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IMAGE IDENTIFICATION ON TELEVISION

by

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and

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ABSTRACT. Four experiments were conducted to measure identification of photographs of geometric symbols and military vehicles both on TV and by direct vision. The number of TV scan lines per image and image angular subtense were systematically varied. The background against which the vehicles were photographed was also varied.

The mean performance of symbol legibility on TV followed a constant-product rule: the symbol size multiplied by the number of scan lines per symbol was constant for a constant level of performance within a specified range of the variables.

The vehicle image required at least 10 scan lines per vehicle and an angular subtense of over 14 minutes of arc to ensure a high probability of identification. Vehicle identification performance also varied as a function of the type of background.

Direct-vision performance was used to estimate the degradation resulting by interposing the TV system between the observer and the photographs. The TV degradation did not vary with image size, but was a function of lines per vehicle and background type.

NAVAL WEAPONS CENTER

CHINA LAKE, CALIFORNIA * SEPTEMBER 1970

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M. R. Etheridge, CAPT, USN .... Commander

H. G. Wilson .... Technical Director

FOREWORD

These experiments on image identification on television were conducted at the Naval Weapons Center, China Lake, California, between January 1968 and July 1969. The work was supported by ONR Project Order P08-0078, AIRTASK No. A34-531-701/216-1/F022-01-07, and Task Assignment AIR 510-103/216-1W107-B0-01 (Condor).

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CONTENTS

INTRODUCTION

Television systems are used by the military in land, sea, and airborne environments to display both symbolic and "real world" imagery to the human operator. The increasing use of these systems has generated a requirement to understand the effects of TV system characteristics on operator performance.

This report describes a series of three laboratory experiments on image identification on a TV monitor, and one experiment on identifying the same images in photographs. The experiments were not intended to simulate an operational military situation; the goal was to produce baseline data describing the identification process. The major variables investigated were (1) image type, (2) size of the image, and (3) number of scan lines making up the image on TV.

The results can be used to estimate observer performance in situations approximating that of the experiments, and as a point of departure for future, more applied experiments or simulations.

DEFINITION OF TERMS

In this report, the terms *line* or *scan line* are used instead of the longer terms such as *TV raster scan line, active TV raster scan line, TV scan line*, etc. These terms refer to a single, continuous narrow strip of the picture area containing brightness variations, formed by one horizontal sweep of the scanning spot of a cathode-ray tube. If an image is said to be made up of 10 lines, this refers to the 10 scan lines of information that make up the image (herein called lines per image). The blank spaces that lie between adjacent scan lines (nine in this example) are not counted in the lines per image measure.

Image size is described in terms of the angular subtense at the subject's eye subtended by the image's vertical limits, measured in minutes of arc.

PREVIOUS WORK

Considerable variation has been found among the various experimental results examining line number requirements for televised alphanumeric symbols. In early studies of identification on TV, relatively high accuracies were reported for three styles of alphanumeric symbols, using 6 lines per symbol with a 0.8-second exposure time (Ref. 1 and 2). In another study, opaque and transparent lines across letters were used to simulate a raster-line structure (Ref. 3). The letters, which were made with either of two stroke widths and either 5 or 11 raster lines, were presented on a tachistoscope. At a 0.03-second exposure time, subjects made correct identifications 98% of the time on the 11-line letters. Performance dropped to 88 or 93%, depending on stroke width, when the letters were composed of only five lines.

Elias, Snadowski, and Rizy (Ref. 4) reported that relatively high performance could be expected with alphanumeric symbols composed of as few as five lines.

The legibility of Leroy and Courtney alphanumeric symbols was measured for 6, 8, 10, and 12 lines per symbol (Ref. 5). Legibility was not found to be significantly different for the two symbol styles. Results did show, however, that resolutions of less than 10 lines per symbol should be avoided if identification time was a critical parameter. Relatively good performance was obtained with as few as 8 lines per symbol, provided that time was not critical and observers were given practice trials.

A set of 20 geometric symbols was developed to provide descriptive information of radar scopes (Ref. 6). TV experiments were conducted at the Naval Weapons Center (NWC) to examine scan line requirements for 16 of these 20 geometric symbols (Ref. 7, 8, and 9). Median scores of 88% correct identification were obtained with 10 lines per symbol. Performance reached 90% correct identification at about 12 lines per symbol and an angular subtense of 14 minutes of arc. On a high-resolution TV system, 80% correct identification was obtained with 8 lines per symbol and 13.8 minutes of arc.

The visual angle subtended by symbol height was related to resolutions of 6, 8, and 10 lines per alphanumeric symbol by Shurtleff, et al. (Ref. 10). Gradual increases in accuracy and of symbol identification were reported as the monitor was moved closer to the subject, thus increasing visual subtense. Although angular subtense and number of lines per symbol were not systematically varied, results did show that a significantly larger angular subtense was required for symbol resolutions of 6 lines than for 8 or 10 lines. The authors concluded that a visual angle of 22 or 25 minutes of arc would probably be required for subjects to identify symbols at a high rate.

In another test (Ref. 11), a flying-spot scanner was used to generate the raster lines making up alphanumeric symbols on a TV monitor. Display "resolution",[1] symbol size and height-to-width ratio, symbol orientation, and viewing distance were controlled variables. Identification of symbols deteriorated below 15 minutes of arc at higher "resolutions" (16 to 20 lines per inch). At 8 lines per inch, the deterioration began at 20 minutes of arc. Better performance was obtained at 16 lines per inch than at 8, 10, or 12 lines per inch for all angular subtenses.

The above studies are difficult to summarize since test conditions varied widely and image size was not always controlled. The consensus seems to be that the image should be made up of at least 10 to 12 scan lines to ensure identification. However, there are not enough data to define the image size required for legibility, or to indicate the presence of interactions between scan lines and image size.

APPARATUS

The four laboratory experiments described in this report were conducted over a 15-month period. The objective was to examine identification performance when both the size of the image on the monitor and the number of scan lines making up the image were systematically varied. The principal difference between the four experiments was the type of imagery used.

1. Experiment I consisted of photographs of geometric symbols viewed on TV.

2. Experiment II consisted of photographs (side views) of vehicles against a plain background viewed on TV.

3. Experiment III consisted of oblique side-view photographs of the same vehicles against a structured background viewed on TV.

4. Experiment IV used the photographs from Experiment III viewed directly.

The basic setup for the TV experiments (Experiments I through III) is shown in Fig. 1. A TV camera viewed an illuminated test chart and transmitted the picture by closed circuit to a nearby TV monitor viewed by the subject. The equipment consisted of a standard Cohu-Kintel, 525-line, Model 3100 TV camera and a 9-inch Conrac TV monitor, Model RNC-9A. The TV camera was directly focused on the test charts by a Schneider-Kreuznach, f/1.4, 25 mm lens. Table 1 gives the specifications of the system.

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[1]Defined in Ref. 11 as the number of scan lines per inch. Quote marks are used to indicate this definition is used only in citing this reference.

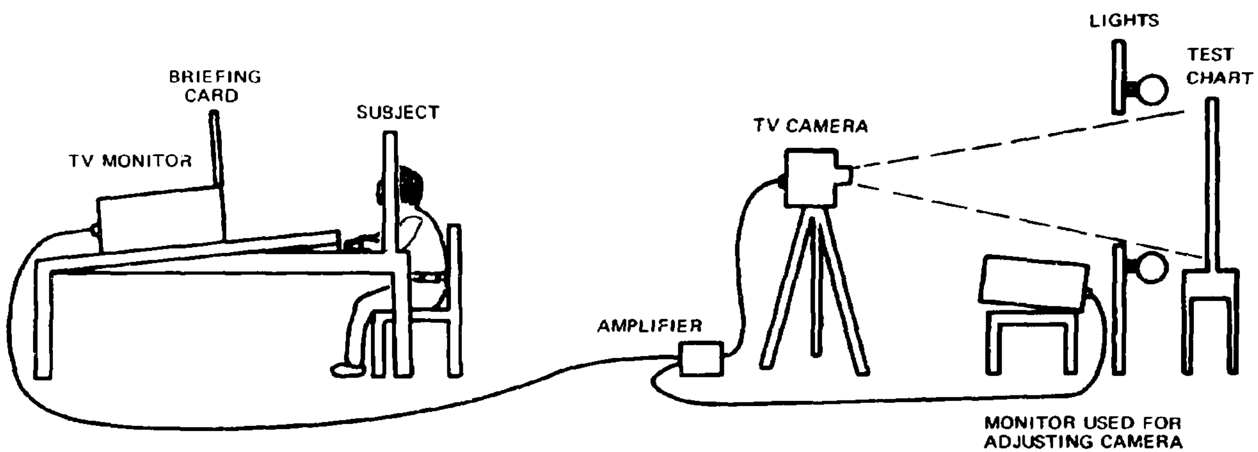


FIG. 1. Sketch of Apparatus Used. Subject and test monitor were in a different room than TV camera and test chart.

TABLE 1. Television System General Description

1.	Rated total scan line number	525
2.	Actual displayed scan line number	about 485
3.	Rated bandwidth	10 Hz to 10 MHz ± 1 db
4.	Interlace	2:1
5.	Interlace quality	uneven spacing (blank spaces of uneven width)
6.	Frame rate	30 frames/sec
7.	Field rate	60 fields/sec
8.	Scan type	standard EIA sync and video[a] (left-to-right, top-to-bottom)
9.	Phosphor type	P-4
10.	Raster line orientation	lines horizontal
11.	Sensor (Vidicon) raster size	0.5 in. wide x 0.37 in. high
12.	Sensor aspect ratio	4:3
13.	Raster size on display	6.5 in. wide x 4.8 in. high
14.	Raster aspect ratio on display	4:3
15.	Viewing distance to display	variable
16.	System signal-to-noise ratio	greater than 30 (peak to peak video/RMS noise)
17.	Ambient illumination on monitor face	less than 3 footcandles

[a]Electronic Industries Association Standard RS-170.

A Kapco TVA2A-3 video amplifier with a flat response to 10 MHz was used between the camera and monitor. This allowed a second monitor (used in adjustments) to be driven from the camera. The camera and monitor were operated from SOLA CVS-402A constant voltage transformers.

The monitor was mounted on long rails so that it could be set at any viewing distance desired. Glassless spacing goggles were used to maintain the desired distance between observer and monitor.

The apparatus for Experiment IV (photographs viewed by direct vision) consisted of the test chart stand shown in Fig. 1, and glassless spacing goggles.

IMAGERY

The imagery used in the experiments is shown in Fig. 2, 3, and 4. The symbols used in Experiment I were photographs of black, line-drawn figures (Fig. 2) mounted in a 5 x 5 matrix on test charts viewed by the TV camera (Fig. 5).

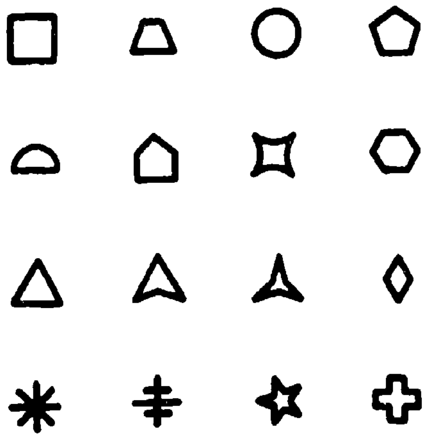


FIG. 2. Geometric Symbols Used in Experiment I.

