AD-A010 126

TARGET DETECTION WITH COLOR VERSUS BLACK AND WHITE
TELEVISION

Dan W. Wagner

Naval Weapons Center
China Lake, California

April 1975

T56065
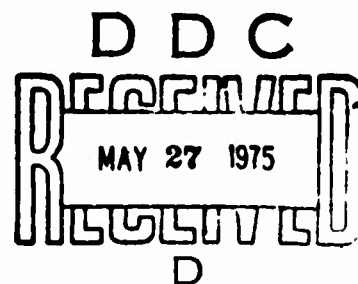
Target Detection With Color Versus Black and White Television

by
Dan W. Wagner
Aircraft Systems Department

APRIL 1975

D D C

MAY 27 1975

D

Naval Weapons Center

CHINA LAKE, CALIFORNIA 93555

Naval Weapons Center

AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

R. G. Freeman, III, RAdm., USN . . . . Commander
G. L. Hollingsworth . . . . Technical Director

FOREWORD

This experiment on target acquisition with color and black and white television systems was conducted at the Naval Weapons Center. China Lake, Calif., between July and November 1974. The task is part of a Naval Air Systems Command program on imaging system specifications and display quality. It is supported by AirTask No. A3400000/008B/5F55-525-402 under the direction of LCDR Paul Chatelier (AIR-340F).

This report was reviewed for technical accuracy by Ronald A. Erickson.

Released by
P. B. HOMER, *Head*
Weapons Systems Analysis Division
19 February 1975

Under authority of
M. M. ROGERS, *Head*
Aircraft Systems Department

NWC Technical Publication 5731

REPORT DOCUMENTATION PAGE

1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
NWC TP 5731		AD-A010126

4. TITLE (and Subtitle)	5. TYPE OF REPORT & PERIOD COVERED
Target Detection With Color Versus Black and White Television	Initial report July through November 1974
	6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)	8. CONTRACT OR GRANT NUMBER(s)
Dan W. Wagner	

9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
Naval Weapons Center China Lake, California 93555	62755N-F55-525-40

11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE
Naval Weapons Center China Lake, California 93555	April 1975
	13. NUMBER OF PAGES
	38

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.

DDC
RECEIVED
MAY 27 1975
D

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

18. SUPPLEMENTARY NOTES

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

Target Detection	Background Color
Color TV	Contrast
Black and White TV	Resolution
Target Color	

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

See back of form.

PRICES SUBJECT TO CHANGE

1

DD FORM 1473 EDITION OF 1 NOV 65 IS OBSOLETE
1 JAN 73
S/N 0102-014-6601

(U) *Target Detection With Color Versus Black and White Television*, by Don W. Wagner. China Lake, Calif., Naval Weapons Center, April 1975. 36 pp. (NWC TP 5731, publication UNCLASSIFIED.)

(U) An experiment was conducted to investigate target detection performance on color and black and white TV. Green, brown, and gray model tank targets were viewed under 25, 35, and 300 TV lines resolution against a green and a brown background on a terrain model. Target-to-background luminance contrasts studied were positive (targets lighter than the surround), negative (targets darker than the surround), and zero. Color provided a slightly higher percentage of target detection than did black and white TV (74 versus 69%). Background color did not significantly affect performance, although it figured prominently in several interaction effects. Gray targets were more detectable than either brown or green targets. Higher resolution improved performance about equally for both color and black and white TV, and targets lighter than the background were detected more easily than either negative or zero contrast targets.

1-a

CONTENTS

INTRODUCTION

Many parameters for monochrome electro-optical imaging systems have been investigated over the past 20 years. Display variables such as brightness, contrast, size, shades of gray, number of scan lines, and resolution have been compared with such viewing variables as viewing distance, scene complexity or clutter, target size and shape, relative motion, field of view, and physical environment. As a result, the relative importance of these parameters has been established for monochrome imaging systems now in use or under development for ground, water, and airborne military applications.

The evolution of color representations has characteristically lagged the development of monochrome and achromatic representations. Color television is no exception. Viewing parameters for color television have not been established, although color TV is being considered for some military applications, airport control tower operations, and security surveillance functions.

A review of the literature on color research indicates that the bulk of the work has been concerned with threshold investigations, theoretical concepts associated with information theory, and physiological mechanisms linked to color vision. Recent literature reviews concerned specifically with the relative effectiveness of color coding as compared to achromatic coding have found insufficient data available concerning its effect on performance of realistic tasks.[1,2]

The present study was designed to compare target detection performance on black and white television with that on color television using realistic imagery while varying background color, target color, resolution, and contrast. Background color was of interest as an experimental variable both to investigate its effect on target detection performance and for practical considerations since the various color regions of the world can be readily identified. For example, it is known that, on the annual average, shades of brown and green, respectively, represent 43 and 39% of the world's total land area.[3]

---

[1] New Mexico State University. Dept. of Psychology. *Color Research for Visual Displays*, by R. E. Christ and W. H. Teichner. Las Cruces. New Mexico, NMSU, LC. July 1973, p. 54. (JANAIR Report 730703, publication UNCLASSIFIED.)

[2] Hughes Aircraft Company. *Master Monitor Display Study*. Aerospace Group. Culver City, Calif., HAC-AG, November 1973, pp. 4-11. (Report No. P73-464, publication UNCLASSIFIED.)

[3] Quartermaster Research & Development Center. *Color Regions of the World*. Environmental Protection Research Division, Natick. Mass., QRDC, November 1956. (Technical Report EP-37, publication UNCLASSIFIED.)

The experiment was also designed to extend the work of other researchers. In one such study, Hilgendorf and Milenski,[4] using a terrain model in a direct vision experiment, investigated target color and contrast. They found that color effects were significant and accounted for a greater proportion of the total variance than did luminance contrast.

A study of resolution is of interest to determine if the findings of Johnston,[5] Oatman,[6,7,8] and others may be generalized to color TV. They found that with static targets on black and white TV, resolution significantly affects an observer's visual responses. On the other hand, in separate studies, Fowler and Jones[9] and Wong and Yacoumelos[10] compared performance using both black and white and color TV. Their studies did not find a general advantage for either presentation mode. The findings are surprising in that the black and white systems exhibited higher resolution than did the color systems.

[4] Aerospace Medical Research Laboratory. *SEEKVAL Project IA1: Effects of Color and Brightness Contrast on Target Acquisition,* by R. L. Hilgendorf and John Milenski. Wright-Patterson AFB, Ohio, AMRL. (Preliminary draft, paper UNCLASSIFIED.)

[5] Johnston, D. M. "Target Recognition on Television as a Function of Horizontal Resolution and Shades of Gray." HUM FACTORS, Vol. 10, No. 3, 1968, pp. 201-210.

[6] Human Engineering Laboratories. *Target Detection Using Black and White Television, Study I: The Effect of Resolution Degradation on Target Detection,* by L. C. Oatman. Aberdeen Proving Ground, Md., APG-HEL, July 1965. (Technical Memorandum 9-65, publication UNCLASSIFIED.)

[7] Human Engineering Laboratories. *Target Detection Using Black and White Television, Study II: Degraded Resolution and Target Detection Probability,* by L. C. Oatman. Aberdeen Proving Ground, Md., APG-HEL, July 1965. (Technical Memorandum 10-65, publication UNCLASSIFIED.)

[8] Human Engineering Laboratories. *Target Detection Using Black and White Television, Study III: Target Detection as a Function of Display Degradation,* by L. C. Oatman. Aberdeen Proving Ground, Md., APG-HEL, September 1965. (Technical Memorandum 12-65, publication UNCLASSIFIED.)

[9] Martin-Marietta Corp. *Target Acquisition Studies: (1) Transition From Direct to TV Mediated Viewing, (2) Target Acquisition Performance: Color vs Monochrome TV Displays,* by F. D. Fowler and D. B. Jones. Orlando, Fla., MMC, January 1972. (Report OR 11,678, publication UNCLASSIFIED.)

[10] Wong, K. W., and N. G. Yacoumelos. "Identification of Cartographic Symbols from TV Displays." HUM FACTORS, Vol. 15, No. 1, 1973.

METHODOLOGY

A closed circuit color television system and a terrain model were
used to investigate the effects of color television, as compared to
black and white television, on target detection performance.

APPARATUS

The equipment used to measure visual detection performance included
a terrain model, targets, luminance discriminator, color television
camera, color television display, an optical comparator, oscilloscope,
telephotometer, two-channel paper recorder with power supplies, and
the subject's booth with chair, forehead restraint, and response button.
Figure 1 provides a sketch of the test layout.
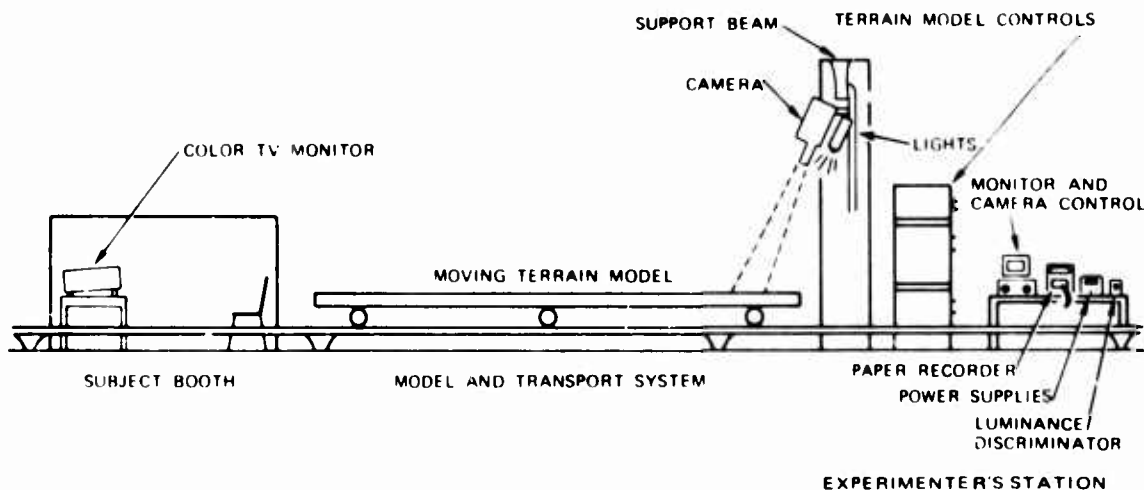
FIGURE 1. Sketch of Experimental Layout.

