) THAT YOU GOT LAST NIGHT:______________________

10. HAVE YOU TAKEN ANY MEDICATION WITHIN THE LAST 48 HOURS? YES, NO.
    IF SO, WHAT WAS THE MEDICATION?____

11. DO YOU PRESENTLY HAVE:

a.	a cold?	YES	NO
b.	a headache?	YES	NO
c.	sinus trouble?	YES	NO
d.	tooth ache?	YES	NO
e.	upset stomach?	YES	NO
f.	arthritis?	YES	NO

12. ARE YOUR EYES FATIGUED OR IRRITATED NOW? YES, NO

APPENDIX 1

ANNEX B

OBSERVER QUESTIONNAIRE (CONT'D)

13. HOW MANY CUPS OF COFFEE HAVE YOU CONSUMED IN THE LAST TWO (2) HOURS?______

14. WHAT WAS YOUR ALCOHOLIC INTAKE IN THE PAST 24 HOURS (NUMBER OF DRINKS)?

BEER______________________ OTHER______________________________

15. HOW WOULD YOU RATE YOUR ABILITY TO DETECT AND IDENTIFY OBJECTS ON THE GROUND IF YOU WERE FLYING IN A MEDIUM SPEED AIRCRAFT (300 knots) AT AN ALTITUDE OF 3,500 FT.

_____	_____	_____	_____	_____	_____	_____
Very poor			Average			Excellent

16. PLEASE INDICATE WHICH OF THE FOLLOWING BETTING SITUATIONS YOU WOULD PREFER IF YOU WERE TO WAGER $300 OF YOUR OWN MONEY:

a. 1 chance in 6 to win $1800
b. 2 chances in 6 to win $900
c. 3 chances in 6 to win $600
d. 4 chances in 6 to win $450
e. 5 chances in 6 to win $360
f. You wouldn't consider betting under any conditions

17. HOW DO YOU FEEL ABOUT PARTICIPATING AS A SUBJECT IN MILITARY-RELATED RESEARCH?

_____	_____	_____	_____	_____	_____	_____
Extremely dislike it			Neither like nor dislike it			Extremely like it

18. INDICATE NUMBER OF YEARS OF ACTIVE MILITARY SERVICE:____________________

19. WHAT BRANCH OF SERVICE?______________________________

20. WHAT WAS SERVICE OCCUPATIONAL SPECIALTY?______________________________

21. HAVE YOU HAD EXPERIENCE IN ACQUIRING TACTICAL GROUND TARGETS FROM AN AIRCRAFT? YES, NO. IF YES, DESCRIBE LENGTH (MONTHS) OF EXPERIENCE, TYPE OF AIRCRAFT AND GROUND TARGETS.

APPENDIX 2

ANNEX B

TASKING INSTRUCTIONS TO SUBJECTS

SEEKVAL IA1 EXPERIMENT #3

(Immediately Prior to Actual Trial)

1. Your head has been placed in a CHIN REST so that we can precisely control the simulated altitude of observation. Please do not remove your head from this CHIN REST until you are told to do so.

2. A masking board will be placed in front of you to initially block your visual field-of-view. When this masking board is removed, your task is to carefully search the area on the model directly in front of you specifically for tanks like those you saw on the small briefing model across the hall. You may move your eyes in any search pattern or technique you desire, but please do not move your head from side to side.

3. The tanks you are searching for may be by themselves or grouped. When you see a tank or group of tanks, immediately call out TANK or TANKS, state the number you see in the immediate area and also state their color and position relative to a prominent landmark.

4. Two examples of responses you might give are:

TANKS, TWO, GREEN ---- on left side of road; or

TANK, ONE, BROWN ---- on far bank of river.

5. Again, please do not remove your head from the CHIN REST until you are told to do so and report TANKS, their number and color, and the location of TANK targets.

6. Do you have any questions?

APPENDIX 3

ANNEX B

DEBRIEFING QUESTIONNAIRE

SUBJECT: ______________________ NUMBER ________ SEEKVAL EXPERIMENT NO. III

1. DO YOU FEEL THAT SUFFICIENT INSTRUCTION AND BRIEFING WERE GIVEN PRIOR TO EXPERIMENTAL RUN? YES_____ NO_____. IF NO, EXPLAIN______________
____.

2. TO WHAT EXTENT DID THE EYE MARK RECORDER INTERFERE WITH OR BOTHER YOU AS A SUBJECT?

   a. VERY LITTLE   b. MODERATE   c. GREAT

3. DID THE COLOR DIFFERENCE BETWEEN TANKS AND BACKGROUND OR TREES ASSIST IN TARGET DETECTION? YES_____. NO_____.

4. DID THE ARRANGEMENT OF MULTIPLE TANKS IN A TARGET AREA ASSIST IN TARGET DETECTION? YES_____. NO_____.

5. DID THE TARGET SHADOWS ASSIST IN TARGET DETECTION? YES_____. NO_____.

6. DO YOU CONSIDER THE TERRAIN TABLE A REALISTIC SIMULATION TO EMPLOY IN TARGET DETECTION STUDIES? YES_____. NO_____. SUBJECT DOESN'T KNOW_____.