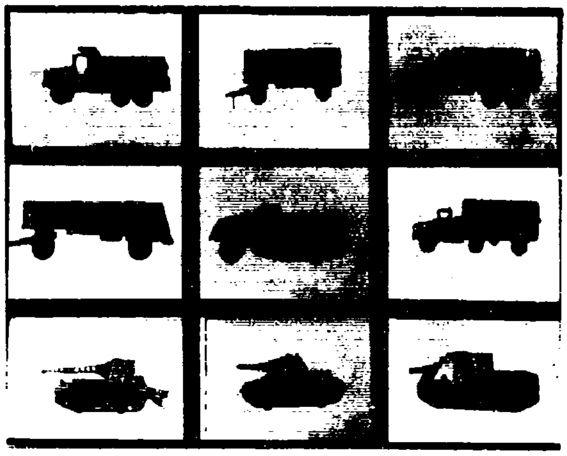


FIG. 3. Side Views of Vehicles Used in Experiment II.

(a) Sandy background (b) Foliage background

FIG. 4. Oblique Side View of the Nine Vehicles Against Two Different Backgrounds Used in Experiments III and IV.

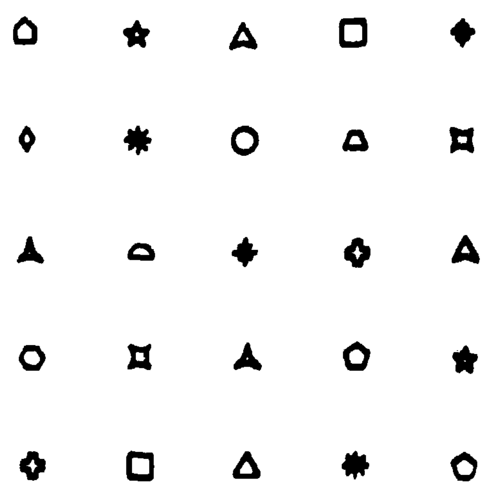


FIG. 5. Photograph of Symbol Legibility Test Chart.

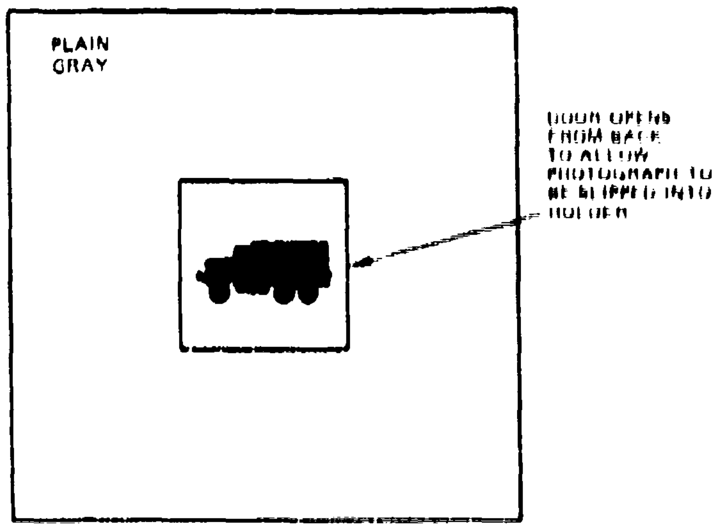


FIG. 6. Sketch of Vehicle Display Mount

The imagery in Experiment II was black and white, 4 x 5-inch photographs of 90:1 scale-model vehicles. They were straight side views of the vehicles against a plain gray background (Fig. 3). Internal detail was visible, but there were no ground shadows or border interuptions. They were shown individually by slipping them in a gray, 35-inch-square mount viewed by the TV camera (Fig. 6).

The photographs used in Experiments III and IV were oblique side views against two types of background (Fig. 4). The obliquity was about 30 degrees down from the horizon and the terrain types were called sandy and foliage backgrounds. The photographs were taken under direct sunlight on a terrain model, so they contained shadows and highlights. A more complete description of the imagery and TV display is given in Appendix A.

PICTURE QUALITY CONTROL

Before each experiment the vertical linearity of the TV system was adjusted by using a chart composed of equally-spaced vertical and horizontal lines. Although there was no line pairing, it was impossible to avoid some uneven spacing between scan lines.

A typical stimulus chart (photograph of symbols or vehicles) was then viewed by the TV camera and displayed on the TV monitor. Brightness and contrast adjustments were made on the monitor by the experimenter to render as clear a picture as possible of the black symbols or gray vehicles. This initial adjustment was completely subjective. Next, a gray-scale calibration chart was viewed by the TV camera and displayed on the monitor. A Spectra brightness spot meter was used to measure the luminance of each gray level on the chart as well as on the TV monitor display. The results were plotted to show the luminance reproduction of the TV system (Fig. 7). Luminance measurements were taken before and after each day's runs, and adjustments were made when necessary to maintain a constant gray-scale rendition throughout each experiment. The differences evident in Fig. 7 are due to the initial subjective adjustment to obtain a "good" picture.

SUBJECTS

Eight subjects participated in Experiment I (which used the symbols). Nine subjects were required in Experiment II (with side view of vehicles); six were from Experiment I and three were new recruits. Experiments III and IV (with oblique views of vehicles) used seven experienced subjects and two new recruits. Subject participation is shown in Table 2.

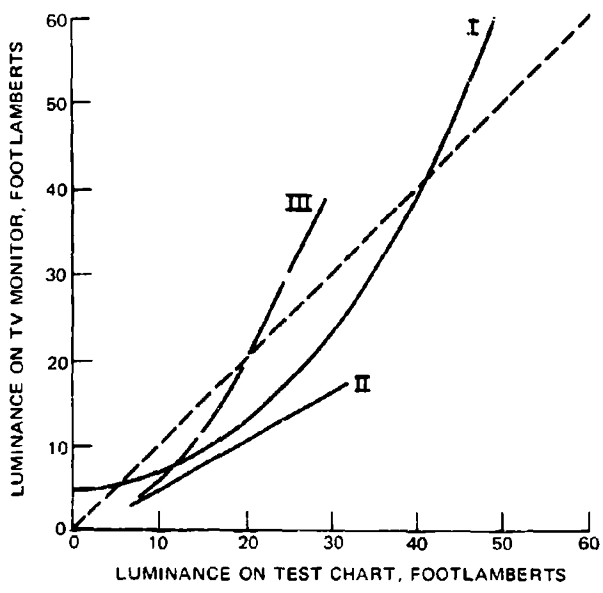


FIG. 7. Test Chart Versus TV Monitor Luminance Levels for Experiments I, II, and III. Dotted line shows 1:1 luminance reproduction.

TABLE 2. Subject Participation in the Four Experiments

(Individual subjects are denoted by letters.)

Experiment			
I	II	III	IV
A	A	A	A
B	B	B	B
C	C	C	C
D	D	D	D
E	E	E	E
F	F	L	L
G	I	I	I
H	J	J	J
	K	M	M

All subjects were adult males with 20/12 or better, uncorrected, near and far visual acuity as measured on the Armed Forces Vision Tester (Bausch & Lomb Ortho-Rater). They were either civilian employees or U.S. Navy pilots.

EXPERIMENT I

Experimental Design

The geometric symbols were displayed to the subjects at 13 combinations of angular subtense and line number (Table 3).

The different line numbers were obtained by maintaining a constant camera-to-chart distance and using six different symbol sizes. The three symbol angular subtenses were obtained by varying the subject-to-monitor viewing distance.[2]

The 13 test charts each contained 25 symbols of the same size, one each of the original 16 and nine additional symbols randomly chosen from the 16. These nine duplicate symbols on each chart made it impossible for the subjects to use a process of elimination to aid them in giving correct answers. To maintain constant symbol content in the results, answers on the nine repeats were not used in the analysis. Symbol location on each chart was random; symbol orientation was constant.

[2]More than three viewing distances were required, however. To change line number, but hold the image angular subtense constant, the viewing distance also had to be changed.

TABLE 3. Combinations of Conditions Used in the Experiment[a]

(Condition 13 was shown to only four subjects.)

Order of presentation	Lines per symbol	Symbol subtense, minutes of arc
1	25.6	10.2
2	15.5	6.0
3	7.8	4.4
4	15.5	10.2
5	7.8	10.2
6	6.3	10.2
7	7.8	6.0
8	6.3	6.0
9	4.8	10.2
10	4.8	6.0
11	4.8	4.4
12	6.3	4.4
13	13.5	4.4

[a]It was originally desired to test with 5, 6.5, 8.0, 15, and 25 lines per symbol at angular subtenses of 4.5, 6.0, and 10.0 minutes of arc. However, the symbol sizes on the final test charts differed slightly from those desired, although not enough to merit redoing. Hence, the odd-size numbers.

Procedure

Each subject was brought into the laboratory and acquainted with the test apparatus. He was then seated and the spacing goggles were adjusted to his height by the experimenter. Tape-recorded instructions described the response procedure to each subject. He was told that he was being tested under the method of forced choice; if he was not certain of a correct answer, he was to give his best guess. The procedure resulted in a matching test; the subject was to look at each symbol on the monitor and call out its number as indicated on a briefing card located just above the monitor. The briefing card resembled Fig. 2 except that a number was near each symbol. After the instructions, each subject was presented one practice chart (25 symbols) before starting the actual test. The presentation order of the conditions (Table 3) was selected for an estimated easy-to-hard, easy-to-hard sequence.

Two experimenters conducted each test. One experimenter recorded the subject's oral responses and adjusted the spacing goggles and monitor position preceding each new chart presentation. The second experimenter masked the TV camera, changed test charts, and unmasked the camera when the subject was ready. No limit was placed on the subject's response times, and no information was given to him as to the correctness of his responses during the actual tests.

Performance on the 4.4 minute of arc images was expected to decrease monotonically as the number of lines per image was decreased. Since the decreases did not occur, this condition was retested with five additional subjects. These subjects had 20/20 or better visual acuity, but near and far acuity was not necessarily matched. The procedure followed on the retest was identical to the first, except that the four charts (one for each line number) were presented in random order to each subject. The instructions used in both tests were identical.

Results

Scores were derived only from 16 different symbols on each chart. The first symbol of its kind to be read was counted as the response. If that symbol occurred again on the chart, the response was simply not counted. This scoring method ensured that using different extra symbols from chart to chart would not introduce error due to unequal symbol difficulty.

Mean scores as a function of symbol angular subtenses and lines per symbol are presented in Fig. 8 and 9.

At all angular subtenses and at all values above 7.8 lines per symbol, performance improved as the number of lines per image increased. Below 7.8, however, the data points appear more random. The data in Fig. 9 illustrate that performance does not continually improve as the angular subtense of the symbol increases when there are only 4.8 or 6.3 lines per symbol; however, there is a definite improvement with increased angular size of symbols made up of 7.8 scan lines or more.

Identification errors made on four of the charts were examined to determine relative symbol-identification difficulty and to determine what symbols were being mistaken for others. The confusion matrix is presented in Table 4. There is substantial agreement between these results and the results of a previous experiment (Ref. 8); the Spearman rank-difference correlation coefficient (ρ) between the results of the experiments was 0.791, significant beyond the 0.01 level.