Terrain Model

The terrain model is a three-dimensional, 1200:1 scale model simu-
lating an area 1.8 miles wide by 4.5 miles long (8 x 20 feet). It con-
tains numerous trees and shrubs that can be relocated as desired and
varies in color from light greens and browns to dark greens and browns.
The entire model moves on rails, with the speed control mounted in an
adjacent console. Two flat areas, similar in dimension and ground cover
texture, were selected for the test tracks; one track was primarily
green (approximately Munsell 5GY 5/6) while the other track was primar-
ily brown (approximately Munsell 5YR 4/2). Each parallel test track

5

measured 10 inches wide by 9 feet long. Trees and shrubs were evenly
distributed throughout each track to provide controlled clutter.
Approximately 40 objects were continuously in view as the scenery moved
down the television display. No object was placed within 100 feet
(simulated) of a target.

Targets

Nine military tanks of 1000:1 scale were used as targets for this
study. Each tank was painted a shade of green, brown, or gray. When
appropriately placed on the test track, the models provided three lumi-
nance contrast values for each of the three colors: 0, -0.3, and +0.3.
The targets were obtained from Hilgendorf and are described in his study
report.[4] Paint spectra and contrast values for the nine tanks are con-
tained in the Appendix. The targets were all oriented in the same
direction (viewed head-on by the TV camera) and placed along the track
so that never more than one target at a time was in the displayed
imagery (see Figure 2). Since contrast values were quite sensitive to
target orientation, slight variations in orientation, about ±5 deg,
were required to provide the desired contrast. The displayed targets
subtended 25 minutes of arc on the TV monitor to the subjects.

Color Television Camera

A Cohu Model 1230D color television camera with a 5 to 1 zoom
lens was suspended on a movable boom over the terrain model. A Cohu
Model 1290 camera control unit was attached by cable to the camera and
located at the experimenter's station. Three levels of horizontal
limiting resolution, 25, 35, and 300 television lines, were investi-
gated. Resolution levels were achieved by adjusting the lens focus
control. These values were obtained with an oscilloscope, bar patterns,
and Retma chart using an average 20-mV peak-to-peak signal as limiting
criteria. The camera look-down angle of 78 deg and field of view of
5.7 by 7.6 deg were kept constant. The camera color setup procedure,
as modified for this experiment, and pertinent camera specifications
can be found in the Appendix.

Color Television Display

A Conrac Model 5022C12 color television was used for the subject's
display. Specifications and color setup procedures are contained in
the Appendix. Displayed scene luminance, measured with a 1-deg
aperture setting on the photometer, was as follows:

Test track	Display mode	Range, ftL	Average, ftL
Green	Color	41-57	50.4
Green	B & W	38-50	45.1
Brown	B & W	31-39	34.9
Brown	Color	37-43	40.1

6

BROWN TRACK   GREEN TRACK

LUMINANCE
SIGNAL SOURCES

TARGET
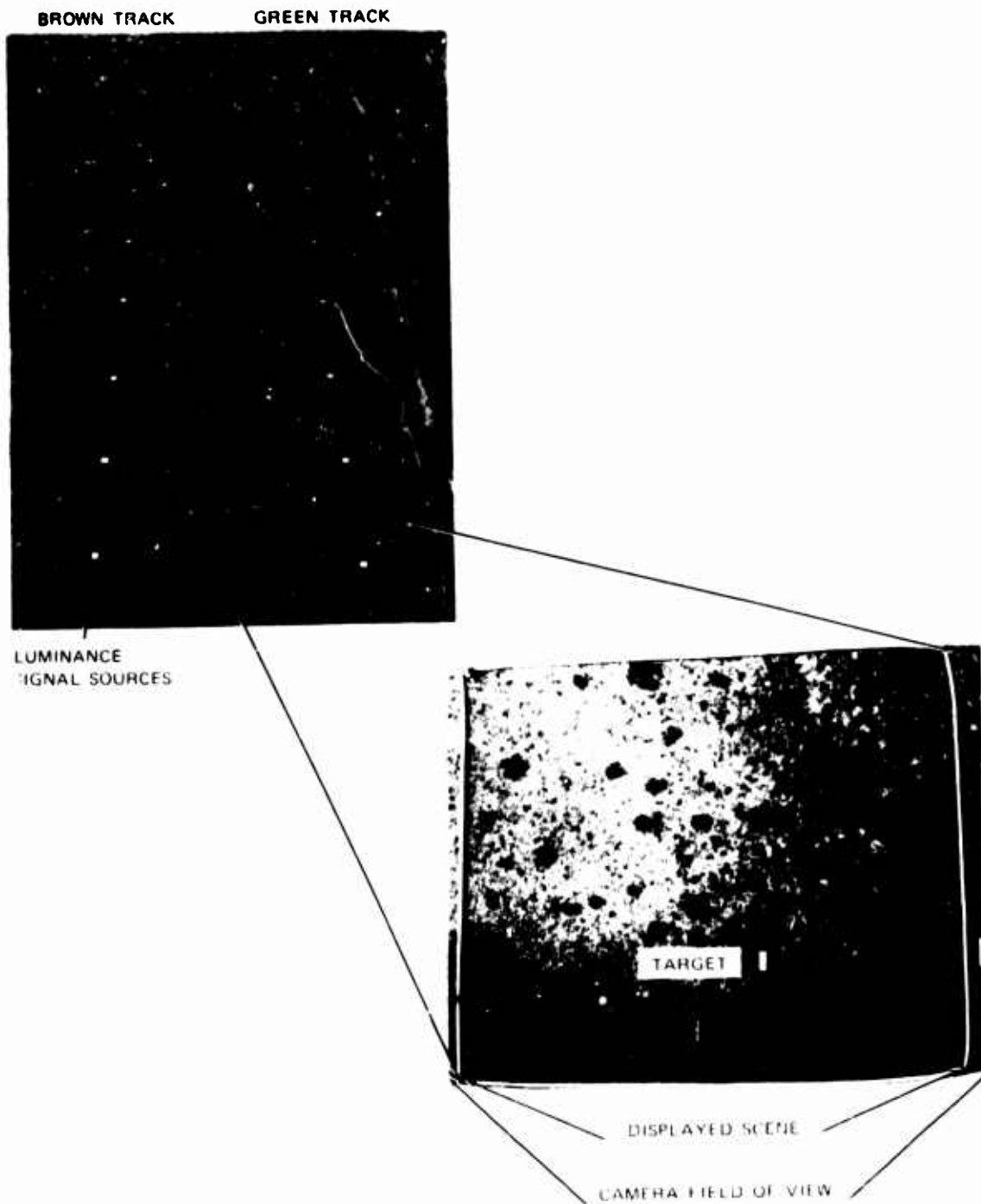
DISPLAYED SCENE

CAMERA FIELD OF VIEW

FIGURE 2. Targets, Test Tracks, and Camera Field of View.

Telephotometer

A Gamma Scientific Model IC 2000 telephotometer was used to measure target-background contrast values on the television display and also luminance settings for display color balance. Background measurements were made with the telephotometer's 6-minutes-of-arc aperture on four areas immediately adjacent to the target (right, left, fore, and aft). The average of the four readings was taken as the background luminance value, provided that no reading exceeded any of the other three readings by more than 3 footlamberts. The same aperture was used to obtain the target luminance value. Target-background contrast was determined using the formula

$$\frac{L_t - L_b}{L_b}$$

where L_t = target luminance and L_b = background luminance, measured in footlamberts. The telephotometer was also used to obtain the high and low luminance settings required for color-balancing the display.

Optical Comparator

A Hellige IRT Mark 3 Color Comparator was used to color-balance the observer's display. The comparator provided a color temperature standard for setting the red, green, and blue background and gain controls to illuminant D (6500°K) as specified by both the TV manufacturer and SMPTE Practice RP371969.[11] The display background (low-light) controls were adjusted to 0.95 footlambert while the gain (high-light) controls were adjusted at 18.50 footlamberts.

Paper Recorder

A Sanborn No. 322 two-channel recorder was used to record both the time each target was in view and the subject's response. A time marker on the right-hand margin provided 1-second time marks.

Contrast Discriminator

The recorder's "target-in-view" channel was activated by a luminance discriminator (a pulse coincidence detector designed and built at the Naval Weapons Center) connected between the camera control unit and recorder. The device was calibrated to be sensitive to 0.4-inch white cardboard squares placed opposite each target but out of the displayed scene. The display width was over-scanned 1/2 inch to provide this capability.

---

[11] CONRAC, Inc. *Installation and Operating Instructions, Video Monitor Model 5000/12 Series.* San Diego, Calif., Manual IB-106212-999A, 1974.

General Equipment

A Tektronix 7613 oscilloscope with a synchronization separator, a standard Retma resolution chart, and two bar patterns capable of indicating limiting horizontal resolution down to 25 TV lines were used to set the resolution values.

A Visual Information Institute No. 216 test pattern generator and No. 306 signal source synchronization generator were used to check initial gray-scale rendition, size, linearity, and focus adjustments as well as to generate the high brightness window signal required for color balance gain adjustments.

Target Area Lighting

Lighting was provided by two Berkey-Colortron Model 100-412 lights with 6-inch sweep focus Fresnal lenses and light diffusers mounted on either side of the cameras. The lights contained 1000-watt, 3200'K bulbs that in the test configuration provided 800 footcandles illumination to the target area.

Subject's Booth

The subject's booth contained the display, a chair, an adjustable forehead restraint that maintained viewing distance at 55 inches, and the subject's response button. The response button was wired to the paper recorder and power supplies. Black curtains were attached to the booth to prevent glare and control ambient illumination. Ambient illumination measured at the display was less than 2 footcandles.