7. ON THE TARGETS YOU DETECTED, CAN YOU GIVE ME A VERY SHORT DESCRIPTION OF ANY REASONS OR FACTORS REGARDING WHY YOU WERE ABLE TO DETECT THE TARGETS?

____

____

____.

ANNEX C

DESCRIPTION OF FALSE TARGETS

1. GENERAL. During the experiment, a total of 10 false target responses were obtained. Although 10 false target responses were obtained during the experiment, each false target response was not necessarily associated with a different false target; in fact, the 10 false target responses were distributed among seven different false targets. Two or more responses were associated with 2 of these 7 false targets.

2. LOCATIONS OF FALSE TARGETS. Locations of the false targets in terms of (left, forward) coordinates are given in Table 12, this table also contains the number of responses associated with each individual false target. Figure 6 depicts the locations of the seven different false targets. Also shown in this figure (which is drawn to scale) are the three target array locations which contained tank and clutter elements.

TABLE 12 FALSE TARGET LOCATIONS AND NUMBER OF RESPONSES WITH EACH FALSE TARGET

False Target	Coordinates (in inches)	No. of Responses
A	(18.3,44.8)	1
B	(89.0,37.5)	1
C	(120.5,49.8)	2
D	(122.5,50.0)	1
E	(149.5,31.5)	1
F	(152.5,40.0)	1
G	(172.8,46.5)	3

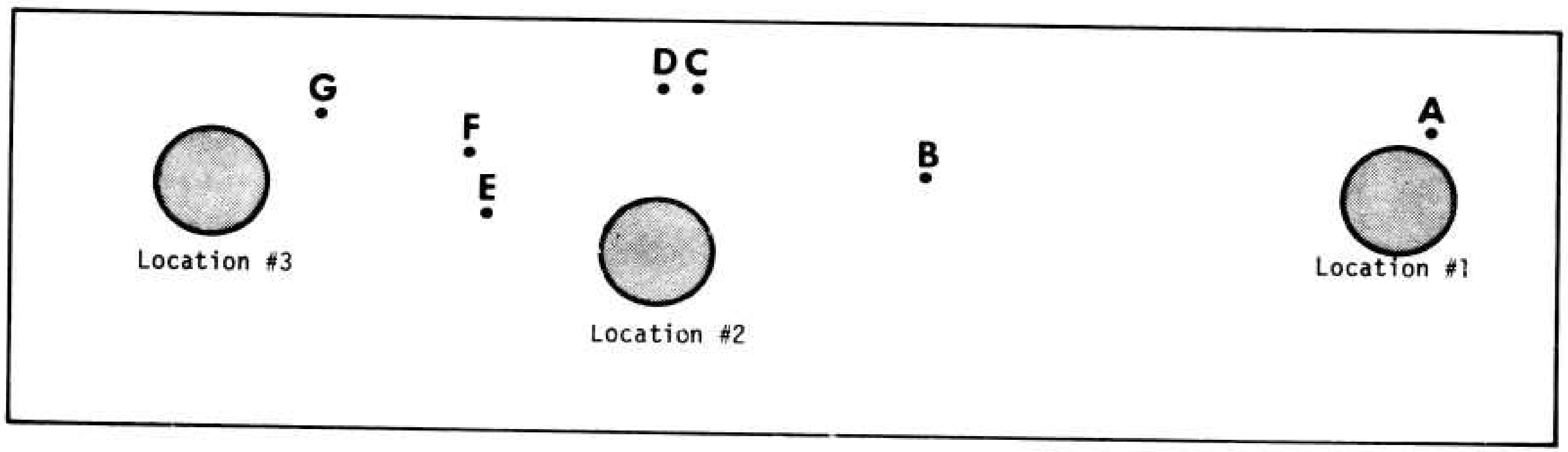


Figure 6. False Target Locations and Target Array Location Areas

3. INDIVIDUAL FALSE TARGET DESCRIPTION. A brief description of each individual false target is given as follows:

False Target A - Small brownish protuberance in model surface. Protuberance is located in a small clearing between two stands of trees on the far side of a road running parallel to the model's major dimension.

False Target B - Brownish "lump" or eruption located immediately to the left of a road which crosses the model perpendicular to its major dimension.

False Target C - Small green bush located between a road running along the crest of the model's highest ridge and a dense group of bushes in proximity to the near side of road.