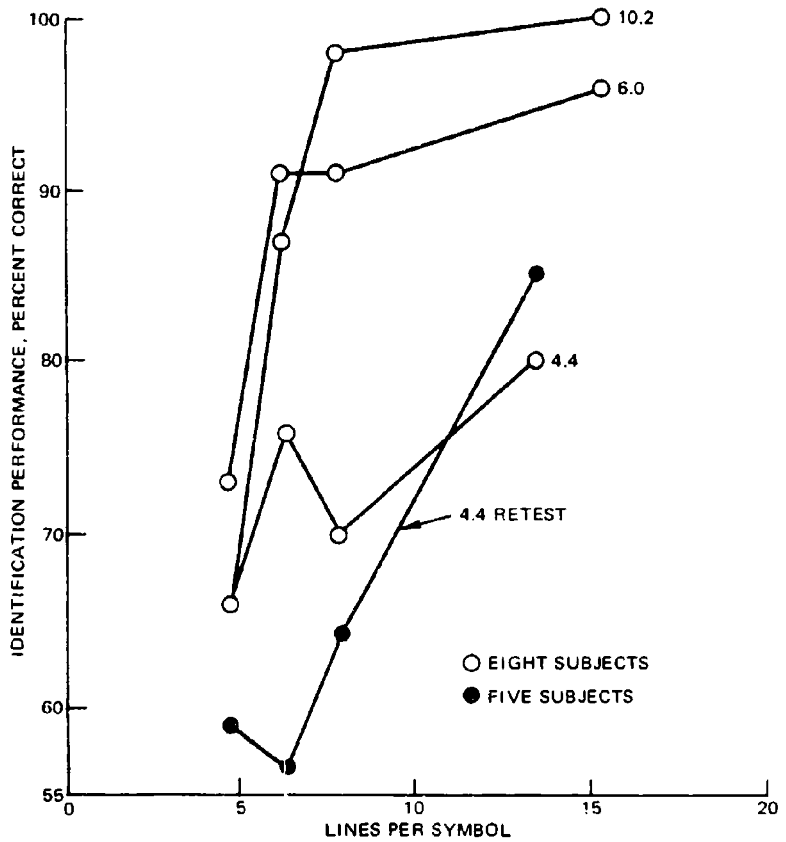


FIG. 8. Mean Performance on Symbol Identification at Three Angular Subtenses as a Function of Number of Lines per Symbol. Numbers on curves indicate angular subtenses in minutes of arc.

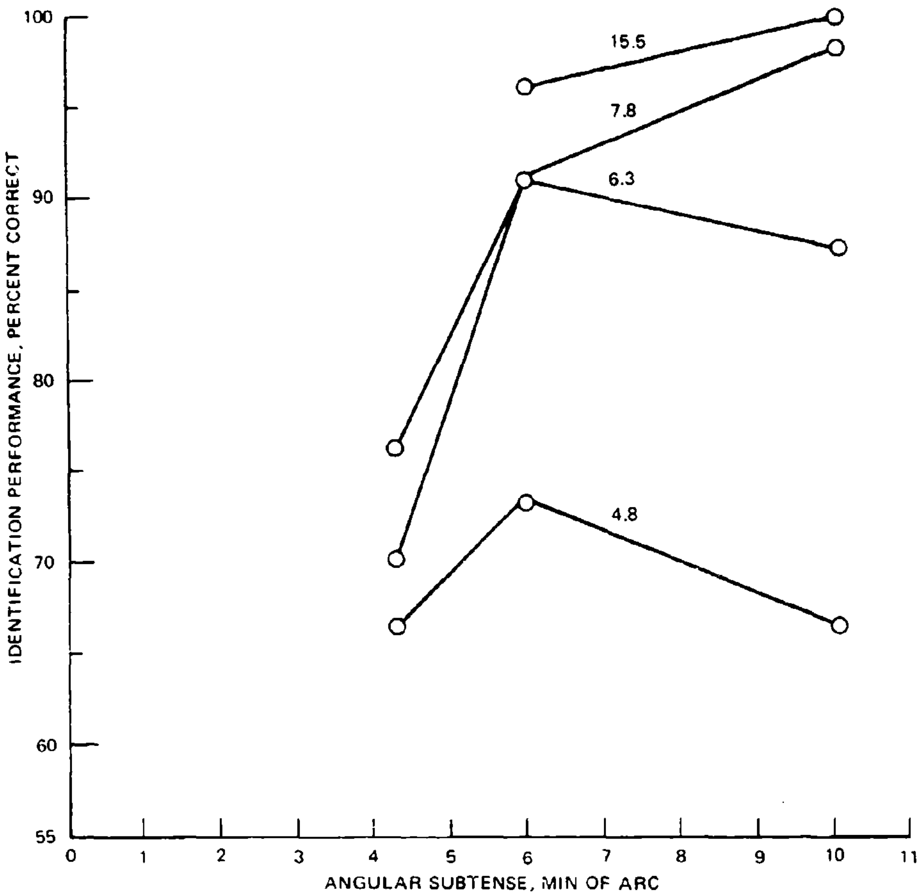


FIG. 9. Mean Performance on Symbol Identification for Four Scan Line numbers as a Function of Angular Subtense. Numbers on curves indicate scan lines per symbol. (Replot of Fig. 10.)

TABLE 4. Confusion Matrix for Symbol Identification on TV

Symbol presented	Response given															
	⌑	△	□	⌓	△	✳	○	⌂	ǂ	◊	⅄	☆	✣	⬠	⏢	○
⌑	100	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
△	...	99	...	...	01	...	...	...	...	...	...	...	...	...	...	...
□	...	...	98	...	...	...	...	...	...	...	...	02	...	...	...	...
⌓	...	...	...	98	...	...	...	...	...	02	...	...	...	...	...	...
△	...	03	...	...	97	...	...	...	...	...	...	...	...	...	...	...
✳	...	...	...	...	...	97	...	...	03	...	...	...	...	...	...	...
○	...	...	...	...	...	...	96	...	...	...	...	...	...	...	...	04
⌂	...	...	...	...	...	...	...	96	...	...	...	...	...	04	...	...
ǂ	...	...	...	...	...	02	...	...	95	03	...	...	...	...	...	...
◊	...	...	...	...	...	...	...	...	06	94	...	...	...	...	...	...
⅄	...	08	...	...	...	...	...	...	...	...	92	...	...	...	...	...
☆	...	...	02	...	...	02½	...	...	02½	...	...	91	02	...	...	...
✣	02	...	...	...	...	...	...	...	...	...	...	04	89	05	...	...
⬠	...	...	...	...	...	...	06	01½	...	...	...	01½	...	86	...	05
⏢	...	04	...	13	...	...	...	...	...	...	...	04	04	...	75	...
○	...	...	02½	...	...	...	40	02½	...	...	...	...	...	05	...	50

The study reported in Ref. 11 also separated the effects of lines per symbol and symbol subtense on legibility. The data were unfortunately pooled when reported, so only a rough comparison can be made. The three symbol heights from Ref. 11 (0.353, 0.418, and 0.448 inch) were assumed to have a mean height of 0.4 inch. The number of scan lines across this mean symbol height was correlated with the listed "raster lines per inch on display". The data were replotted in Fig. 10 for the only condition comparable to this study (10 minutes of arc target subtense). The agreement is encouraging. The data from both studies indicate that there is a knee to the curve at about 8 lines per symbol. The fact that performance in Ref. 11 was not as good as performance in this study might be attributed to three factors.

1. In the Ref. 11 study, 20 alphanumeric symbols were used, reducing the probability of being correct by chance.

2. The discrimination of one symbol from the others may have been more difficult.

3. The subjects in this study had 20/12 or better uncorrected near and far acuity.[3] The Ref. 11 subjects had at least 20/20 corrected visual acuity.

EXPERIMENT II

Experimental Design

The vehicles (Fig. 3) were displayed to each subject at all combinations of three line numbers and three angular subtenses—3.7, 7.0, and 10.8 lines per vehicle and 4.4, 6.0, and 10.2 minutes of arc per vehicle. As before, the three line numbers were obtained by maintaining TV camera-photograph distance constant and using three sizes of vehicle in the photographs. Angular subtense was varied by varying the viewing distance between TV monitor and the subject.

Twelve vehicles were shown at each test condition (Table 5), one each of the original nine and three additional vehicles randomly chosen from the nine. As before, the duplicate trials were included only to preclude using a process of elimination to give correct answers.

Responses on them were not used in the data analysis. Order of presentation of the vehicles was random within a condition. The order of presentation of the conditons to the subjects is given in Table 6.

[3] The five subjects used in the Experiment I retest had 20/20 corrected visual acuity.

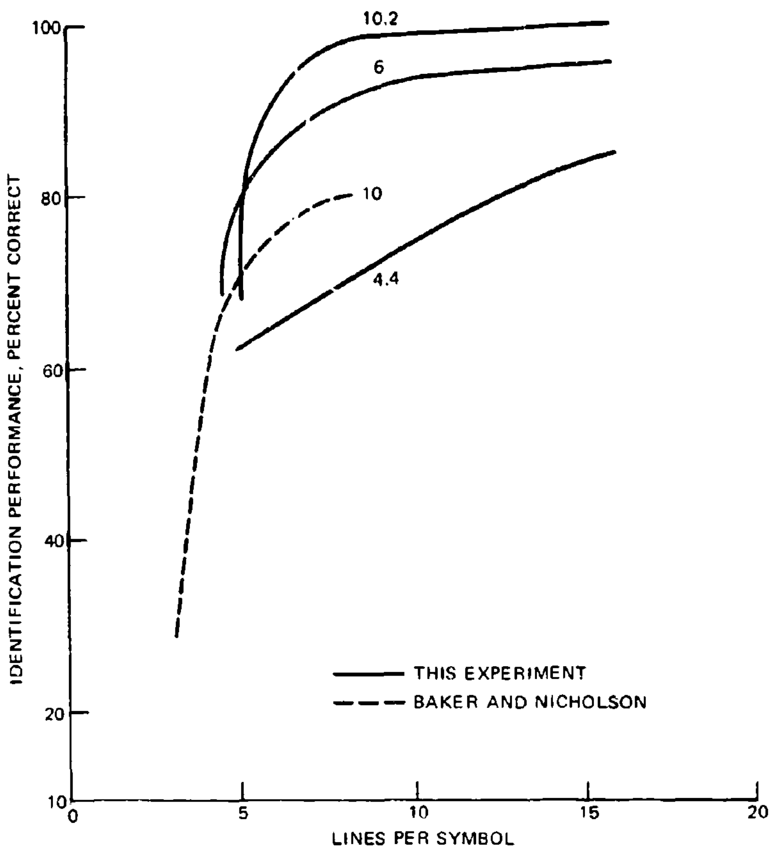


FIG. 10. Comparison of Smoothed Data From This Experiment With Modified Data From Baker and Nicholson (Ref. 11). Numbers on curves indicate angular subtenses in minutes of arc.

TABLE 5. The Nine Test Conditions

Condition	Vehicle height, minutes of arc	Lines per vehicle
A	10.2	3.7
B	10.2	7.0
C	10.2	10.8
D	6.0	3.7
E	6.0	7.0
F	6.0	10.8
G	4.4	3.7
H	4.4	7.0
I	4.4	10.8

TABLE 6. Order of Presentation of the Conditions

Subject	Order of presentation of conditions								
	1	2	3	4	5	6	7	8	9
1	A	B	C	E	D	H	G	F	I
2	B	C	E	D	H	G	F	I	A
3	C	E	D	H	G	F	I	A	B
4	E	D	H	G	F	I	A	B	C
5	D	H	G	F	I	A	B	C	E
6	H	G	F	I	A	B	C	E	D
7	G	F	I	A	B	C	E	D	H
8	F	I	A	B	C	E	D	H	G
9	I	A	B	C	E	D	H	G	F

Procedure

The subject briefing and procedure were the same as described for Experiment I. The briefing card resembled Fig. 3 with a number (1 to 9) near the vehicle in each square. Twenty-seven practice trials were given. Each vehicle of each size was shown once at a constant viewing distance, so the subjects saw images of different sizes and line numbers before the actual test began.