EXPERIMENTAL DESIGN

Color TV was compared to black and white TV to assess the effects on detection performance of the following variables: two colors of background, three levels of resolution, and three target colors each with three levels of contrast. A 2 x 2 x 3 x 3 x 3 treatments-by-subjects factorial design was used in which each of ten subjects provided one observation for each treatment combination, for a total of 108 observations per subject. The experimental design is shown in Figure 3. A data gathering test run consisted of nine trials and presented all combinations of target color and contrast. Twelve test runs were presented to each subject, with all combinations of resolution and presentation mode presented randomly and background order counterbalanced over subjects. The first five subjects observed the green background condition initially and came back the next day to see the brown background condition. The order was just reversed for the second five subjects.

GREEN BACKGROUND										
PRESENTATION MODE	RESOLUTION, TV LINES	GREEN TARGETS			BROWN TARGETS			GRAY TARGETS		
		CONTRAST								
		+0.3	0.0	-0.3	+0.3	0.0	-0.3	+0.3	0.0	-0.3
COLOR	25									
	35									
	300									
BLACK AND WHITE	25									
	35									
	300									
BROWN BACKGROUND										
COLOR	25									
	35									
	300									
BLACK AND WHITE	25									
	35									
	300									

FIGURE 3. Experimental Design.

SUBJECTS

Subjects were ten male civilian employees of the Naval Weapons Center, between the ages of 27 and 37. Three of the subjects had participated previously in target acquisition studies, although none of the ten subjects had experience with color TV target acquisition. The selection criteria for the subjects was 20/20 or better near and far visual acuity as tested on the Bausch and Lomb Armed Forces Vision Tester and an error score of 20 or less ($\geq$80th percentile) on the Farnsworth-Munsell 100 Hue Test for the examination of color discrimination.

PROCEDURE

Each subject was brought into the test booth and given recorded instructions (see the Appendix). The subject was then shown an unpainted but otherwise duplicate model of the experimental targets and given 22 practice trials. At the "Ready" signal, the subject placed his forehead against the restraint bar and the paper tape recorder was activated. At the "Begin" signal the terrain model was switched on and the subject began searching the scene for a target. The task of detecting a target entailed perceiving it as an object in the scene, and then differentiating it (as a tank) from the other clutter objects (trees). When a target was detected, the subject pressed the hand-held response button, recording a spike on the recorder paper. At the end of a test run a color (or gray-scale) bar pattern was generated on the subject's display and the subject was requested to "Relax." The experimenter then returned the terrain model to the starting position and arranged the experimental variables for the next set of conditions. Each target exposure lasted 10 sec. There was an interval of from 1 to 6 sec between target exposures and about 30 sec between test runs. Fifty-four trials per subject were presented during each of two sessions administered over a two-day period. A practice test run with 11 targets preceded the second session for each subject.

ANALYSIS

Two measures were used to assess the effects of the experimental variables: target detection time (or latency) and percent targets detected. Target detection time was defined as the time between the target first coming within view and subject response. Missed targets were scored as 10 seconds, the time elapsed from the moment a target appeared at the top of the display (target onset) to the moment a target went out of sight off the bottom of the display. Percent targets detected was calculated as

$$P = \frac{D_c}{D_t} \times 100$$

where D_c = correct detections and D_t = total detections possible.

Analysis of variance was used to determine the significance of both the latency data and the percent detections data. When a main effect with more than two levels was found to affect detection performance significantly, Newman-Keul's post hoc comparison tests were made to determine significant differences of the levels of that parameter.[12]

---

[12] Keppel, Geoffrey. *Design and Analysis A Researchers Handbook.* Englewood Cliffs, N. J., Prentice-Hall, 1973.

RESULTS

PERCENT TARGETS DETECTED

Percent correct target detections as a function of the five primary variables are shown in Table 1. The analysis of variance summary in Table 2 indicates that correct target detection was significantly af..cted by four of the five variables: color compared to black and white presentation mode ($p < .05$), color of targets ($p < .01$), resolution ($p < .01$), and contrast ($p < .01$). Table 2 also indicates that there were ten significant interactions at $p < .05$ or $.01$.

Mean percent detections, as a function of the five primary variables, are illustrated in Figures 4a through 4e. Mean percent target detection as a function of the five signficant two-factor interactions are shown in Figures 5a through 5e. The three- and four-factor interactions were: presentation mode, target color, and contrast; background, contrast, and resolution; background, contrast, and target color; contrast, resolution, and target color; and background, contrast, resolution, and target color.

TABLE 1. Percent Correct Target Detections.

Green background										
		Green targets			Brown targets			Gray targets		
Mode	Resolution	Contrast								
		+0.3	0.0	-0.3	+0.3	0.0	-0.3	+0.3	0.0	-0.3
Color	25	30	20	10	0	0	30	90	10	10
	35	70	20	0	20	20	40	100	50	30
	300	100	30	90	100	20	80	100	90	80
B & W	25	20	0	10	10	10	10	100	10	20
	35	70	10	20	0	10	30	100	0	30
	300	100	30	90	100	40	70	100	40	90
Brown background										
Color	25	80	0	20	20	50	10	100	40	50
	35	70	0	30	50	30	10	100	70	50
	300	90	30	80	100	20	80	100	30	100
B & W	25	60	0	0	10	40	0	100	30	40
	35	80	0	10	70	30	20	100	40	40
	300	100	20	80	100	10	80	100	0	100

TABLE 2. Analysis of Variance Summary of Percent Targets Detected as a Function of Presentation Mode (M), Background (B), Target Color (T), Resolution (R), and Contrast (C).

Source	d_f	Mean square	F	Source	d_f	Mean square	F
M	1	0.58	6.82^a	MBR	2	0.14	0.93
MS	9	0.08		MBRS	18	0.15	
B	1	1.01	4.62	MBC	2	0.06	0.55
BS	9	0.22		MBCS	18	0.11	
T	2	6.89	24.61^b	MTR	4	0.19	1.46
TS	18	0.28		MTRS	36	0.13	
R	2	17.14	77.91^b	MTC	4	0.29	3.10^a
RS	18	0.22		MTCS	36	0.09	
C	2	22.41	80.04^b	MRC	4	0.10	0.91
CS	18	0.28		MRCS	36	0.11	
S	9	0.88		BTR	4	0.15	1.36
MB	1	0.02	0.29	BTRS	36	0.11	
MBS	9	0.08		BTC	4	0.64	6.13^b
MT	2	0.13	1.63	BTCS	36	0.11	
MTS	18	0.08		BRC	4	0.39	4.06^b
MR	2	0.02	0.25	BRCS	36	0.10	
MRS	18	0.09		TRC	8	0.94	6.71^b
MC	2	0.36	5.44^a	TRCS	72	0.14	
MCS	18	0.07		MBTR	4	0.09	0.90
BT	2	0.08	0.40	MBTRS	36	0.10	
BTS	18	0.20		MBTC	4	0.19	2.00
BR	2	1.06	7.24^b	MBTCS	36	0.09	
BRS	18	0.15		MBRC	4	0.06	0.86
BC	2	0.31	2.98	MBRCS	36	0.07	
BCS	18	0.10		MTRC	8	0.04	0.44
TR	4	0.58	6.44^b	MTRCS	72	0.09	
TRS	36	0.09		BTRC	8	0.57	5.70^b
TC	4	1.63	5.79^b	BTRCS	72	0.10	
TCS	36	0.28		MBTRC	8	0.03	0.30
RC	4	2.92	15.37^b	MBTRCS	72	0.10	
RCS	36	0.19					
MBT	2	0.04	0.67	Total	1,079		
MBTS	18	0.06					

NOTE: d_f = degrees of freedom; F = ratio.
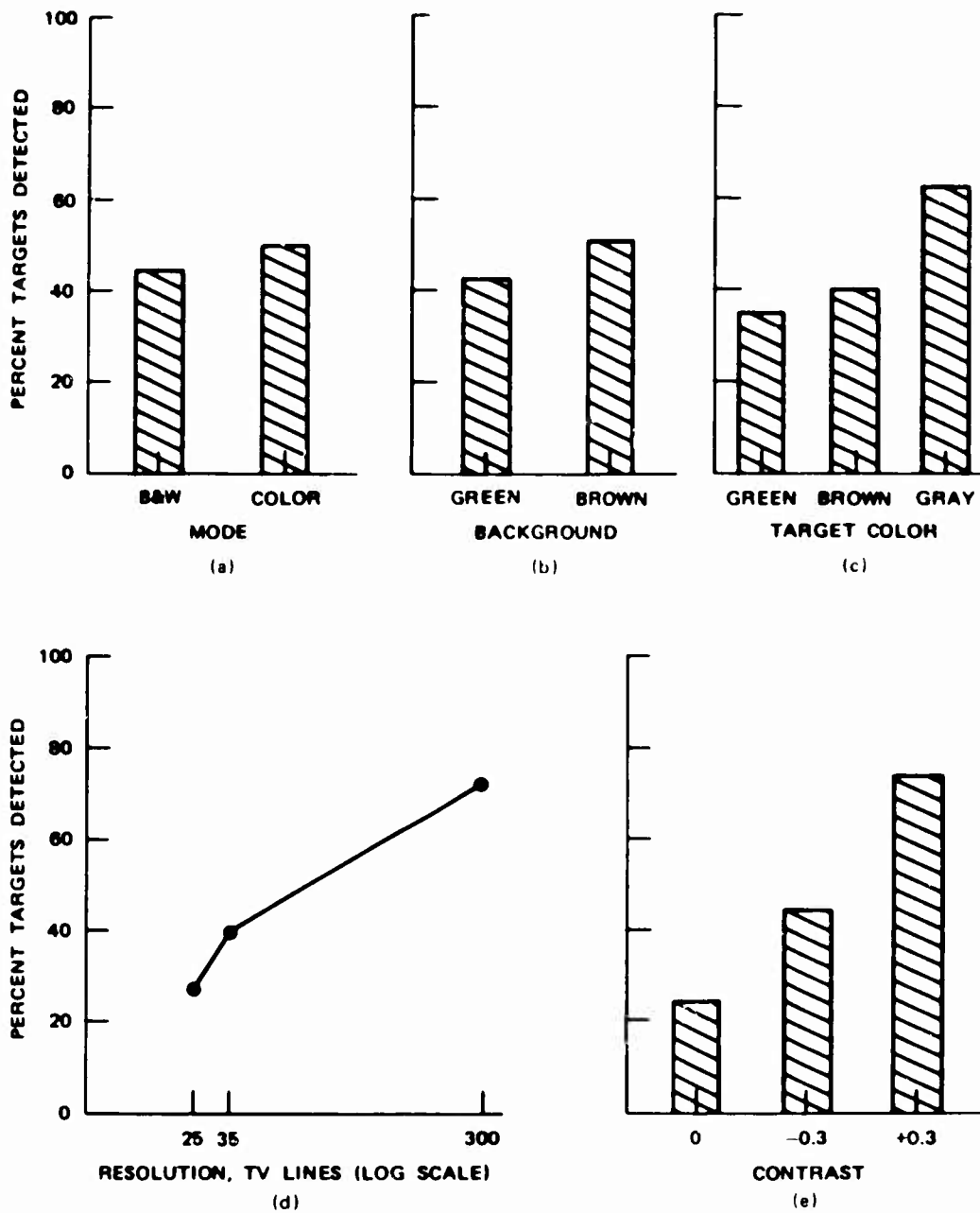
[a] $p < .05.$