False Target D - Small light green tree positioned near the crest of the model's highest ridge and immediately on the near side of the road running along the crest of the ridge.

False Target E - Two brownish green bushes standing alone in a clearing between two heavily foliated areas on the far side of the model's river.

False Target F - Green bush located in a clearing near the base of a small ridge on the far side of the river.

False Target G - Greenish brown bush located in a barren area on the forward slope of a small ridge on the far side of the river.

4. REMARKS. None of the 7 false targets were located within the scaled 200 meter radius circles defining target/clutter area configurations. Only one false target (False Tgt A) was located within 100 meters (scaled) of the configuration boundaries. Typically, false targets were single trees, bushes, or protuberances of the same general size as the scale model tanks. False targets were generally somewhat isolated or located a finite distance from dense foliage of bushes or trees.

ANNEX D

CONTRAST CONTROL

1. GENERAL.

a. Definition of Contrast. For this experiment, the luminance or brightness contrast for a single tank element was defined as:

$$C = (B_T - B_B)/B_B$$

Where: C = Luminance contrast between a single tank and background.

B_T = Average luminance over single tank area.

B_B = Average luminance over target background area taken to be 10 times the target area. Target shadow was excluded.

b. Contrast Levels and Direction of Measurements. Three levels of nominal contrast values were -0.6, -0.2 and +0.6. Allowable tolerances for each contrast level were ±0.1. Photometric measurements to assist in contrast control were taken along the observer's line-of-sight directly opposite the target array at a distance equal to slant range between observer and targets.

2. BACKGROUND LUMINANCE MEASUREMENTS. Background measurements were made with a Photo Research model 1970 photometer according to the procedures described in the first experiment report (Hilgendorf et al., AMRL-TR-74-4). These background luminance measurements for each of three tanks at each location are shown in Table 13. Tank #1 denotes the center tank while tank #2 and tank #3 denote the right and left tanks respectively.

TABLE 13. TANK BACKGROUND LUMINANCES

Tank Number	Background Luminance (fl) Loc. #1	Loc. #2	Loc. #3
1	202	57.8	32.8
2	193	42.9	16.1
3	212	45.9	27.6

These background luminances are somewhat different from those reported in the first experiment (Hilgendorf et al., AMRL-TR-74-4). Differences are related to replacement of faulty or burned out solar illumination globes with new ones.

3. TANK LUMINANCE MEASUREMENTS. Required target luminances, based on background luminances and contrast values were established. These are presented in Table 14. Tank luminance measurements were made with the photometer which contained a six-minutes-of-arc mirror aperture. The six-minutes-of-arc sensitive area in the optical field-of-view was always positioned on the projected geometric center of the tank near the turret and the photometer output observed to assess the measured tank luminance. Should this luminance be too high or too low to provide the required contrast, then the tank orientation was changed in azimuth and/or elevation by very small rotations so as to produce the luminance which would allow the required contrast to be attained. Reflectance of light from the tank was quite sensitive to tank orientation and the maximum amount of rotation necessary to give the required contrast was only four or five degrees.

TABLE 14. REQUIRED TARGET LUMINANCES FOR CONTRAST CONTROL

LOCATION #1

C	Tank#	B_T* (Nom)	Allowable Range of B_T*
	1	323.0	$303.0 \leq B_T \leq 343.0$
+0.6	2	309.0	$290.0 \leq B_T \leq 328.0$
	3	339.0	$318.0 \leq B_T \leq 360.0$
	1	162.0	$141.0 \leq B_T \leq 182.0$
-0.2	2	154.0	$135.0 \leq B_T \leq 174.0$
	3	170.0	$148.0 \leq B_T \leq 191.0$
	1	81.0	$61.0 \leq B_T \leq 101.0$
-0.6	2	77.0	$58.0 \leq B_T \leq 97.0$
	3	85.0	$64.0 \leq B_T \leq 106.0$

TABLE 14. **REQUIRED TARGET LUMINANCES** FOR CONTRAST CONTROL

LOCATION #2

C	Tank#	B_T* (Nom)	Allowable Range of B_T*
	1	92.5	$86.7 \leq B_T \leq 98.3$
+0.6	2	68.6	$64.4 \leq B_T \leq 72.9$
	3	73.4	$68.8 \leq B_T \leq 78.0$
	1	46.2	$40.4 \leq B_T \leq 52.0$
-0.2	2	34.3	$30.0 \leq B_T \leq 38.6$
	3	36.7	$32.1 \leq B_T \leq 41.3$
	1	23.1	$17.3 \leq B_T \leq 28.9$
-0.6	2	17.2	$12.9 \leq B_T \leq 21.5$
	3	18.4	$13.8 \leq B_T \leq 23.0$