Results

The results are shown in Fig. 11 and Table 7. Performance improved rapidly when the lines-per-vehicle was increased from 1.7 to 7.0. Further improvment was less, with none at 4.4 minutes of arc. To obtain 100% correct performance on this test, the vehicle had to subtend about 10 minutes of arc and be made up of 10 scan lines. The two tanks were confused with one another most often, with the dump truck/half track confusion next most frequent. These data are compared to other data in a later section of this report.

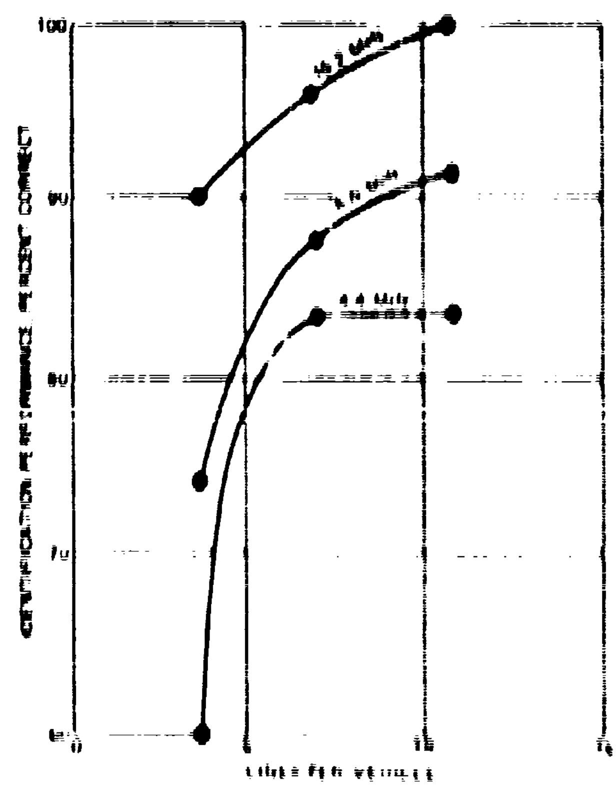


FIG. 11. Experiment II Vehicle Identification Performance. Numbers on curves indicate target subtenses in minutes of arc.

TABLE 7. Experiment II Confusion Matrix

Target actually presented	Subjects' responses, %									
	Truck & van	Tank trailer	Van trailer	Cargo truck	Crane	Dump truck	Half track	Large tank	Small tank	Total
Truck & van	99	...	...	1	...	...	...	...	...	100
Tank trailer	...	99	1	...	...	...	...	...	...	100
Van trailer	1	2	96	...	...	...	...	...	1	100
Cargo truck	1	...	...	91	...	6	1	1	...	100
Crane	...	...	...	...	88	...	...	1	11	100
Dump truck	5	1	...	4	...	86	4	...	...	100
Half track	2	...	2	7	...	7	76	4	2	100
Large tank	2	...	...	...	1	1	4	76	16	100
Small tank	2	...	...	1	5	...	6	25	61	100

EXPERIMENT III

Experimental Design

The procedure used was essentially the same as that of Experiment II. The vehicles were displayed to each subject at all combinations of two backgrounds (Fig. 4), three line numbers, and three angular subtenses (Table 8). Twenty-four vehicles (12 from each terrain background) were presented at each conditon. As in Experiment II, each set of 12 contained one each of the original nine and three duplicates. The order of presentation of the 24 vehicles within a condition was completely randomized without regard to terrains. A randomized Latin Square design was used to present the nine conditions to the nine subjects (Table 9).

TABLE 8. Conditions of Experiment

Condition	Vehicle height, minutes of arc	Lines per vehicle
A	6	15
B	10	15
C	14	15
D	6	10
E	10	10
F	14	10
G	6	6
H	10	6
I	14	6

TABLE 9. Randomized Latin Square Design

Subject	Order of presentation								
	1	2	3	4	5	6	7	8	9
1	B	E	H	A	I	D	F	G	C
2	G	D	F	I	B	H	C	A	E
3	E	B	G	H	A	I	D	C	F
4	F	A	I	B	C	G	H	E	D
5	A	C	E	D	G	B	I	F	H
6	H	F	C	E	D	A	G	B	I
7	D	H	A	C	F	E	B	I	G
8	I	G	D	F	E	C	A	H	B
9	C	I	B	G	H	F	E	D	A

Procedure

The subject briefing and testing procedures were the same as described for Experiments I and II. The briefing card resembled the left or right half of Fig. 4 except that the vehicles were on a plain gray background. The pictures were oblique side views with shadows visible (Fig. 4). There was a number (1 to 9) near each vehicle.

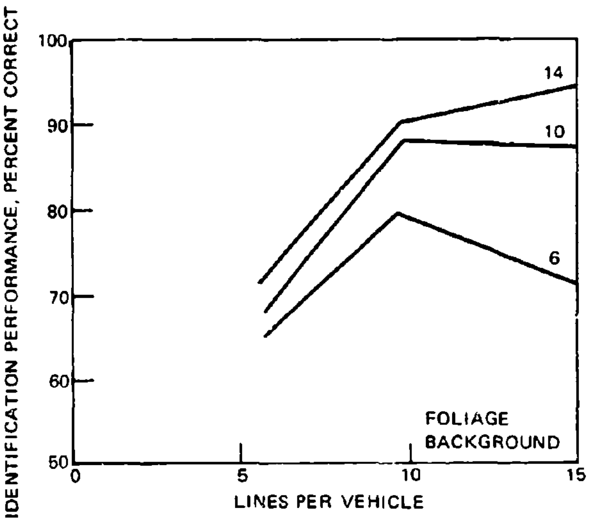
After the instructions, the subject was given 27 practice trials at a 25-inch viewing distance. The 27 photographs consisted of nine of each of the three sizes (one each of each vehicle). The choice of background for these practice trials was random, so the subject did not see each vehicle against each background.

Results

The mean scores are shown in Fig. 12 as functions of target size, lines per vehicle, and background type. Performance dropped off rapidly when the lines per vehicle was below 10. Improvements in performance were not statistically significant when the lines-per-vehicle was increased to 15. Hence, in further analysis the data from these two conditions were combined. Performance improved as the angular subtense of the image increased. An asymptote was not reached in this study: it appears that performance would continue to increase as the image increases in size beyond 14 minutes of arc.

The effect of the type of background against which the vehicles were photographed is illustrated in Fig. 13. Vehicle identification on the sandy background was more difficult than identification on the foliage background for all target sizes. Student's t tests (using the subject's mean scores) showed this difference in identification to be statistically significant at the 0.05 level. The sandy background was more difficult probably because the highlights on the vehicles had the same luminance as the background. Hence, there was no contrast against the background for that portion of the vehicle and the whole form was therefore not visible as a unit. As discussed in Appendix A, the tone reproduction of the photographs was not linear; the lignt end of the luminance range was compressed in the photographs. Although the photographs did not faithfully represent the particular terrain model, they could represent a type of terrain/target relationship. In that context, the data are meaningful and do demonstrate possible background effects in the identification process.

The confusion matrices are shown in Tables 10 and 11. The Spearman rank-difference correlation coefficient is 0.26, indicating little agreement between the rankings. These results indicate that both the recognition probability and the relative difficulty of the individual vehicle are dependent upon the type of background against which the target is viewed.



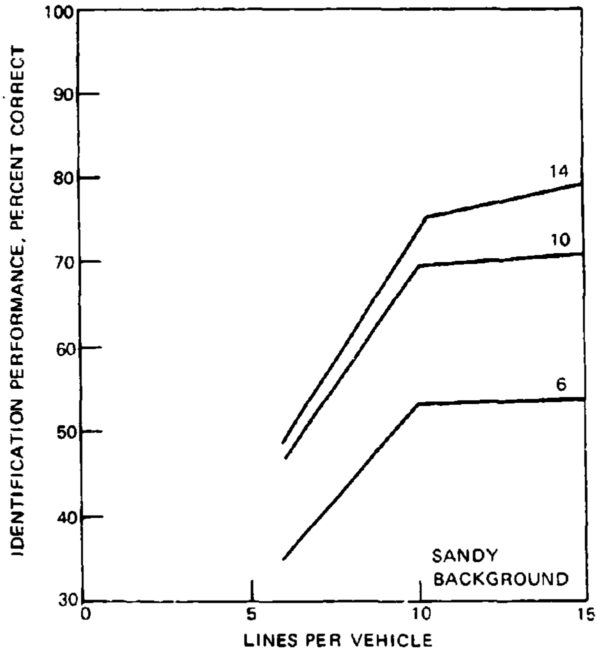


FIG. 12. Experiment III Vehicle Identification Performance. Numbers on curves indicate angular subtenses in minutes of arc.

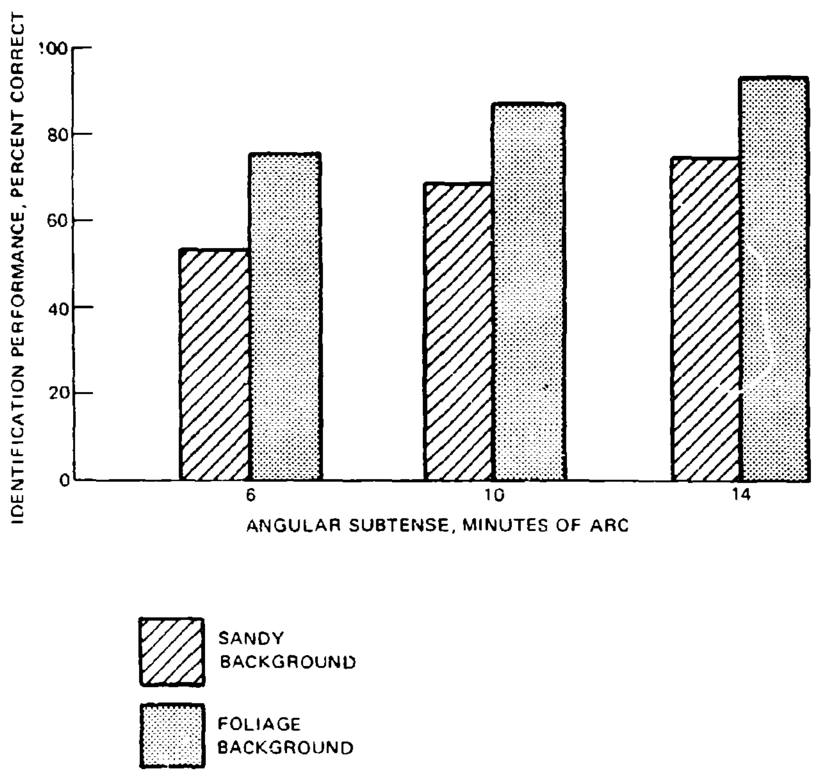


FIG. 13. Effect of Target Background on Experiment III Identification Performance. Data for 10 and 15 lines per vehicle are combined.