[b] $p < .01.$

FIGURE 4. Percent Targets Detected as a Function of (a) Presentation Mode, (b) Background, (c) Target Color, (d) Resolution, and (e) Contrast.
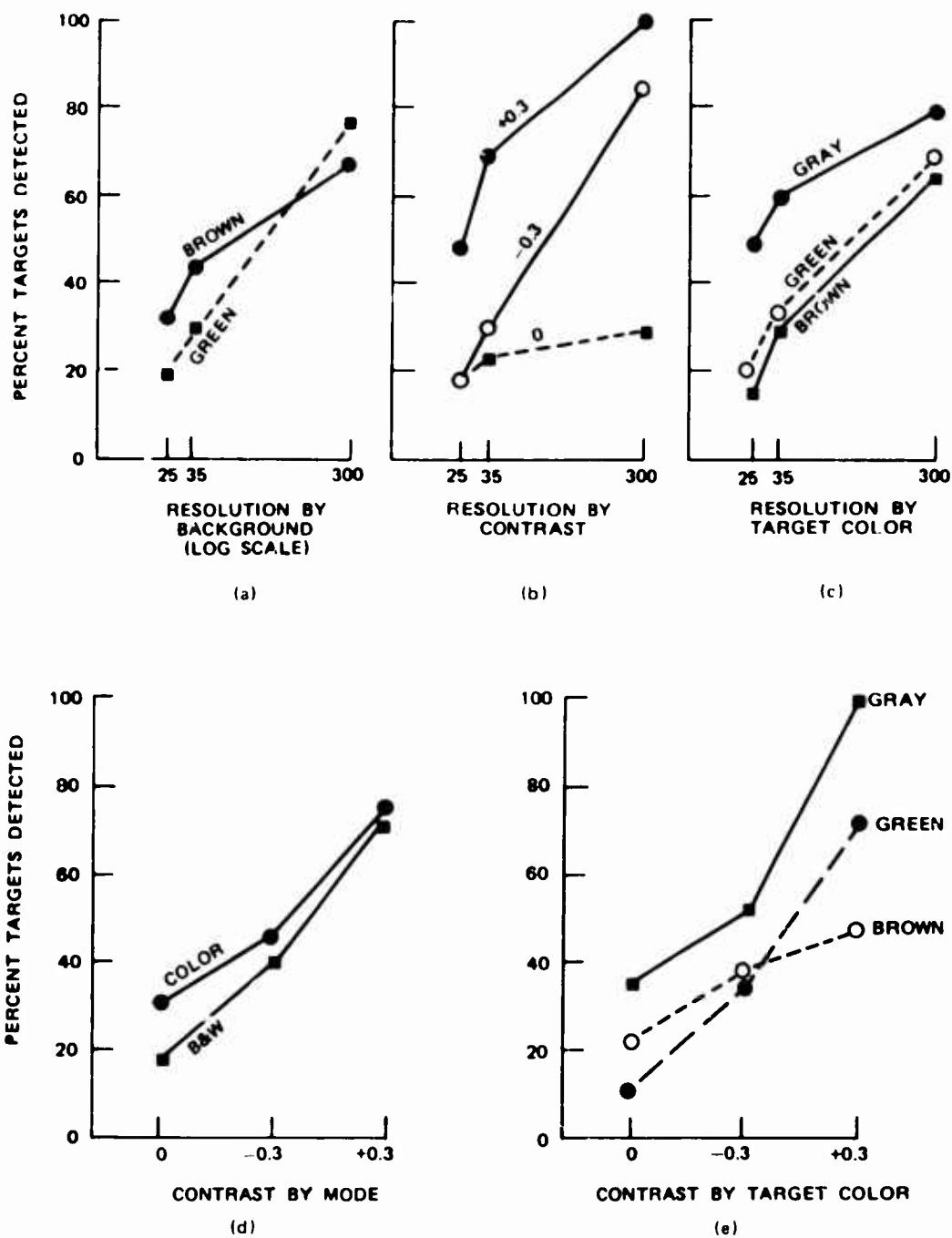
FIGURE 5. Percent Targets Detected as a Function of Two-Factor Interactions: Resolution by (a) Background, (b) Contrast, (c) Target Color, and Contrast by (d) Mode, and (e) Target Color.

The Newman-Keul's post hoc comparison tests, made to determine the significant levels of the main effects, are shown in Tables 3, 4, and 5. Table 3 shows there was a significant ($p < .01$) difference in detection performance between gray and brown targets and between gray and green targets, but no significant (NS) difference between green and brown targets. Table 4 shows there were significant ($p < .01$) differences in target detection between 25 and 35, 25 and 300, and between 35 and 300 TV lines limiting horizontal resolution. Table 5 shows there were significant ($p < .01$) differences in target detection between +0.3 and -0.3, +0.3 and 0, and between -0.3 and 0 target-to-background contrast.

TABLE 3. Significance Between Levels
of Target Color for Detection.

Color	Color	
	Green	Gray
Brown	NS	$p < .01$
Green	...	$p < .01$

TABLE 4. Significance Between Levels
of Resolution for Detection.

TV lines	TV lines	
	35	300
25	$p < .01$	$p < .01$
35	...	$p < .01$

TABLE 5. Significance Between Levels
of Contrast for Detection.

Ratio	Ratio	
	-0.3	+0.3
0	$p < .01$	$p < .01$
-0.3	...	$p < .01$

TARGET DETECTION TIME

Mean target detection times as a function of the five primary variables are shown in Table 6. The analysis of variance summary in Table 7 indicates that time to target detection was significantly affected by three primary variables: target color (p < .01), resolution (p < .01), and contrast (p < .01). Figures 6a through 6e illustrate mean target detection times as a function of the five variables.

Nine interactions were found to affect target detection time significantly, as shown in Table 7. Mean target detection time as a function of the five significant 2-factor interactions are shown in Figures 7a through 7e. The four 3- and 4-factor interactions were: background, contrast, and resolution; background, contrast, and target color; contrast, resolution, and target color; and background, contrast, resolution, and target color.

TABLE 6. Mean Target Detection Times, Seconds.

		Green background								
		Green targets			Brown targets			Gray targets		
Mode	Resolution	Contrast								
		+0.3	0.0	-0.3	+0.3	0.0	-0.3	+0.3	0.0	-0.3
Color	25	8.6	8.7	9.5	10.0	10.0	9.6	3.3	9.3	9.3
	35	5.4	9.5	10.0	9.1	8.8	9.3	2.4	7.3	8.3
	300	2.5	8.9	3.7	2.3	8.6	4.7	1.7	3.4	3.6
B & W	25	8.8	10.0	9.9	9.7	9.5	9.8	3.6	9.6	8.8
	35	5.2	9.3	9.1	10.0	9.1	9.1	2.2	10.0	8.1
	300	2.2	7.9	3.0	2.4	7.5	4.6	1.7	7.0	3.3
		Brown background								
Color	25	5.1	10.0	9.2	9.4	7.2	9.5	3.7	7.5	7.2
	35	5.0	10.0	8.3	7.0	8.2	9.2	3.4	6.4	6.5
	300	3.1	8.2	4.7	1.6	9.2	4.3	2.1	8.9	2.0
B & W	25	5.7	10.0	10.0	9.8	8.0	10.0	4.3	8.6	7.6
	35	5.0	10.0	9.3	5.7	8.3	9.1	3.4	7.8	7.8
	300	1.5	9.4	4.6	1.6	9.4	4.2	1.8	10.0	1.3

TABLE 7. Analysis of Variance Summary of Target Detection Time as a Function of Presentation Mode (M), Background (B), Target Color (T), Resolution (R), and Contrast (C).