TABLE 14. REQUIRED TARGET LUMINANCES FOR CONTRAST CONTROL

LOCATION #3

C	Tank#	B_T* (Nom)	Allowable Range of B_T*
	1	52.5	$49.2 \leq B_T \leq 55.8$
+0.6	2	25.8	$24.2 \leq B_T \leq 27.4$
	3	44.2	$41.4 \leq B_T \leq 46.9$
	1	26.2	$22.9 \leq B_T \leq 29.5$
-0.2	2	12.9	$11.3 \leq B_T \leq 14.5$
	3	22.1	$19.3 \leq B_T \leq 24.9$
	1	13.1	$9.8 \leq B_T \leq 16.4$
-0.6	2	6.4	$4.8 \leq B_T \leq 8.1$
	3	11.0	$8.3 \leq B_T \leq 13.8$

ANNEX E

ANALYSIS OF VARIANCE COMPUTATIONAL PROCEDURES

1. GENERAL. The experimental design specified for this experiment (SEEKVAL, 1973b) is a 3 X 3 X 3 factorial design with components of two-factor and three-factor interactions partially confounded with block effects. The foundation for this design together with a discussion of advantages and disadvantages of factorial experimental designs which involve confounding of interactions with block effects is provided by Winer (1962, Chap. 8). However, Winer's discussion of computational procedures to obtain the sum of squares for individual sources of variation is limited. Including the overall mean sum of squares, a total of seventeen sources of variation exist for this particular design. Winer (1962, p. 430) provides explicit formulas to determine the sum of squares for only two of the seventeen sources of variation; in addition, one of these two formulas (last equation on p. 430) is in error and has not been corrected in a later edition (Winer, 1971, p. 659).

2. OVERALL DESIGN CONSIDERATIONS AND CONFOUNDING.

a. Replications and Blocks. This design consists of four replications with each replication containing nine blocks. Thus, a total of thirty-six blocks is inherent to the design. The block size is three, corresponding to the number of data points within a block. An observer or subject is construed as a "block" since he makes three observations under specified treatment or factor combinations. Each of these three observations by an individual observer is under a different treatment combination. A total of 108 observations results from the thirty-six blocks and three observations per block.

b. Confounding. The method of confounding associated with this design has enabled a small block size to be attained by dividing the set of all possible factor level combinations (27 = 3 X 3 X 3) into subsets and subsequently allocating each subset to different blocks or observers. All possible factor combinations are employed four times via replication. Factor combinations imbedded within each block (observer) are such that main effects A, B, and C due to the three experimental factors a, b, and c (each factor at three levels: 0, 1, 2) are not confounded with block effects. Some, but not all, two-factor and three-factor interaction components are confounded in each replication. The specific factor combinations assigned to individual blocks within each replication ultimately provide for some information to be available for all of the interactions (i.e., one-half information on all components of the two-factor interactions and three-quarters information on all components of the three-factor interaction). In the analysis of variance, the sum of squares for a partially confounded interaction is based only on observations in which it is not confounded.

3. OBSERVATIONS REQUIRED FOR INTERACTION EFFECTS. Major effort and considerations in the determination of sum of squares for each source of variation must be directed to the interaction components. Table 15 provides the ten interaction effect components and the replications

TABLE 15. FACTOR COMBINATION SETS FOR INTERACTION EFFECTS

Interaction Effect	Interaction Effect Components	Replications Containing Unconfounded Effect	Modular Equations Defining Factor Combination Sets to be Employed with each Replication Containing Unconfounded Effect
AXB	AB	1,2	$x_1 + x_2 + 0x_3 \equiv i(\mathrm{mod}3);\ i = 0,1,2$
	AB^2	3,4	$x_1 + 2x_2 + 0x_3 \equiv i(\mathrm{mod}3);\ i = 0,1,2$
AXC	AC	1,3	$x_1 + 0x_2 + x_3 \equiv i(\mathrm{mod}3);\ i = 0,1,2$
	AC^2	2,4	$x_1 + 0x_2 + 2x_3 \equiv i(\mathrm{mod}3);\ i = 0,1,2$
BXC	BC	1,4	$0x_1 + x_2 + x_3 \equiv i(\mathrm{mod}3);\ i = 0,1,2$
	BC^2	2,3	$0x_1 + x_2 + 2x_3 \equiv i(\mathrm{mod}3);\ i = 0,1,2$
AXBXC	ABC	2,3,4	$x_1 + x_2 + x_3 \equiv i(\mathrm{mod}3);\ i = 0,1,2$
	ABC^2	1,3,4	$x_1 + x_2 + 2x_3 \equiv i(\mathrm{mod}3);\ i = 0,1,2$
	AB^2C	1,2,4	$x_1 + 2x_2 + x_3 \equiv i(\mathrm{mod}3);\ i = 0,1,2$
	AB^2C^2	1,2,3	$x_1 + 2x_2 + 2x_3 \equiv i(\mathrm{mod}3);\ i = 0,1,2$