TABLE 10. TV Confusion Matrix of Targets on Sandy Background

Target actually presented	Subjects' responses, %									
	Tank trailer	Van trailer	Truck & van	Crane	Half track	Cargo truck	Dump truck	Small tank	Large tank	Total
Tank trailer	93	4	...	...	1	1	1	...	...	100
Van trailer	9	72	8	...	5	3	3	...	...	100
Truck & van	5	1	70	...	11	9	4	...	...	100
Crane	...	2	...	69	9	1	4	5	10	100
Half track	...	...	...	23	56	1	9	2	9	100
Cargo truck	...	...	12	...	17	46	25	...	...	100
Dump truck	3	3	21	3	10	21	37	...	2	100
Small tank	...	1	...	7	15	...	14	32	31	100
Large tank	...	3	2	...	27	4	24	10	30	100

TABLE 11. TV Confusion Matrix for Targets on Foliage Background

Target actually presented	Subjects' responses, %									
	Small tank	Van trailer	Half track	Crane	Truck & van	Tank trailer	Dump truck	Large tank	Cargo truck	Total
Small tank	99	...	...	...	...	...	...	1	...	100
Van trailer	...	98	1	...	...	1	...	...	...	100
Half track	10	...	86	3	...	...	...	1	...	100
Crane	...	4	11	81	...	...	4	...	...	100
Truck & van	...	...	1	...	78	...	...	...	21	100
Tank trailer	2	17	2	...	...	77	...	2	...	100
Dump truck	6	1	14	1	6	...	68	...	4	100
Large tank	15	...	4	...	...	1	12	68	...	100
Cargo truck	...	...	...	...	42	1	...	...	57	100

EXPERIMENT IV

Current techniques to analytically specify or describe image quality in terms that can be directly related to observer performance are of uncertain validity. The primary imagery used in this TV experiment (photographs) can be described in meaningful terms, however, by measuring the subject's performance when he is directly viewing the photographs.

Experimental Design

In a retest, the same photographs that were viewed by the TV camera were viewed directly. The same nine subjects, photograph mount, briefing card, and vehicle angular subtenses were used. Twenty-four vehicles (12 of each background) of the same size were shown at three viewing distances—7.3, 10.3, and 17.1 feet, which resulted in angular subtenses of 14, 10, and 6 minutes of arc, respectively.

The vehicles were shown, one at a time as in the TV test, in randomized order within each condition. The order of presentation of the three conditions is given in Table 12.

TABLE 12. Order of Presentation of Target Angular Subtenses

Subject	Order of presentation		
	1	2	3
1, 4, 7	6[a]	14[a]	10[a]
2, 5, 8	14[a]	10[a]	6[a]
3, 6, 9	10[a]	6[a]	14[a]

[a] Minutes of arc.

Procedure

The retest began 6 weeks after the completion of the TV study. Four weeks were required to complete the experiment because the subjects were not always available.

The subject entered the room and was given a short briefing and nine practice trials. The briefing card and procedure were the same as the earlier TV experiments. One experimenter adjusted the spacing goggles and recorded responses; the other changed photographs in the mount.

Results

Ident ication performance in the direct-view experiment showed the same trends a were found in the TV experiment. Performance decreased as the size of the target decreased, and identification was more difficult on the sandy background than on the foliage background (Fig. 14). Figure 14 also shows subject response error from Ref. 12. Although the forms and procedures of Ref. 12 were different from those used in this study, the agreement in the data is encouraging. Identification was at least 98% correct for targets subtending 15 minutes of arc for all three displays. Performance began to drop off in all displays when the target size decreased below 14 to 15 minutes of arc. These data are compared to the TV results in a later section.

The confusion matrices for the direct-view test are given in Tables 13 and 14. To assess the relative difficulty in identifying each vehicle, the Spearman rank-difference correlation coefficient was computed between the two rankings. The coefficient, $\rho = 0.93$, indicates that the relative difficulty is very similar, unlike the TV results.

COMPARISION AND SYNTHESIS OF RESULTS

Symbols

The symbol legibility data from Baker and Nicholson (Ref. 11), Shurtleff (Ref. 10), and the NWC studies can be compared at various levels of performance. Values were taken from Fig. 5 of Baker and Nicholson's report and Fig. 2 of Shurtleff's report. The three symbol heights pooled by Baker and Nicholson (0.353, 0.418, and 0.448 inch) were assumed to have a mean height of 0.4 inch. The number of scan lines across this mean symbol height was correlated with the listed "raster lines per inch on the display". Figure 2 of Shurtleff's report was used after angular subtense was computed from symbol height and viewing distance. The data are plotted for three levels of correct responses (Fig. 15, 16, and 17) and summarized in Fig. 18.

As the lines per symbol decrease, the same performance level can be maintained by increasing the angular subtense of the symbol; however, this statement holds only for symbol subtenses from 7.8 to 16 minutes of arc.

These summary data appear to follow a constant-product rule. The 95% correct response curve can be closely approximated by the equation

$$SA = 90 \text{ for } 6 \leq A \leq 16$$

where S is the number of lines per symbol, and A is the angular subtense of the symbol in minutes of arc. For 90% correct response, SA = 75: for 80% correct response, SA = 60.

TABLE 13. Confusion Matrix for Sandy Background

Target actually presented	Subjects' responses, %									
	Half track	Crane	Tank trailer	Van trailer	Truck & van	Dump truck	Cargo truck	Small tank	Large tank	Total
Half track	100	...	...	...	...	...	...	...	...	100
Crane	...	100	...	...	...	...	...	...	...	100
Tank trailer	...	...	96	...	4	...	...	...	...	100
Van trailer	...	...	8	88	4	...	...	...	...	100
Truck & van	...	...	8	4	84	...	4	...	...	100
Dump truck	8	...	...	...	4	80	8	...	...	100
Cargo truck	...	...	...	...	4	24	72	...	...	100
Small tank	...	8	...	...	...	...	...	68	24	100
Large tank	4	...	...	...	...	4	...	28	64	100

TABLE 14. Confusion Matrix for Foliage Background

Target actually presented	Subjects' responses, %									
	Van trailer	Half track	Crane	Tank trailer	Dump truck	Truck & van	Small tank	Cargo truck	Large tank	Total
Van trailer	100	...	...	...	...	...	...	...	...	100
Half track	...	100	...	...	...	...	...	...	...	100
Crane	...	...	100	...	...	...	...	...	...	100
Tank trailer	...	...	...	96	...	...	4	...	...	100
Dump truck	...	4	...	...	92	...	...	...	4	100
Truck & van	...	...	...	...	...	92	...	8	...	100
Small tank	...	4	...	...	...	...	88	...	8	100
Cargo truck	...	...	...	...	...	16	...	84	...	100
Large tank	...	4	...	...	...	...	16	...	80	100

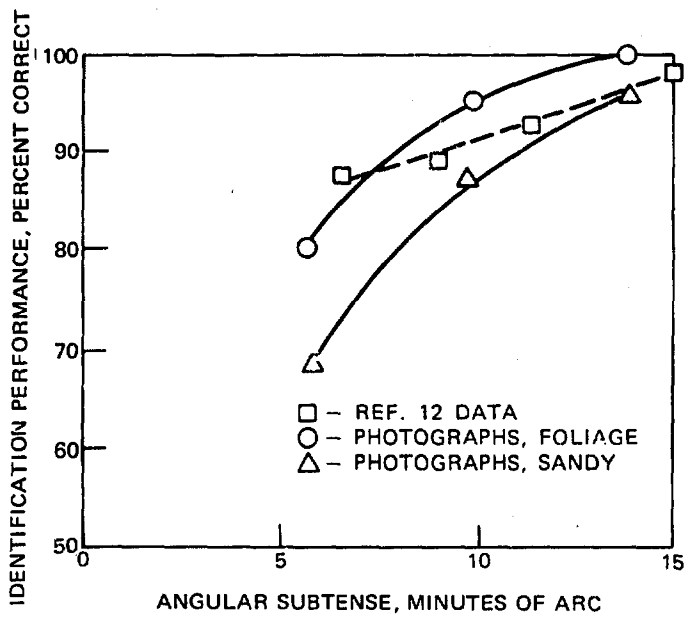


FIG. 14. Experiment IV Identification Performance (Photographs Viewed Directly).

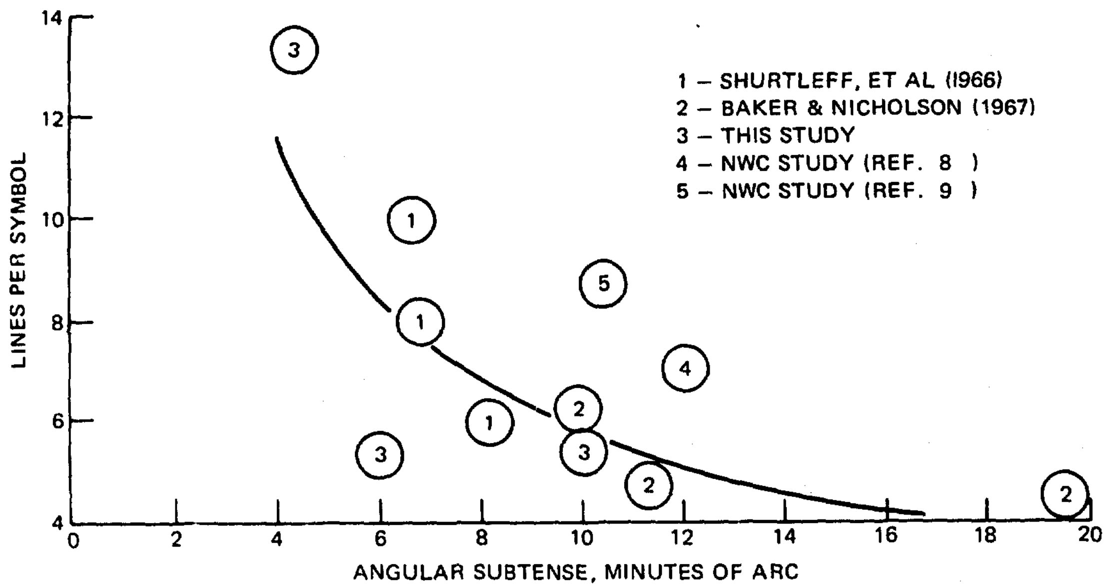


FIG. 15. Summary of Symbol Legibility Performance at 80% Correct.

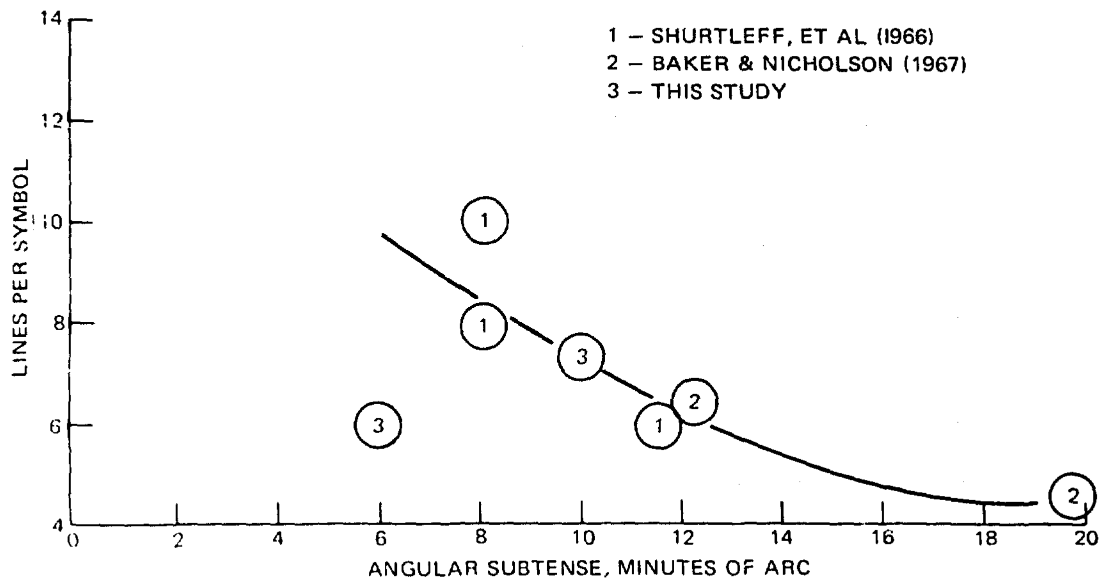


FIG. 16. Summary of Symbol Legibility Performance at 90% Correct.