Source	d_f	Mean square	F	Source	d_f	Mean square	F
M	1	13.11	4.50	MBR	2	1.29	0.24
MS	9	2.92		MBRS	18	3.76	
B	1	27.08	3.02	MBC	2	3.38	0.96
BS	9	8.98		MBCS	18	3.51	
T	2	416.11	32.96^a	MTR	4	3.02	0.85
TS	18	12.63		MTRS	36	3.55	
R	2	1,391.40	99.62^a	MTRS	4	7.95	2.20
RS	18	13.97		MTCS	36	3.62	
C	2	1,411.60	119.88^a	MRC	4	1.80	0.56
CS	18	11.78		MRCS	36	3.23	
S	9	31.98		BTR	4	4.13	0.90
MB	1	2.05	0.45	BTRS	36	4.61	
MBS	9	4.59		BTC	4	30.47	8.57^a
MT	2	9.20	2.54	BTCS	36	3.55	
MTS	18	3.62		BRC	4	17.08	3.59^b
MR	2	3.55	1.10	BRCS	36	4.76	
MRS	18	3.23		TRC	8	45.02	8.47^a
MC	2	12.90	5.29^b	TRCS	72	5.31	
MCS	18	2.44		MBTR	4	5.34	1.33
BT	2	8.01	1.24	MBTRS	36	4.01	
BTS	18	6.47		MBTC	4	4.11	0.80
BR	2	45.76	5.43^b	MBTCS	36	5.13	
BRS	18	8.43		MBRC	4	2.09	0.66
BC	2	16.94	2.68	MBRCS	36	3.16	
BCS	18	6.32		MTRC	8	2.67	0.81
TR	4	18.44	5.48^b	MTRCS	72	3.28	
TRS	36	3.37		BTRC	8	31.33	7.85^a
TC	4	79.04	8.06^a	BTRCS	72	3.99	
TCS	36	9.80		MBTRC	8	3.06	0.99
RC	4	236.30	21.53^a	MBTRCS	72	3.08	
RCS	36	10.98					
MBT	2	1.48	0.48	Total	1,079		
MBTS	18	3.09					

NOTE: d_f = degrees of freedom; F = ratio.

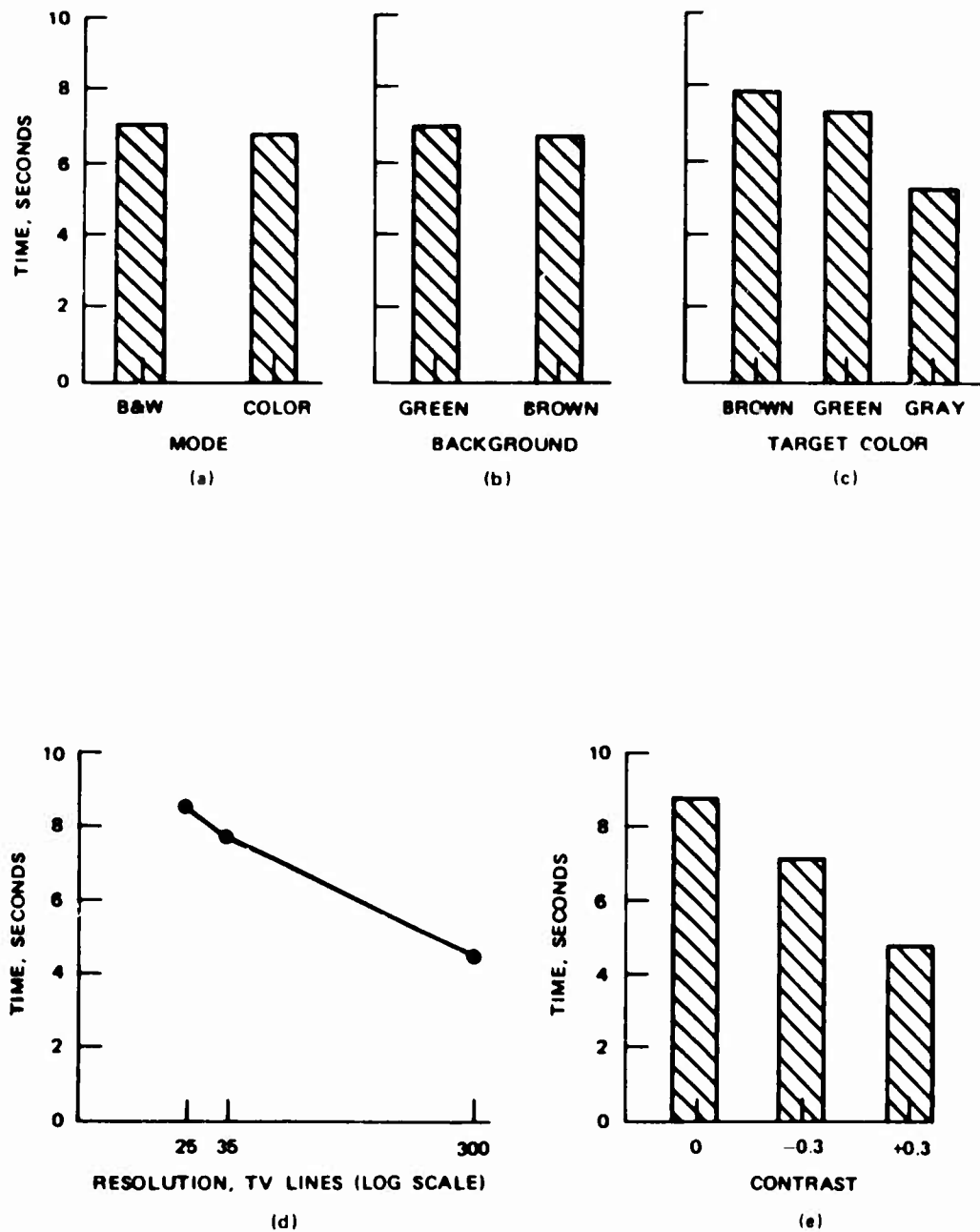[a] $p < .01$.
[b] $p < .05$.

FIGURE 6. Mean Target Detection Response Time as a Function of (a) Presentation Mode, (b) Background, (c) Target Color, (d) Resolution, and (e) Contrast.
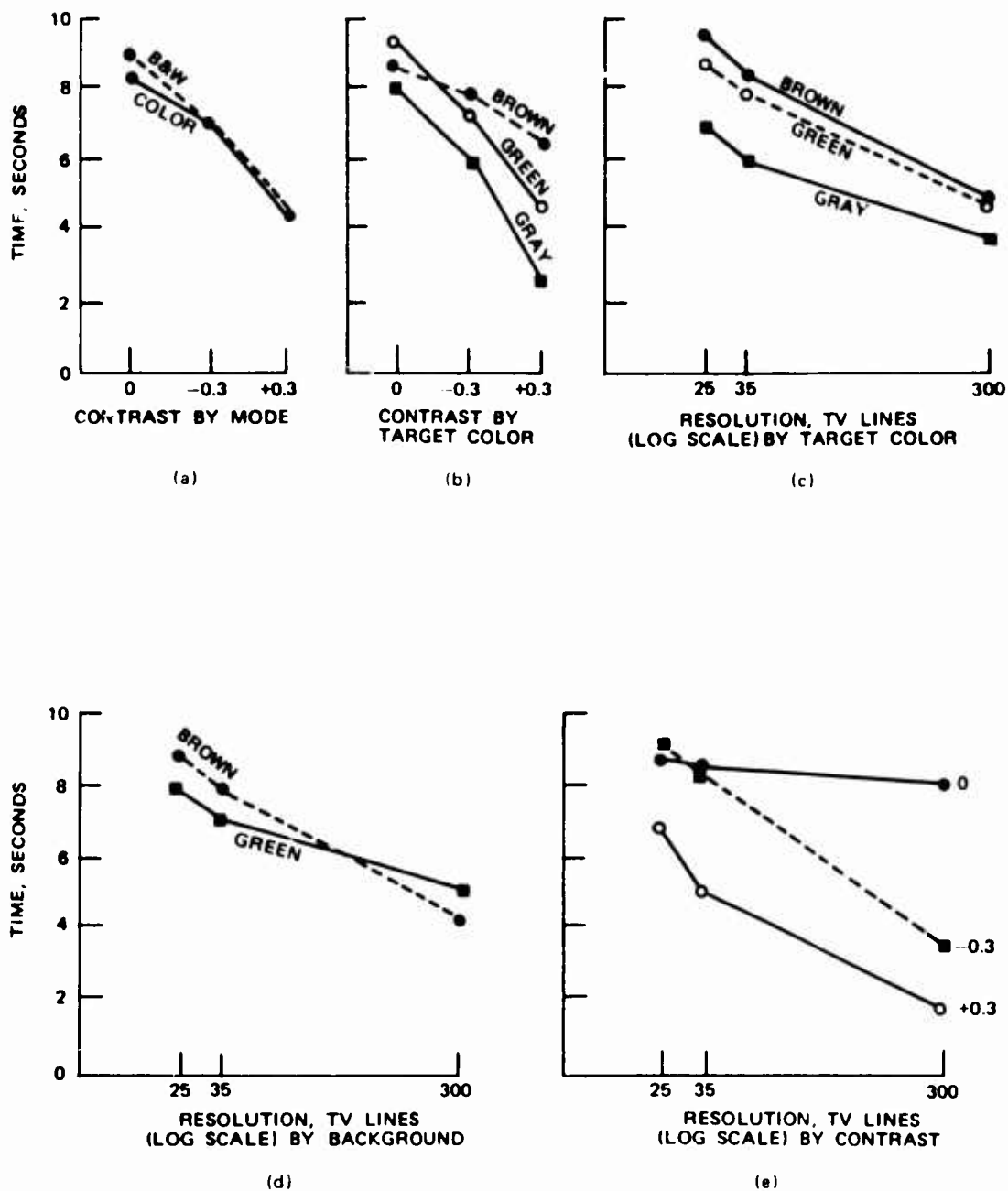
FIGURE 7. Mean Target Detection Time as a Function of Significant Two-Factor Interactions: Contrast by (a) Mode, (b) Target Color, and Resolution by (c) Target Color, (d) Background, and (e) Contrast.

The post hoc comparison tests of significant factor levels are shown in Tables 8, 9, and 10. Table 8 shows there was a significant (p < .01) difference in detection time between gray and brown targets and between gray and green targets. The table also shows there was a significant (p < .05) difference in detection time between brown and green targets. Table 9 shows there were significant (p < .01) differences in target detection time between 25 and 35, 25 and 300, and between 35 and 300 TV lines limiting horizontal resolution. Table 10 shows there were significant (p < .01) differences between +0.3 and 0, -0.3 and 0, and between -0.3 and 0 target-to-background contrast.

TABLE 8. Significance Between Levels of
Target Color for Response Time.