containing information to obtain interaction effects. This table also contains the modular algebraic equations which define the factor combination sets to be employed for information from each replication. In these modular equations, x_1, x_2 and x_3 are equal to either 0, 1 or 2 corresponding to the three levels of the factors a, b and c, respectively. The coefficients of x_1, x_2 and x_3 correspond to the exponents in the interaction components and thus possess values of 0, 1 and 2. The integer i possessing three values 0, 1, 2 allows accommodation for all necessary factor combinations. Each of the thirty modular equations serves to define nine factor combinations.

4. DATA FORMAT TABLE. Table 16 presents the time response data for correct target detections. This table is in a format well suited to perform the analysis of variance (ANOVA). Observer numbers are the "block" numbers and three time responses are associated with each block. Factor combination sets under which the response time observations were made are identified as ordered triplets in the left column. It should be noted that observer numbers in this table are those required for the analysis. In actual execution of the experiment, observers were reordered from those shown in Table 16 to facilitate efficient experimental conduct.

5. DETERMINATION OF SUMS OF SQUARES.

a. <u>Sum of Squares, Total.</u>

$$SS_{tot} = \sum_{i=1}^{i=108} X_i^2 = 64.8^2 + 6.0^2 + \ldots + 2.4^2 = 97,314.84000$$

TABLE 16. EXPERIMENT TIME RESPONSE DATA IN FORMAT FOR ANOVA COMPUTATIONS

Levels of Factors a (x_1)	b (x_2)	c (x_3)	REPLICATE 1 Obs. No.	REPLICATE 1 Time Response (seconds)	REPLICATE 2 Obs. No.	REPLICATE 2 Time Response (seconds)	REPLICATE 3 Obs. No.	REPLICATE 3 Time Response (seconds)	REPLICATE 4 Obs. No.	REPLICATE 4 Time Response (seconds)
0	0	0	1	64.8	10	32.4	19	2.1	28	3.0
1	0	0	5	6.0	14	13.8	23	2.7	32	6.9
2	0	0	9	3.0	18	3.0	27	1.2	36	5.1
0	1	0	6	3.0	15	20.1	26	9.6	35	22.8
1	1	0	7	1.8	16	3.0	21	7.2	30	2.1
2	1	0	2	3.6	11	1.5	22	3.0	31	3.0
0	2	0	8	4.5	17	2.1	24	1.5	33	1.5
1	2	0	3	3.9	12	4.8	25	2.4	34	13.8
2	2	0	4	3.6	13	1.5	20	1.2	29	1.5
0	0	1	4	4.5	16	45.0	22	4.8	34	3.0
1	0	1	8	12.9	11	9.3	26	76.8	29	108.0
2	0	1	3	12.9	15	8.7	21	6.9	33	10.8
0	1	1	9	7.8	12	58.2	20	1.8	32	6.0
1	1	1	1	63.9	13	69.6	24	35.7	36	1.5
2	1	1	5	3.6	17	2.4	25	2.4	28	11.1
0	2	1	2	2.1	14	5.1	27	2.4	30	50.4
1	2	1	6	3.0	18	12.0	19	1.8	31	71.1
2	2	1	7	1.5	10	1.8	23	2.1	35	1.8
0	0	2	7	1.8	13	3.6	25	2.7	31	75.6
1	0	2	2	60.0	17	2.1	20	14.4	35	176.4
2	0	2	6	2.7	12	2.4	24	4.5	30	1.2
0	1	2	3	7.5	18	13.2	23	7.8	29	81.0
1	1	2	4	9.6	10	9.6	27	2.4	33	9.9
2	1	2	8	6.3	14	9.0	19	1.8	34	1.5
0	2	2	5	3.6	11	1.5	21	3.3	36	1.5
1	2	2	9	14.1	15	2.4	22	7.2	28	2.7
2	2	2	1	2.4	16	2.7	26	9.9	32	2.4

a = Color Factor ; a_0 = Gn , a_1 = Bn , a_2 = Gy

b = Contrast Factor; b_0 = -0.6, b_1 = -0.2, b_2 = +0.6

c = Location Factor; c_0 = #1 , c_1 = #2 , c_2 = #3

b. Mean of Square of Grand Total.

$$M = \frac{1}{108}\left(\sum_{i=1}^{i=108} X_i\right)^2 = \frac{1}{108}(64.8 + 6.0 + \ldots + 2.4)^2 = 22{,}256.85333$$

c. Sum of Squares, Total Variability among Blocks.