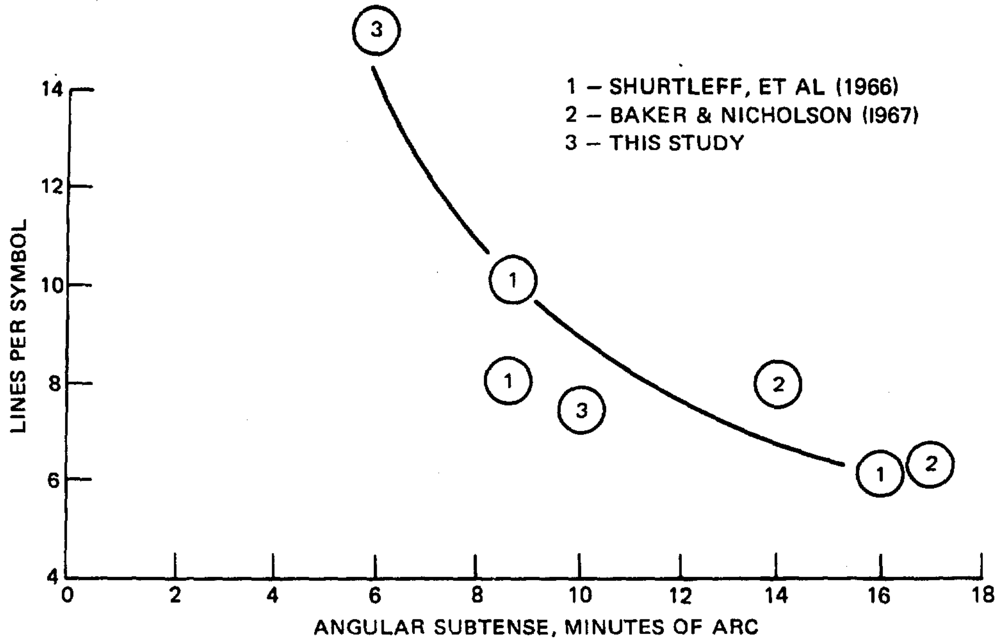


FIG. 17. Summary of Symbol Legibility Performance at 95% Correct.

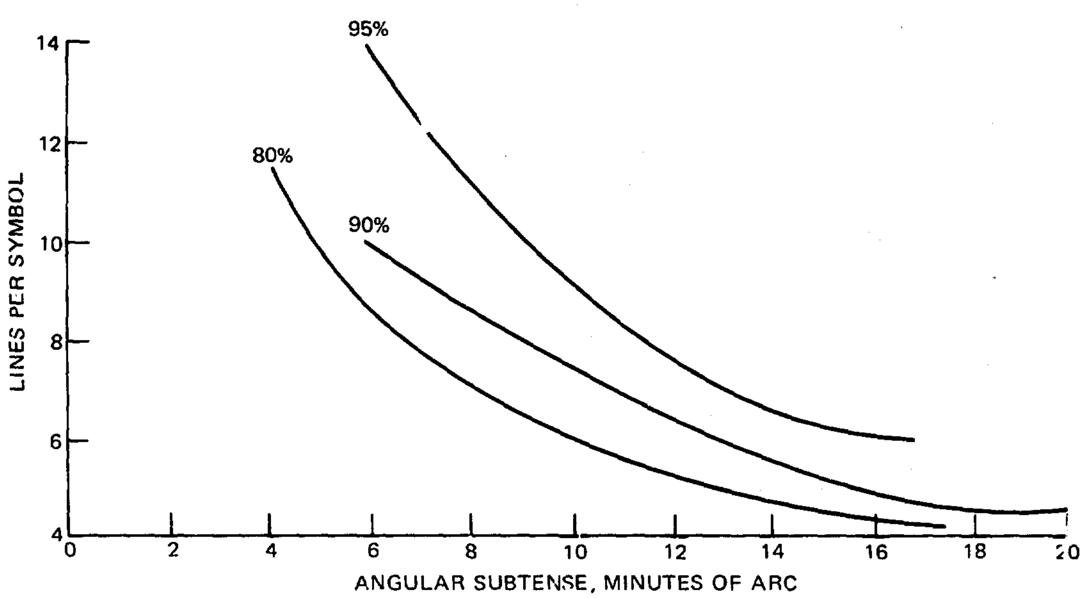


FIG. 18. Summary of Symbol Legibility Performance at 80, 90, and 95% Correct.

Vehicles

The data from the three TV experiments described in this report are shown in Fig. 19 and 20. The degradation introduced by oblique views, highlights, shadows, and a terrain model background is evident. As might be expected, the simple model (the constant-product rule) derived from the symbol experiments is not valid in this more complex, "real-world" situation. For high identification performance, the objects should be made up of at least 10 scan lines and should subtend more than 14 minutes of arc. The results should be extended by additional experiments.

Performance Degradation by TV

The scores of the subjects on both the directly viewed photographs and TV monitor illustrate that the target-background border interruptions and small target sizes interact to degrade performance in both viewing modes (Fig. 21). The performance degradation due to interposing the TV system between the subjects and the photographs can be estimated by factoring out this direct-view degradation. The TV scores shown in Fig. 21 were divided by the photograph scores at corresponding angular subtenses. This produces a "corrected" TV performance expressed as a fraction or percent of the best possible score that can be expected, which is that obtained by direct viewing of photographs (Fig. 22). In other words, direct vision performance is taken as 100%, and TV performance expressed as a fraction of that. It is seen that the degradation varies little with target size, but is a function of lines per vehicle and background type.

The degradation factor can be expressed in a product or difference relationship with direct-view performance, as indicated in the equations below.

$$\text{Product degradation (\%)} = \frac{\text{TV performance}}{\text{Direct-view performance}} \times 100$$

$$\text{Difference degradation (\%)} = 100 - \text{Product degradation}$$

The product degradation, as taken from Fig. 22, indicates that TV performance is about 92% of direct-view performance for 10 and 15 lines per vehicle on the foliage background, and drops to 72% for 6 lines per vehicle. These factors are about 76 and 48% for the more difficult sandy background.

For those preferring the difference concept, the degradation is 8% down for the 10 and 15 lines per vehicle and 28% down for 6 lines per vehicle on the foliage terrain. On the sandy terrain, performance is 24% down for 10 and 15 lines per vehicle and 52% down for 6 lines per vehicle.

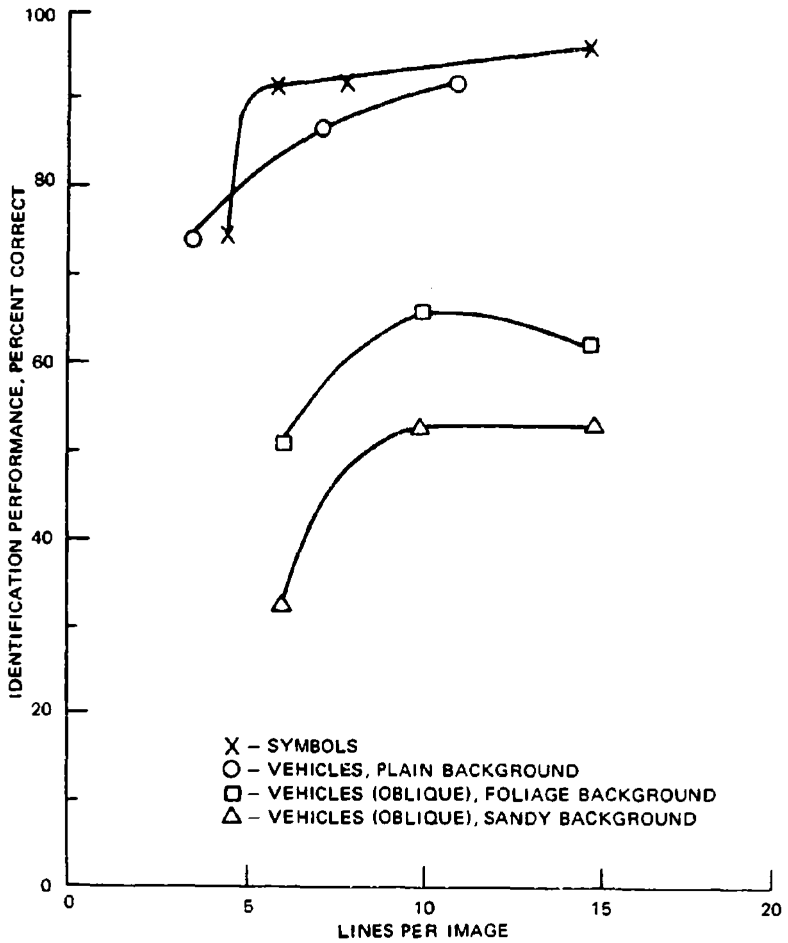


FIG. 19. Identification Performance on Images Subtending 6 Minutes of Arc.

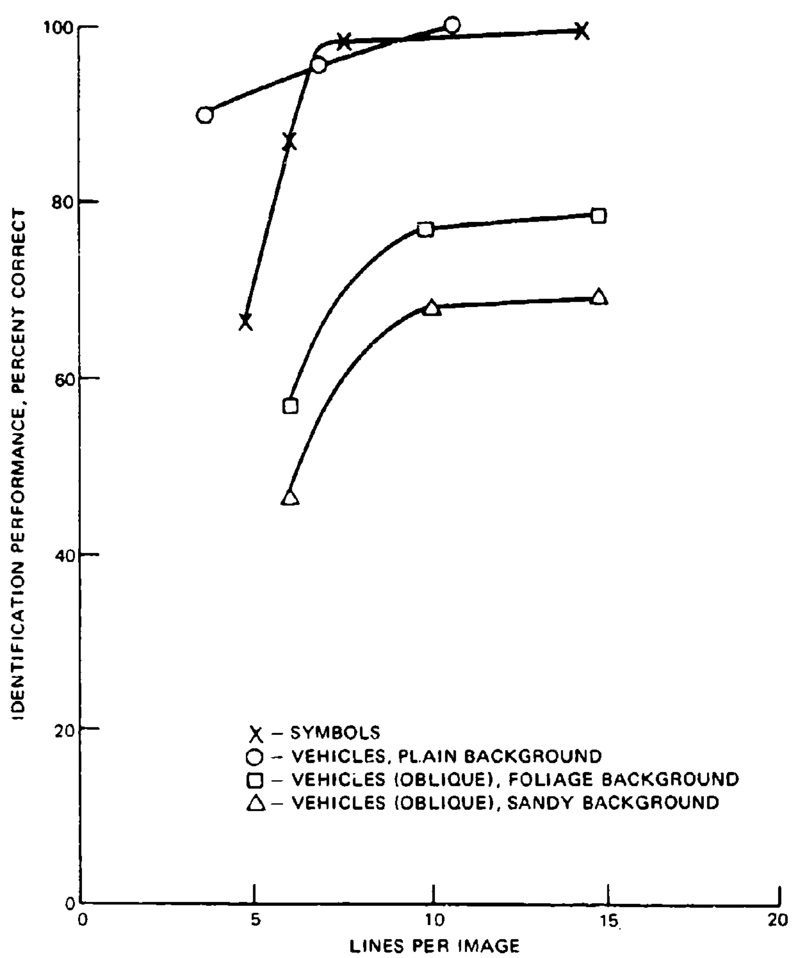


FIG. 20. Identification Performance on Images Subtending 10 Minutes of Arc.