Color	Color	
	Green	Gray
Brown	p < .05	p < .01
Green	...	p < .01

TABLE 9. Significance Between Levels of
Resolution for Response Time.

TV lines	TV lines	
	35	300
25	p < .01	p < .01
35	...	p < .01

TABLE 10. Significance Between Levels of
Contrast for Response Time.

Ratio	Ratio	
	-0.3	+0.3
0	p < .01	p < .01
-0.3	...	p < .01

DISCUSSION

The results of this experiment indicate first that color television may offer a small but significant improvement in target detection over conventional black and white television. Second, target color affects detection performance, with gray targets providing better results than either brown or green targets. Third, increased resolution improves detection performance about equally for both color and black and white TV. Fourth, positive contrast (+0.3) markedly increases percentage of target detection and decreases response time over both neg. ive (-0.3) and zero contrast conditions.

COLOR VERSUS BLACK AND WHITE

Analysis of the effects on performance of color TV, compared to black and white TV, showed a difference in percentage of correct target detections but no significant difference in detection time. Color TV provides about a 5% increase in correct target detections when summed across the other variables. Figures 8a through 8d show color TV and black and white TV comparisons when each of the experimental variables is considered individually. The figures show that color TV provides a higher percentage of correct target detection than does black and white TV when compared: with either the green or brown background (Figure 8a); to green, brown, and particularly gray targets (Figure 8b); with limiting horizontal resolution of 25, 35, and 300 TV lines (Figure 8c); and to negative (-0.3) and zero contrast. No difference in percent targets detected is noted for positive (+0.3) contrast (Figure 8d).

These findings are not surprising in view of prior research in the applied experimental setting. Even though the black and white TV had higher resolution than did the color TV for the Wong and Yacoumelos study, they state that "...color did help in identifying [map] symbols on a TV display."[10] Hilgendorf and Milenski, in their direct vision experiment, state, "The results of this experiment indicate that the effects of color may have more impact on target detection performance than was traditionally thought."[4]

Other factors being equal, it seems clear that color TV can improve target detection performance. What remains unclear is whether this relatively small increase in detection can compensate for the added initial cost and continued maintenance of the more complex color television equipment.
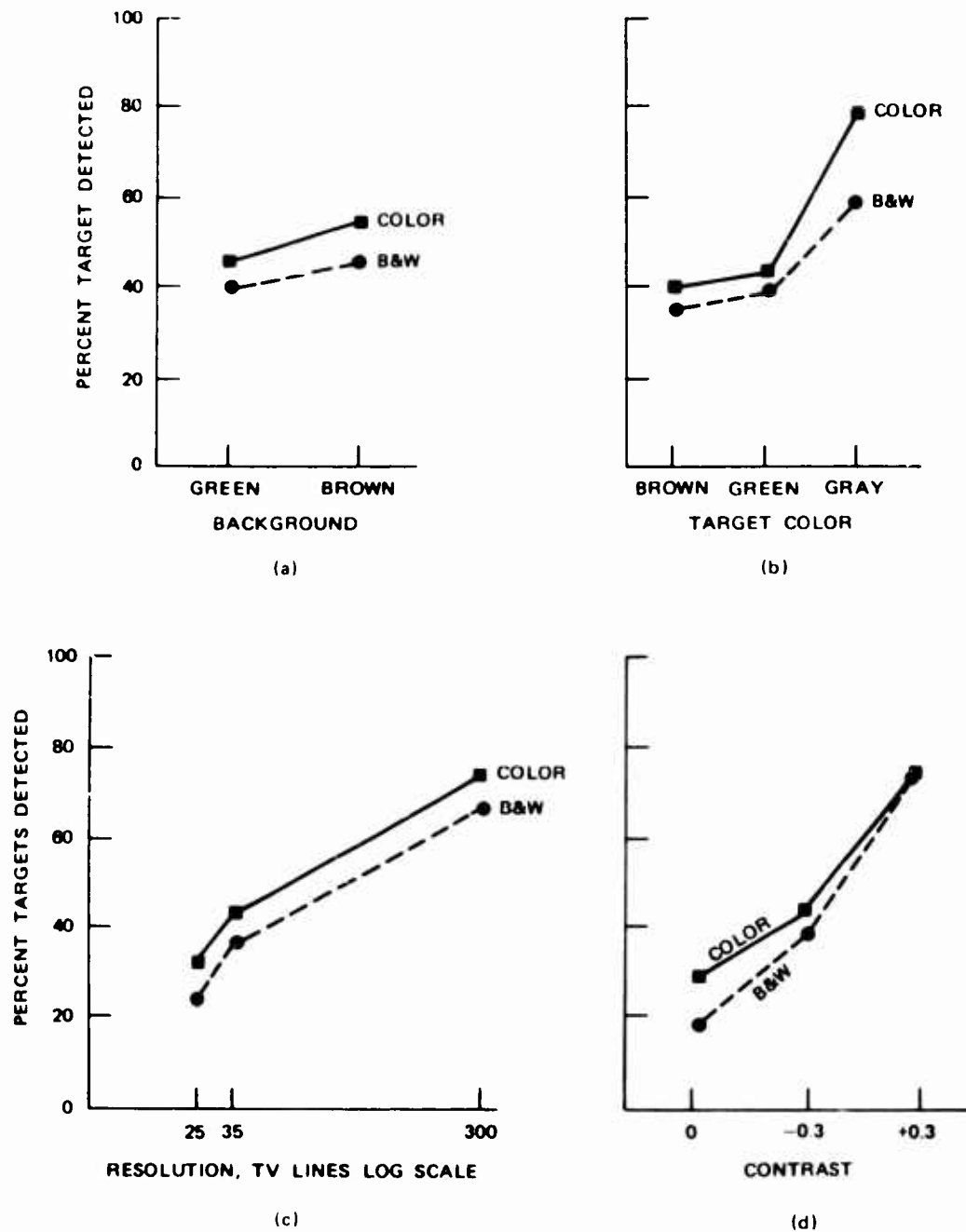
FIGURE 8. Percent Targets Detected With Color and Black and White TV as a Function of (a) Background. (b) Target Color, (c) Resolution. and (d) Contrast.

23

TARGET BACKGROUND

The effect of background on target detection performance is shown in Figures 4b, 5a, 7d, and 8a. The analysis indicates that background main effects are not significant. However, background is involved in nearly half of the significant interaction effects.

Results are mixed when background effects on performance obtained in this study are compared with other studies employing terrain model scenery. One study found better performance measures resulting when targets are seen on a foliage background than when seen on a sandy background.[13] A second study found background to be virtually insignificant.[4] A third study found that background affected only one of several conditions, and that one may have been confounded by search.[9] The present study found that background does not have a significant overall effect on performance. It is not known whether the various findings are due to differing methodologies, inherent terrain model characteristics, or some other specious reason. Since the target background has been shown to affect performance in other studies, and is involved in interactions in this study, it appears that background color cannot be ignored in studies related to target acquisition.

TARGET COLOR

Analysis of the experimental results with the three target colors showed that gray targets were detected more frequently and with greater speed than either tan or green targets (Figures 4c, 6c, and 8b). These findings are consistent with those of Hilgendorf and Milenski, who state that "...it was always much easier for observers to detect the gray targets than either the green or brown targets, regardless of brightness contrast."[4]

Green targets appear slightly easier to detect than brown targets. This difference essentially is traceable to the contrast interaction effect (Figures 5c and 7b). It can be seen that the small difference between green and brown targets at the 0 and -0.3 contrast levels becomes a relatively large difference or positive (+0.3) contrast targets.

It can be argued that gray is not a color--rather, varying ratios of blacks and whites give rise to shades of gray. This approach suggests that black and white TV should provide performance measures as good as color TV for gray targets. The evidence does not support this view. Gray targets were more detectable on color TV than on black and

---

[13] Naval Weapons Center. *Image Identification on Television*, by R. A. Erickson and J. C. Hemingway. China Lake, Calif., NWC, September 1970. (NWC TP 5024, publication UNCLASSIFIED.)

white TV (see Figure 8b). It appears that the added dimension of color supplements target detection, to varying degrees, depending upon the sign of contrast. Furthermore, achromatic targets on colored backgrounds appear easier to detect than do colored targets. This effect is perhaps due to the concept of lateral inhibition which, according to Cornsweet,[14] affects the perception of target hues by inhibiting certain color receptors in the eye. The target color receptors are somewhat desensitized to the dominant color in the background. Achromatic targets thus take on a hue that is the complement of the background color. Color targets take on a hue that is a mixture of the original target color and the complement of the background color. This phenomenon, commonly called color contrast, appears to operate to the benefit of gray targets for the background colors used in this study.

RESOLUTION

The analysis of the effect of 25, 35, and 300 TV line resolution levels showed that each level affected both performance measures (Figures 4d and 6d). It may be somewhat surprising to find a difference between 25 and 35 TV lines. The television picture at these unusually low levels can best be described as extremely fuzzy; few detections and no differences were expected. The primary contributor to detection at the low resolution values was positive contrast targets (see Figure 5b). As described in the contrast section, this difference appears to be due to the negative clutter effect rather than positive contrast per se.

These findings are consistent with other studies which show that performance deteriorates with degraded resolution.[5-8] The effect of resolution on percent targets detected for this study and one by Johnston[15] are presented in Figure 9. Negative contrast data obtained under the black and white TV condition were extracted from the present study for the figure since only negative contrast targets on black and white TV were used in the Johnston study. An observation to be made regarding the figure is that dynamic imagery may require higher resolution th does static imagery for equivalent performance.[16] The higher performance levels associated with the Johnston study may be due in part to static (still) imagery used in the cited study as opposed to the dynamic (moving) imagery used in the present study. This fact, plus the higher contrast values employed in the Johnston study (33, 60, and 80%), probably accounts for the different performance levels between the two studies.

[14] Cornsweet, Tom N. *Visual Perception.* New York, Academic Press, Inc., 1970.