$$SS_{\text{between blocks}} = \frac{1}{3}\sum_{i=1}^{i=36} (\text{sum of three observations in block})_i^2 - M$$

$$= \frac{1}{3}(131.1^2 + 65.7^2 + \ldots + 8.1^2) - M$$

$$= 29{,}901.32667$$

d. Sum of Squares, Variability among Replications.

$$SS_{\text{reps}} = \frac{1}{27}\sum_{i=1}^{i=4} (\text{sum of twenty-seven observations in replication})_i^2 - M$$

$$= \frac{1}{27}(314.4^2 + 340.8^2 + 219.6^2 + 675.6^2) - M = 4{,}396.90667$$

e. Sum of Squares, Variability among Blocks within Replications.

$$SS_{\text{blocks within reps}} = \frac{1}{3}\sum_{i=1}^{i=36} (\text{sum of three observations in block})_i^2$$

$$- \frac{1}{27}\sum_{i=1}^{i=4} (\text{sum of twenty-seven observations in replication})_i^2$$

$$= 25{,}504.4200$$

f. Sum of Squares, Total Variability within Blocks.

$$SS_{\text{within blocks}} = SS_{tot} - \frac{1}{3}\sum_{i=1}^{i=36} (\text{sum of three observations in block})_i^2$$

$$= 45,156.66000$$

g. Sum of Squares, Main Effect A.

$$SS_A = \frac{1}{36}\sum_{i=1}^{i=3} (\text{sum of all observations at each fixed level of a})_i^2 - M$$

$$= 6,904.74667$$

h. Sum of Squares, Main Effect B.

$$SS_B = \frac{1}{36}\sum_{i=1}^{i=3} (\text{sum of all observations at each fixed level of b})_i^2 - M$$

$$= 4,115.22167$$

i. Sum of Squares, Main Effect C.

$$SS_C = \frac{1}{36}\sum_{i=1}^{i=3} (\text{sum of all observations at each fixed level of c})_i^2 - M$$

$$= 2,964.50167$$

j. Sum of Squares, AB Component of AXB Interaction Effect (1/2 info.). Within block information on the AB component is computed from a summary table prepared from Replications 1 and 2. This summary table contains observations from factor combination sets which satisfy the three modular equations $x_1 + x_2 + 0X_3 = i(\text{mod}3)$; $i = 0,1,2$. Information from the preceding two tables in this annex is employed to generate the AB summary table given as Table 17. From this summary table, the requisite sum of squares is generated according to the following equation.

$$SS'_{AB} = \frac{1}{18}\left[(AB)'^2_0 + (AB)'_1 + (AB)'^2_2\right] - \frac{1}{54}\left[(AB)'_0 + (AB)'_1 + (AB)'_2\right]^2$$

The general term $(AB)'_i$ for $i = 0,1,2$ is the sum of all observations which satisfy the modular equations $x_1 + x_2 + 0x_3 = i(\text{mod}3)$; $i = 0,1,2$ from Replications 1 and 2. The prime denotes the fact that the sums are only from these two replications rather than all four replicates of the experiment. Since but two replicates are employed, the relative within block information is said to be "one-half information." Each sum consists of eighteen observations. Numerically,

$$(AB)'_0 = 64.8 + 3.9 + \ldots + 9.0 = 218.7$$

$$(AB)'_1 = 3.0 + 6.0 + \ldots + 2.7 = 227.4$$

$$(AB)'_2 = 4.5 + 1.8 + \ldots + 2.4 = 209.1$$

Therefore: $SS'_{AB} = 9.31000$

TABLE 17. AB SUMMARY TABLE

$x_1 + x_2 + 0x_3 = i(\text{mod}3)$; $i = 0,1,2$. Employed with Reps. 1 and 2														
$x_1 + x_2 + 0x_3 = 0(\text{mod}3)$					$x_1 + x_2 + 0x_3 = 1(\text{mod}3)$					$x_2 + x_2 + 0x_3 = 2(\text{mod}3)$				
Levels of Factors			Replications and Time Responses		Levels of Factors			Replications and Time Responses		Levels of Factors			Replications and Time Responses	
a (x_1)	b (x_2)	c (x_3)	Rep. 1	Rep. 2	a (x_1)	b (x_2)	c (x_3)	Rep. 1	Rep. 2	a (x_1)	b (x_2)	c (x_3)	Rep. 1	Rep. 2
0	0	0	64.8	32.4	0	1	0	3.0	20.1	0	2	0	4.5	2.1
1	2	0	3.9	4.8	1	0	0	6.0	13.8	1	1	0	1.8	3.0
2	1	0	3.6	1.5	2	2	0	3.6	1.5	2	0	0	3.0	3.0
0	0	1	4.5	45.0	0	1	1	7.8	58.2	0	2	1	2.1	5.1
1	2	1	3.0	12.0	1	0	1	12.9	9.3	1	1	1	63.9	69.6
2	1	1	3.6	2.4	2	2	1	1.5	1.8	2	0	1	12.9	8.7
0	0	2	1.8	3.6	0	1	2	7.5	13.2	0	2	2	3.6	1.5
1	2	2	14.1	2.4	1	0	2	60.0	2.1	1	1	2	9.6	9.6
2	1	2	6.3	9.0	2	2	2	2.4	2.7	2	0	2	2.7	2.4