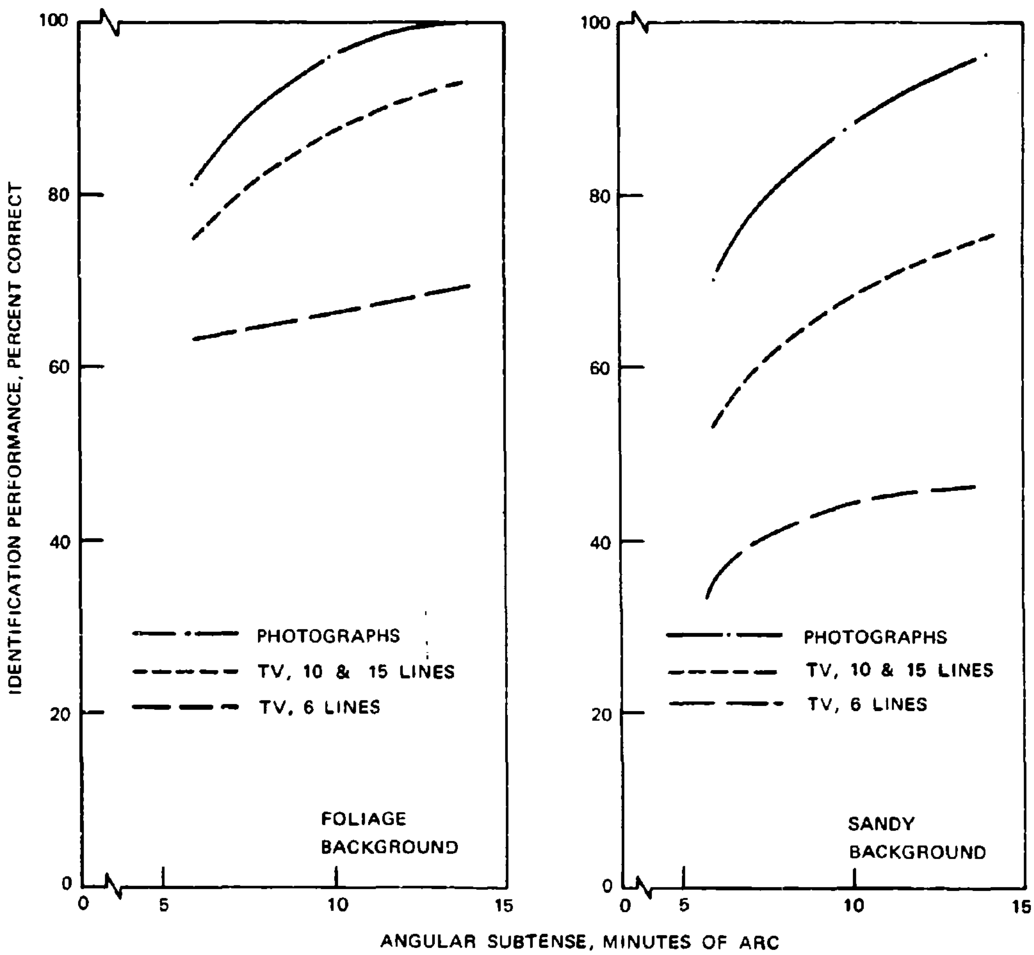


FIG. 21. Identification Performance on Images Subtending 10 and 15 Minutes of Arc and on Directly-Viewed Photographs.

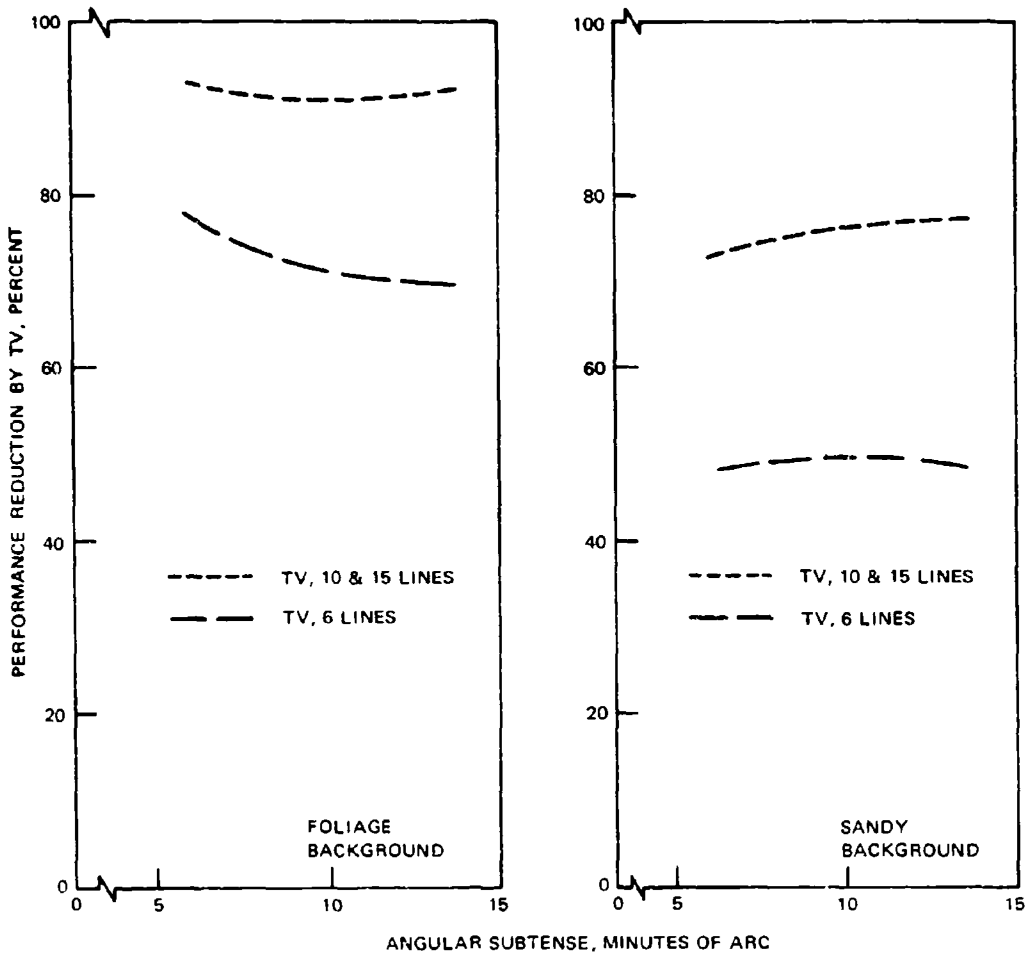


FIG. 22. Performance Identification Corrected to Remove Performance Degradation Due to TV System. Curves show TV performance divided by direct-view performance, which gives a factor by which direct-view performance must be multiplied to give TV performance.

The TV degradation cited above is for target size held constant. This degradation could be compensated for by using magnification on the TV system. The magnification can be determined by comparing the target sizes for direct vision and TV at constant identification levels. Table 15 shows such values taken from Fig. 21.

TABLE 15. Target Size Comparison Between TV and Direct Vision at Constant Identification Level

Performance level, % correct	Direct-vision target size, minutes of arc	TV target size, minutes of arc	Direct vision[a] / TV
Foliage background			
80	6.0	7.4	1.2
85	6.7	9.0	1.3
90	7.8	11.3	1.4
93	8.9	13.9	1.5
Sandy background			
70	6.0	10.6	1.7
73	6.4	12.0	1.9
75	6.7	13.9	2.1

[a]TV magnification to equal direct-vision performance.

An experiment conducted in a cockpit under normal daylight with geometric symbols and vehicles indicated that a magnification by the TV system of 2.6 to 4.0 would be required to match direct-vision performance (Ref. 9). Visual acuity measurements made in Ref. 13 indicated that the minimum visual angle resolved[4] in TV viewing was 4 times larger than that resolved in direct viewing for high-contrast objects, but only 2 times larger for lower-contrast objects. In summary, experiments have shown a required magnification of 1.2 to 4.0 depending on performance level, target, background, and viewing conditions.

Confusions

The confusion matrices for the direct-view test and the TV tests have been given. To assess the relative difficulty in identifying each vehicle, the Spearman rank-difference correlation coefficient was

[4]Minimum angle resolved is taken to be the 49% correct level in Ref. 13.

computed between all rankings (Table 16). The coefficients indicate that the relative difficulty is variable from one viewing mode to another (TV to direct vision) and also varies with the type of background. The highest coefficient is within the directly viewed test, from one background to the other. In comparison, only one of the three coefficients within the TV test is high (lower right of Table 16).

This instability in the relative difficulty in identifying vehicles indicates that the prediction of difficulty and the applicability of the constant-ratio rule may be questionable for these types of tasks.

TABLE 16. The Spearman Rank-Difference Correlation Coefficient Between Vehicle Difficulty in all Experiments

	P_f	P_s	TV_f	TV_s
Photo, foliage (P_f)				
Photo, sandy (P_s)	0.93[a]			
TV, foliage (TV_f)	0.56	0.34		
TV, sandy (TV_s)	0.70[a]	0.72[a]	0.25	
TV, plain (TV_p)	0.23	0.30	0.26	0.80[a]

[a] p 0.05

SUMMARY

This report describes a series of four experiments on the visual identification of geometric symbols and military vehicles. The test images used were photographs of geometric symbols and vehicles. In the first three experiments, the photographs were viewed via a TV system. In the fourth experiment, one set of the photographs was viewed directly.

In the TV experiments, the size (angular subtense) of the image, and the number of scan lines making up the image were systematically varied. The results showed that symbol legibility could be estimated from symbol size and scan lines per symbol by a constant-product rule: SA is constant for a constant level of performance, where S = lines per symbol and A = angular subtense of image, minutes of arc. Vehicle identification could not be so easily quantified, however. The vehicles had to be made up of 10 scan lines and subtend over 14 minutes of arc to ensure a high probability of correct identification.

The backgrounds against which the vehicles were photographed had a significant effect upon ease of identification. Targets subtending 6 minutes of arc were correctly identified in 55% of the trials against a sandy background and in 75% of the trials against a foliage background. For targets subtending 10 minutes of arc, the scores were 75 and 95% for sandy and foliage backgrounds, respectively.

Performance in viewing the photographs directly was higher, but showed the same trends as the performance via TV. Identification was more difficult on the smaller targets, as well as on the sandy background.

The direct-view data were used to estimate the degradation resulting from interposing the TV system between the observer and the photograph. For equal-size targets made up of either 10 or 15 scan lines, TV performance was about 92% of direct-view performance on the foliage terrain and 76% on sandy terrain. This degradation was independent of target size.

The degradation resulting from use of the TV system could be compensated for by using magnification. For example, if the image on the TV monitor was 1.45 times larger than that seen by direct vision, the TV performance would be the same as direct-vision performance (90% correct) on the foliage terrain. This magnification factor varied with performance level and terrain type.

The relative difficulty of identifying individual vehicles was not the same from one viewing condition to the other. For example, on the foliage background, the small tank was the easiest vehicle to identify. On the sandy background it was the next to most difficult. These results indicate that generalizing relative identification difficulty may not be possible for these types of targets.

The results of these experiments have important implications to the mathematical modeling of the identification process. The experiments should be repeated with other targets and backgrounds to validate the results.