[15] North Carolina State University. *Information Processing Through Visual Perception as a Function of Signal-to-Noise Ratio, Bandwidth, Contrast, and Type of Noise on a Television Display, Project Thennis,* by Dorothy M. Johnston. Raleigh, N. Carolina, NCSU, 1971.

[16] Naval Weapons Center. *Pattern Size, Velocity and Orientation Effects Upon Television Viewing Performance,* by Dan W. Wagner. China Lake, Calif., NWC, 1971. (NWC Technical Note 4011-9, publication UNCLASSIFIED.)
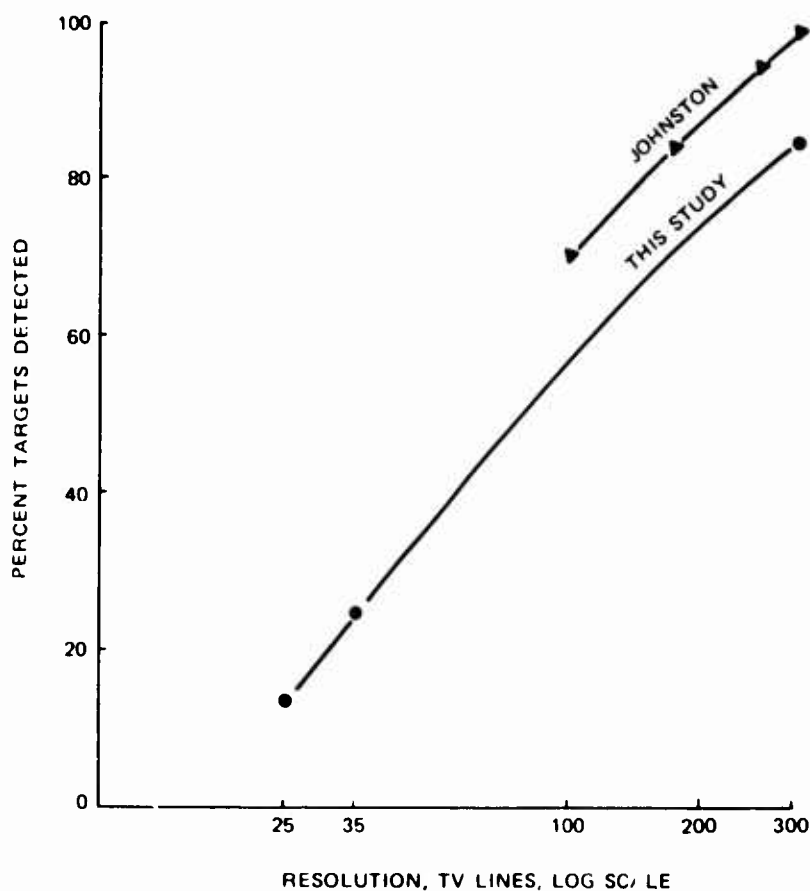
FIGURE 9. Comparison of Resolution Curves as a Function of Percentage of Targets Detected for This Study and Johnston's Study.[15]

Performance measures at the low resolution levels are not, in themselves, of practical importance. There is no reason to believe a 25 or 35 TV line system offers advantages over a 300 TV line system. However, it is important to note that detection performance as a function of resolution varies comparably for both color and black and white TV (see Figure 8c). It appears, then, that the resolution findings on black and white TV are generalizable to color TV.

CONTRAST

Analysis of the effects of contrast indicated that it significantly affected both target detection time and percentage of targets detected. Light targets on dark background (positive contrast, +0.3) consistently provided better performance than dark targets on light background (negative contrast, -0.3); both were better than zero contrast (Figures 4c and 7c).

These findings are in agreement with Hilgendorf and Milenski, who found that positive contrast improves performance over negative contrast when magnitude is held constant. Generally, previous laboratory studies investigating contrast have found little or no difference in the sign of the contrast as long as the values are equal. Hilgendorf quotes from Duntley, who states, "...under virtually all circumstances geometrically identical objects are equally detectable if their universal contrasts are equal in magnitude even if opposite in sign..."[4] This accepted view is carried over into publications providing display design guidelines that make no distinction between positive and negative contrast.[17,18]

One possible reason for the better performance measures with positive contrast targets in the present study is the lack of positive contrast clutter on the terrain model employed. All the trees and shrubs used to produce background clutter provided essentially negative contrast objects, perhaps making it more difficult to detect a negative contrast target than a positive contrast target.

---

[17] McCormick, Ernest J. *Human Factors Engineering.* New York, McGraw-Hill, 1970.

[18] VanCott, H. P., and R. G. Kinkade, eds. *Human Engineering Guide to Equipment Design,* revised edition. Washington, D. C., U.S. Government Printing Office, 1972.

LIMITATIONS

There are three limitations, not necessarily unique to the present study, that must be noted. First, and most important, color calibration procedures for a television monitor--and to a lesser degree, the camera--are largely subjective. The color fidelity between actual imagery and displayed imagery is, in addition to the idiosyncrasies of a given TV system, dependent upon individual preference, bias, and experience. Standardized techniques and procedures for obtaining color fidelity on TV simply are not available, although instruments such as the optical comparator, spectroradiometer, and digital photometer/radiometer seem to be promising devices for establishing specifiable colors on TV monitors. Considerable effort is required in this area before a meaningful comparison between different experiments (and different apparatus) can be made.

Second, contrast measuring methods are somewhat arbitrary. In the present study, for example, some luminance gradients on the target were simply too small in area to be accurately measured with the smallest aperture on the photometer. The targets contained slight shadows and some highlights that in effect were averaged by the photometer to yield a particular value. While luminance gradients provide realism to target and background imagery, investigators are not in agreement as to the most appropriate way to account for these differences.

Finally, experiments with color television generally use subjects with normal color vision, yet an unequivocable color vision test is not available. Paulson, in reviewing the five different color vision tests administered by the Armed Forces, has determined that a color-defective person has between a 4 and 52% chance of being accepted by a color vision test, depending upon the degree of defect and the test given.[19]

[19] Paulson, Helen M. "Comparison of Color Vision Tests Used by the Armed Forces," in *Color Vision*. National Academy of Sciences. Washington, D.C., 1973.
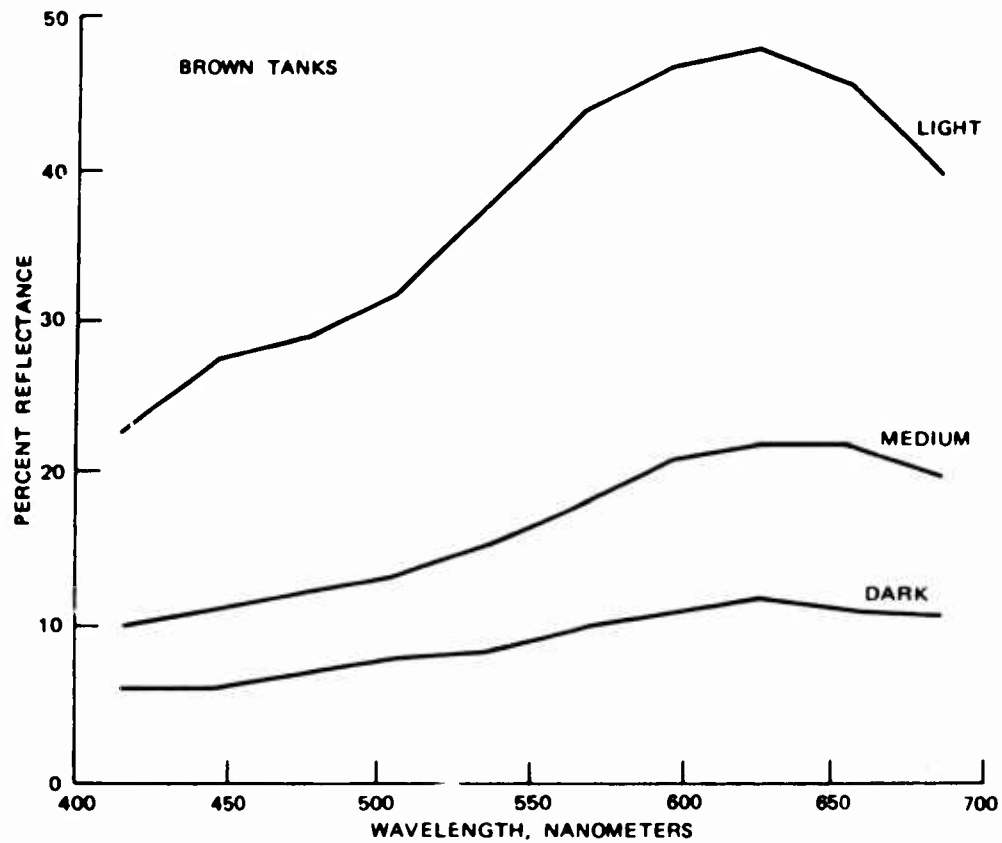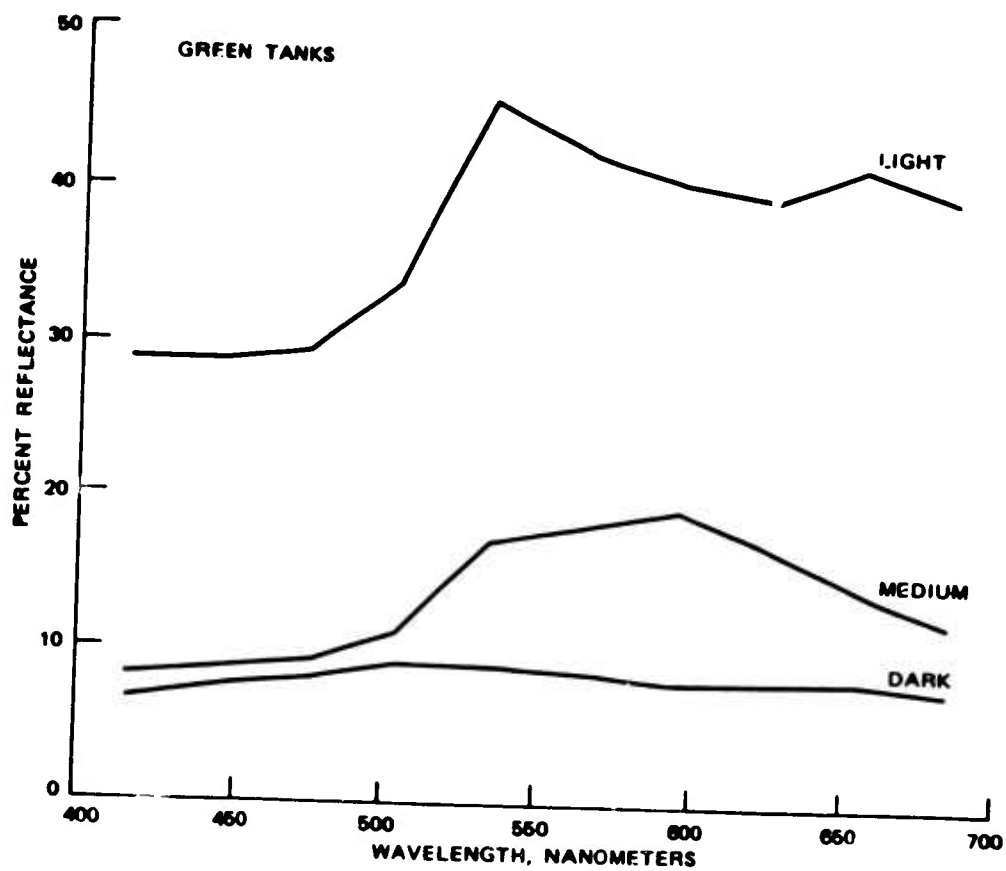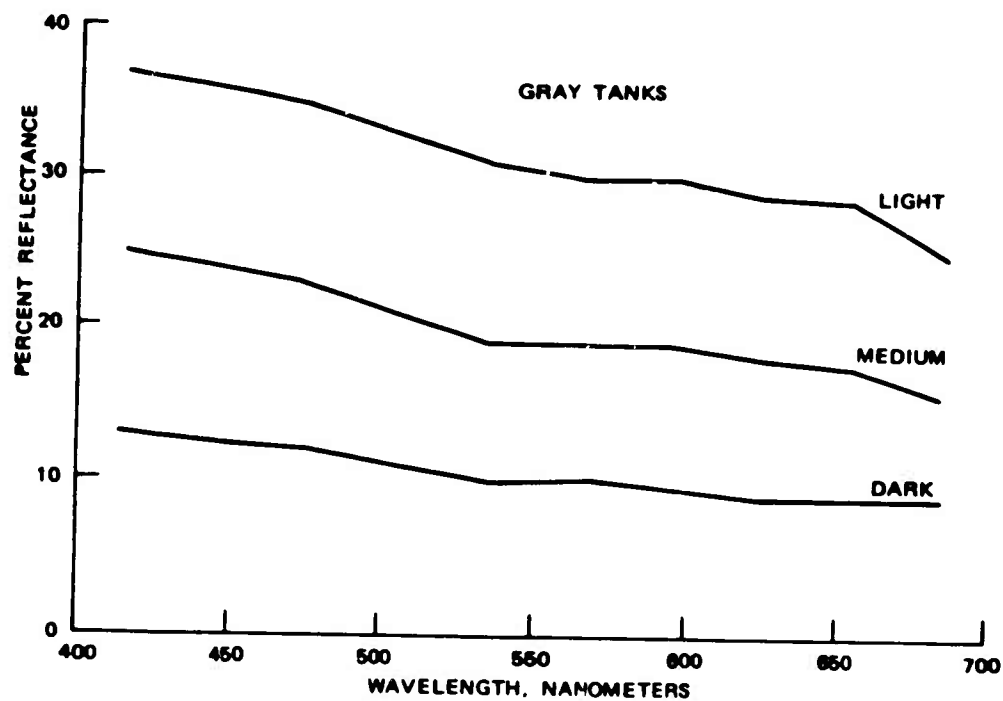
Appendix
EXPERIMENT DETAILS