k. Sum of Squares, AB^2 Component of AXB Interaction Effect (1/2 info.). The necessary sums are generated from an AB^2 summary table containing observations from Replicates 3 and 4 made under factor combination sets satisfying $x_1 + 2x_2 + 0x_3 = i(\mathrm{mod}3)$; $i = 0,1,2$.

$$(AB^2)'_0 = 168.9 \; ; \; (AB^2)'_1 = 468.6 \; ; \; (AB^2)'_2 = 257.7$$

$$SS'_{AB^2} = \frac{1}{18}(168.9^2 + 468.6^2 + 257.7^2) - \frac{1}{54}(168.9 + 468.6 + 257.7)^2$$

$$= 2{,}633.04333$$

l. Sum of Squares, AC Component of AXC Interaction Effect (1/2 info.). From Replications 1 and 3 and $x_1 + 0x_2 + x_3 = i(\mathrm{mod}3)$; $i = 0,1,2$:

$$(AC)'_0 = 222.6 \; ; \; (AC)'_1 = 75.0 \; ; \; (AC)'_2 = 236.4 \text{ and } SS'_{AC} = 889.37333$$

m. Sum of Squares, AC^2 Component of AXC Interaction Effect (1/2 info.). From Replications 2 and 4 and $x_1 + 0x_2 + 2x_3 = i(\mathrm{mod}3)$; $i = 0,1,2$:

$$(AC^2)'_0 = 372.6 \; ; \; (AC^2)'_1 = 257.4 \; ; \; (AC^2)'_2 = 386.4$$

$$\text{and } SS'_{AC^2} = 557.45333$$

n. Sum of Squares, BC Component of BXC Interaction Effect (1/2 info.). From Replications 1 and 4 and $0x_1 + x_2 + x_3 = i(\mathrm{mod}3)$; $i = 0,1,2$:

$$(BC)'_0 = 334.5 \; ; \; (BC)'_1 = 215.1 \; ; \; (BC)'_2 = 440.4$$

$$\text{and } SS'_{BC} = 1{,}411.69000$$

o. Sum of Squares, BC^2 Component of BXC Interaction Effect (1/2 info.). From Replications 2 and 3 and $0x_1 + x_2 + 2x_3 = i \pmod 3$; $i = 0,1,2$:

$$(BC^2)'_0 = 252.3 \; ; \; (BC^2)'_1 = 99.3 \; ; \; (BC^2)'_2 = 208.8$$

$$\text{and } SS'_{BC^2} = 690.58333$$

p. Sum of Squares, ABC Component of AXBXC Interaction Effect (3/4 info.). Within block information on the ABC component is computed from a summary table prepared from Replications 2, 3, and 4. This summary table contains observations from factor combination sets which satisfy the three modular equations $x_1 + x_2 + x_3 = i \pmod 3$; $i = 0,1,2$. Information from Tables 15 and 16 in this annex is employed to generate the ABC summary table presented as Table 18. From this summary table, the requisite sum of squares is generated according to the following equation:

$$SS'_{ABC} = \frac{1}{27}\left[(ABC)'^2_0 + (ABC)'^2_1 + (ABC)'^2_2\right] - \frac{1}{81}\left[(ABC)'_0 + (ABC)'_1 + (ABC)'_2\right]^2$$

The general term $(ABC)'_i$ for $i = 0,1,2$ is the sum of all observations which satisfy the modular equations $x_1 + x_2 + x_3 = i \pmod 3$; $i = 0,1,2$ from Replications 2, 3 and 4. The prime denotes the fact that the sums are only from these three replications rather than all four replicates of the experiment. Since but three replicates are employed, the relative within block information is said to be "three-quarters information." Each sum consists of twenty-seven observations. Numerically,

TABLE 18. ABC SUMMARY TABLE

$x_1 + x_2 + x_3 = i(\mathrm{mod}3)$; $i = 0,1,2$. Employed with Reps. 2, 3 and 4

$x_1 + x_2 + x_3 = 0(\mathrm{mod}3)$						$x_1 + x_2 + x_3 = 1(\mathrm{mod}3)$						$x_1 + x_2 + x_3 = 2(\mathrm{mod}3)$					
Levels of Factors			Replications and Time Responses			Levels of Factors			Replications and Time Responses			Levels of Factors			Replications and Time Responses		
a (x_1)	b (x_2)	c (x_3)	Rep. 2	Rep. 3	Rep. 4	a (x_1)	b (x_2)	c (x_3)	Rep. 2	Rep. 3	Rep. 4	a (x_1)	b (x_2)	c (x_3)	Rep. 2	Rep. 3	Rep. 4
0	0	0	32.4	2.1	3.0	0	1	0	20.1	9.6	22.8	0	2	0	2.1	1.5	1.5
1	2	0	4.8	2.4	13.8	1	0	0	13.8	2.7	6.9	1	1	0	3.0	7.2	2.1
2	1	0	1.5	3.0	3.0	2	2	0	1.5	1.2	1.5	2	0	0	3.0	1.2	5.1
0	2	1	5.1	2.4	50.4	0	0	1	45.0	4.8	3.0	0	1	1	58.2	1.8	6.0
1	1	1	69.6	35.7	1.5	1	2	1	12.0	1.8	71.1	1	0	1	9.3	76.8	108.0
2	0	1	8.7	6.9	10.8	2	1	1	2.4	2.4	11.1	2	2	1	1.8	2.1	1.8
0	1	2	13.2	7.8	81.0	0	2	2	1.5	3.3	1.5	0	0	2	3.6	2.7	75.6
1	0	2	2.1	14.4	176.4	1	1	2	9.6	2.4	9.9	1	2	2	2.4	7.2	2.7
2	2	2	2.7	9.9	2.4	2	0	2	2.4	4.5	1.2	2	1	2	9.0	1.8	1.5

$(ABC)'_0 = 32.4 + 4.8 + \ldots + 2.4 = 567.0$

$(ABC)'_1 = 20.1 + 13.8 + \ldots + 1.2 = 270.0$

$(ABC)'_2 = 2.1 + 3.0 + \ldots + 1.5 = 399.0$

Therefore: $SS'_{ABC} = 1642.88889$

q. Sum of Squares, ABC^2 Component of AXBXC Interaction Effect (3/4 info.). The necessary sums are generated from an ABC^2 summary table containing observations from Replications 1, 3 and 4 made under factor combination sets satisfying $x_1 + x_2 + 2x_3 = i(\text{mod}3)$; $i = 0,1,2$;

$$(ABC^2)'_0 = 357.0 \; ; \; (ABC^2)'_1 = 357.6 \; ; \; (ABC^2)'_2 = 495.0$$

$$SS'_{ABC^2} = \frac{1}{27}(357.0^2 + 357.6^2 + 495.0^2) - \frac{1}{81}(357.0 + 357.6 + 495.0)^2$$

$$= 468.18667$$

r. Sum of Squares, AB^2C Component of AXBXC Interaction Effect (3/4 info). From Replications 1, 2 and 4 and satisfying $x_1 + 2x_2 + x_3 = i(\text{mod}3)$; $i = 0,1,2$:

$$(AB^2C)'_0 = 556.1 \; ; \; (AB^2C)'_1 = 362.7 \; ; \; (AB^2C)'_2 = 402.0$$

and, $SS'_{AB^2C} = 862.28222$

s. Sum of Squares, AB^2C^2 Component of AXBXC Interaction Effect (3/4 info.). From Replications 1, 2 and 3 satisfying $x_1 + 2x_2 + 2x_3 = i(\text{mod}3)$; $i = 0,1,2$:

$$(AB^2C^2)'_0 = 296.4 \; ; \; (AB^2C^2)'_1 = 196.5 \; ; \; (AB^2C^2)'_2 = 381.9$$

$$\text{and, } SS'_{AB^2C^2} = 637.82000$$

t. Sum of Squares, Residual.

$$SS_{residual} = SS_{within\ blocks} - (SS_A + SS_B + SS_C + SS'_{AB} + SS'_{AB^2} + SS'_{AC} + SS'_{AC^2} + SS'_{BC} + SS'_{BC^2} + SS'_{ABC} + SS'_{ABC^2} + SS'_{AB^2C} + SS'_{AB^2C^2})$$

$$= 21{,}369.55889$$

5. ANALYSIS OF VARIANCE TABLE. The sums of squares and the degrees of freedom for each source of variation allow the analysis of variance table to be constructed. The ANOVA table for correct detection response times is shown as Table 5. A condensed version of the ANOVA table is in the results and discussion section of this report. It is pointed out that in the ANOVA table, partially confounded effects have the same number of degrees of freedom as those in an unconfounded experiment. This, in turn, implies that the F ratio test is less sensitive for the partially confounded effects since only some information is available for the interaction effects.

☆U.S. Government Printing Office: 1974 — 657-017/376