TARGET CONTRAST VALUES

Target	Color	Green background		Brown background	
		Color mode	B & W mode	Color mode	B & W mode
1	brown	+0.32	+0.30	+0.32	+0.35
2	green	0	0	0	0
3	green	−0.33	−0.32	−0.32	−0.32
4	green	+0.33	+0.31	+0.32	+0.31
5	gray	+0.34	+0.33	+0.32	+0.32
6	brown	0	0	0	0
7	gray	0	0	0	0
8	brown	−0.32	−0.31	−0.33	−0.33
9	gray	−0.33	−0.31	−0.31	−0.31

TARGET COLORIMETRY

30

GRAY TANKS

LIGHT

MEDIUM

DARK

PERCENT REFLECTANCE

WAVELENGTH, NANOMETERS

GREEN TANKS

LIGHT

MEDIUM

DARK

PERCENT REFLECTANCE

WAVELENGTH, NANOMETERS

CAMERA SPECIFICATIONS

The camera is a single-tube Cohu No. 1230D with automatic control board No. 8436-9 and No. 1290 remote camera control.[*]

Vertical sweep rate	59.95 Hz, 30 frames/sec
Horizontal sweep rate	15,734 Hz, 525 lines
Scanning	2:1 interlace
Sync	Internal
Vidicon	Type 4846B, separate mesh
Tube	1x6-inch magnetic deflection and focus
Resolution	300 lines horizontal center limiting, minimum (luminance)
Shades of gray	10 with 150 ftL illumination at f/2.8
Sensitivity	50 dB S/N with 150 ftL illumination at f/2.8
Illuminations	All specifications with 3200°K
Video output	Two, NTSC compatible
Geometric distortion	<2%
Optional equipment	Automatic control of black level, target voltage and lens iris

CAMERA SETUP

The camera was set up according to factory procedures[*] except the following:

Camera aimed at black and white card with black about 30% of picture.
Beam control to 77 (meter) .... adjust for evenness of white.
Iris control to 80 (meter) .... adjust for evenness of white.
Auto Sens to 80 (meter) ..... adjust for evenness of black and white.

NOTE: The auto iris was turned off for the experiment and final Sens adjustment was made using terrain model, not meter.

---

[*] Detailed specifications and procedures can be found in Cohu Technical Manual 6X-609(A), Cohu, Inc., Box 623, San Diego, Calif.

MONITOR SPECIFICATIONS

The monitor is a Conrac 12-inch diagonal, single-gun, three-beam CRT, No. 5022C12.*

Video input	Return loss > 40 dB
Video response	To 5 MHz ± 2 dB
Differential gain	<5% for 20 ftL
Decoder accuracy	Error < 2.5 deg
Linearity and geometry	Within 2% of raster height
Convergence	Maximum deviation, center--0.75%, edges 1% of picture height
Phosphor colorimetry	$\quad\quad\quad$ x $\quad\quad$ y Red $\quad$ 0.645 $\quad$ 0.335 Green $\quad$ 0.290 $\quad$ 0.600 Blue $\quad$ 0.150 $\quad$ 0.065
Color temperature	6500°K
Interlace	Better than 90%
Black level stability	Shift <1% of peak from 10 to 90% average picture level
Discernible shades of gray	10 minimum
Optional equipment	Color/monochrome switch, underscan switch, horizontal and vertical delay switches

MONITOR SETUP PROCEDURE

Follow factory setup procedure except following:

Red, green, blue background pots	Adjust to optical comparator low brightness white at 0.95 ftL
Red, green, and blue gain pots	Adjust to optical comparator high brightness (6500°K) white at 18.5 ftL
Brightness control	Reduce to 0.95 ftL
Background controls	Increase to 18.5 ftL
Gain controls	Adjust to filter 1 white

---

* Detailed specifications and procedures can be found in CONRAC Installation and Operating Instructions Manual No. 1B-106212-999A.

SUBJECTS' RECORDED INSTRUCTIONS

You are participating in an experiment designed to assess an observer's target detection performance on television, under differing target presentation conditions, such as black and white or color TV and varying degrees of target resolution. Your task throughout this experiment will be to detect these tank targets, as they appear on the television screen (Experimenter shows example of tank target). You are to indicate that you see the tank by immediately pressing and releasing this button (Experimenter demonstrates hand-held response button). The targets and imagery will move from the top to the bottom of the television. There will never be two targets in view at the same time. There will be 12 recorded runs in two sessions; 6 today and 6 tomorrow, taking a total of 1/2 hour. In addition, there will be two practice runs before the first session, one run in color and one in black and white. Tomorrow there will be one practice run. When I say "Ready," before each run, place your forehead against this bar. Be prepared to respond when I say "Begin." Remember to press the button the moment you detect a target. Any questions?

1 Autonetics/Rockwell International Corp., Anaheim, Calif.
  (Dr. C. P. Greening)
1 Calspan Corporation, Buffalo, New York (Life Sciences Avionics Dept.)
1 Hughes Aircraft Company, Culver City, Calif. (Walter Carel)
1 Human Factors Research Inc., Goleta, Calif.
2 Institute for Defense Analyses, Arlington, Va.
    Robert E. L. Johnson (1)
    Technical Library (1)
1 Ling-Temco-Vought Aeronautics Division, Dallas, Tex. (Human Factors
  Engineering)
1 McDonnell Douglas Corporation, St. Louis, Mo. (Dr. Edward Jones)
1 McDonnell Douglas Corporation, Long Beach, Calif. (Director Scientific
  Research, R&D Aircraft Division)
1 The Martin-Marietta Corporation, Orlando, Fla. (Dr. Daniel Jones)
1 Montana State University, Bozeman, Mont. (Dr. William Bliss)
1 Rockwell International Corporation, Columbus, Ohio
1 Systems and Research Center, Minneapolis, Minn. (Dr. Leon G. Williams)
1 The Boeing Company, Seattle, Wash. (James D. Gilmour)
1 University of California, Scripps Visibility Laboratory, San Diego,
  Calif.
1 Virginia Polytechnic Institute and State University, Blacksburg, Va.
  (Dr. Harry L. Snyder)