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Appendix A

IMAGERY FOR EXPERIMENT III

The luminance of gray-scale test charts being viewed by the camera was measured. The luminance of these same charts as displayed on the monitor was also measured. Figure 23 shows the curve plotted from these data. The luminance of parts of the target scenes were also measured directly from the photographs (Fig. 24 through 29). Although the images were too small to measure on the monitor, luminance can be calculated by using conversion factors derived from Fig. 23. These are, of course, further attenuated if the areas are smaller than several scan lines or less than three or four times the horizontal resolution of the system. Photographs of the monitor face displaying the largest targets are shown in Fig. 30 through 33.

Luminance measurements made directly on the terrain model can be compared to luminance measurements made on the photographs. Figure 34 is a plot of this tone reproduction for the sandy background. The reproduction is linear except at the light end of the luminance range, where luminances from 600 to 1,000 footlamberts on the model are shown as one luminance (approximately 33 footlamberts) in the photographs. This undesirable effect is thought to account for poorer performance on the sandy background.

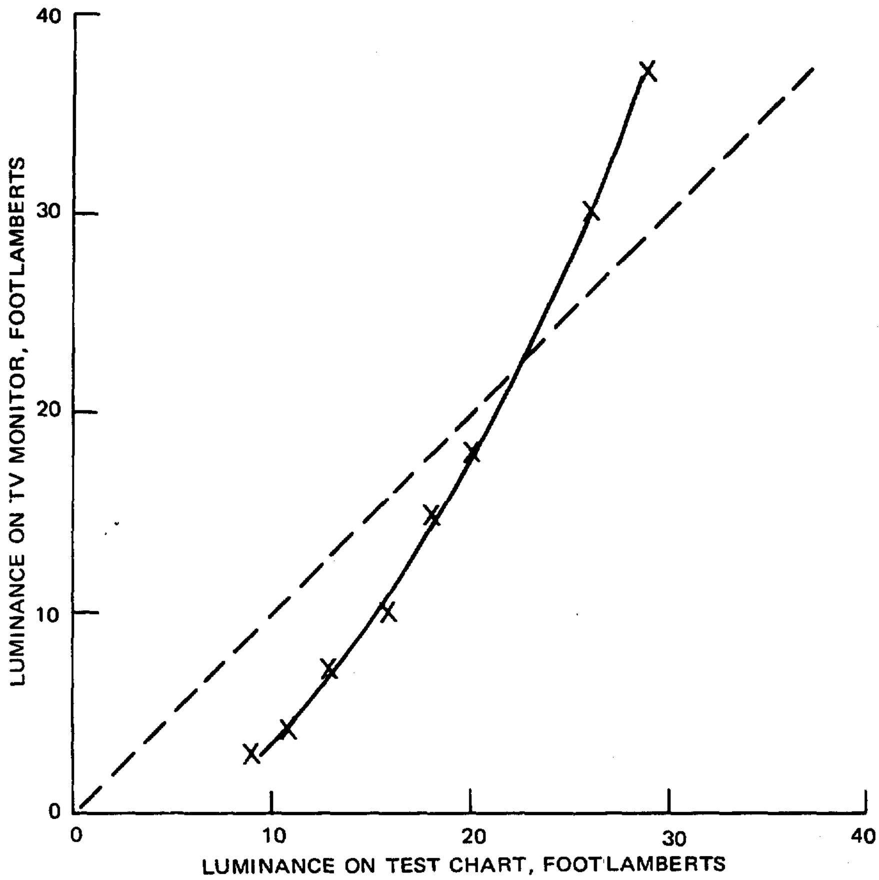

FIG. 23. Luminance of TV System. Dashed line shows 1:1 correspondence.

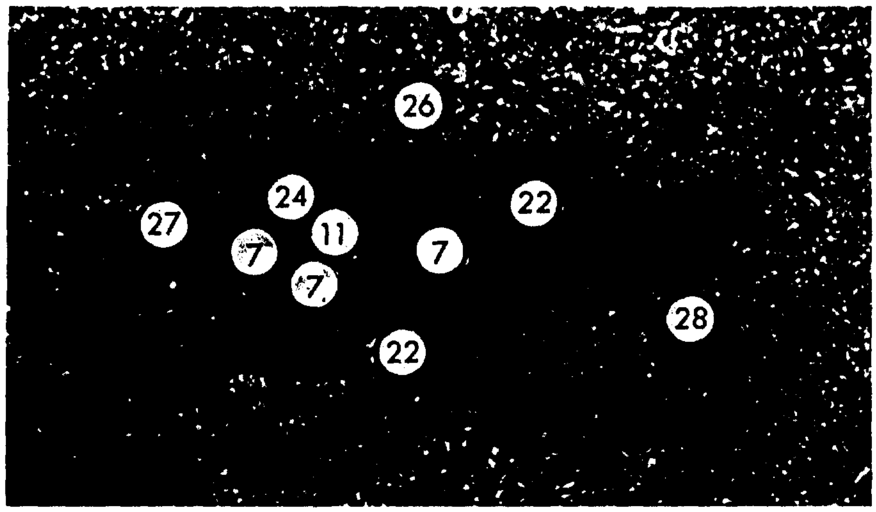

FIG. 24. Luminance Measurements on Photograph of Fuel Tanker. Numbers indicate luminance in footlamberts.

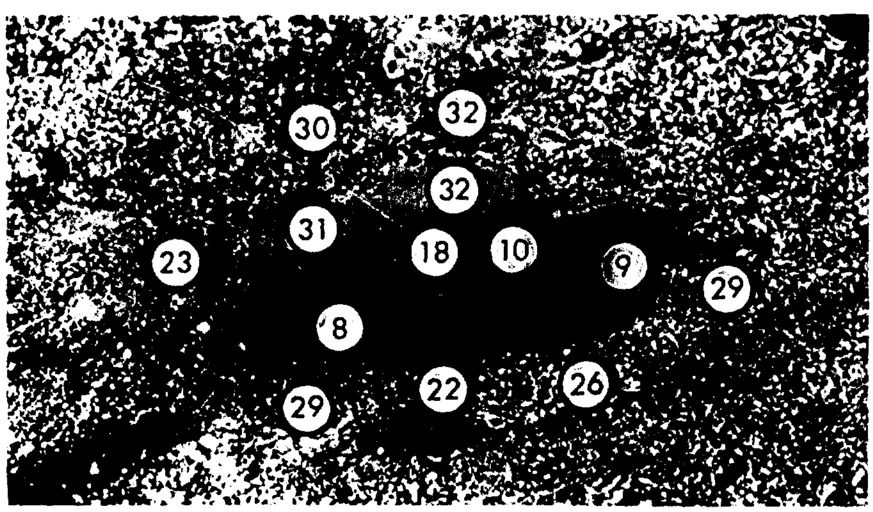

FIG. 25. Luminance Measurements on Photograph of Tank. Numbers indicate luminance in footlamberts.

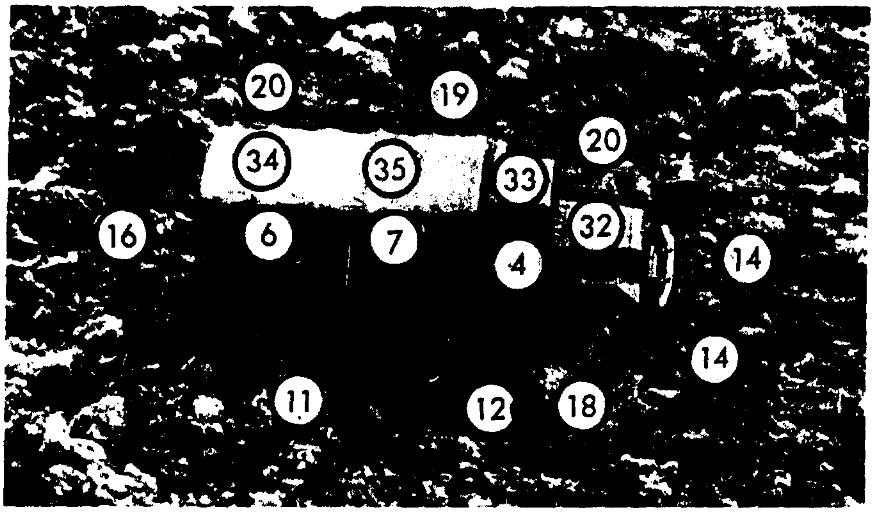

FIG. 26. Luminance Measurements on Photograph of Cargo Truck. Numbers indicate luminance in footlamberts.

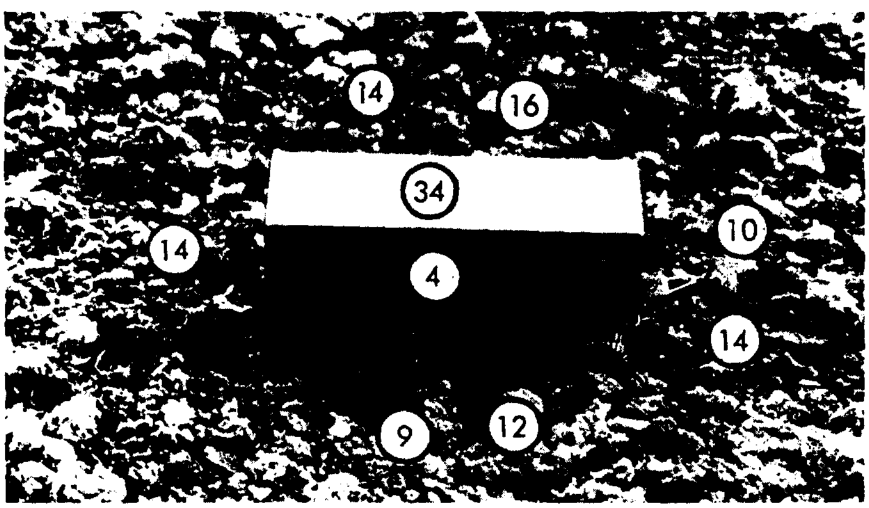

FIG. 27. Luminance Measurements on Photograph of Van. Numbers indicate luminance in footlamberts.

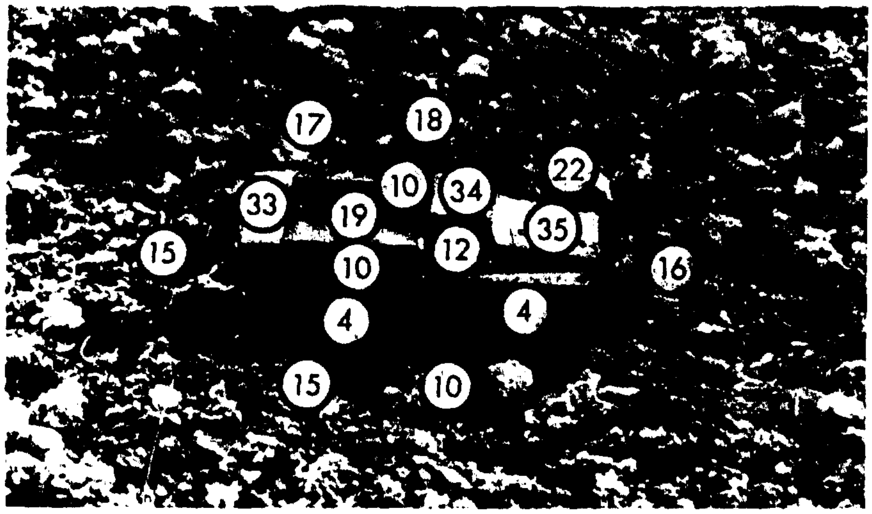

FIG. 28. Luminance Measurements on Photograph of Armored Personnel Carrier. Numbers indicate luminance in footlamberts.

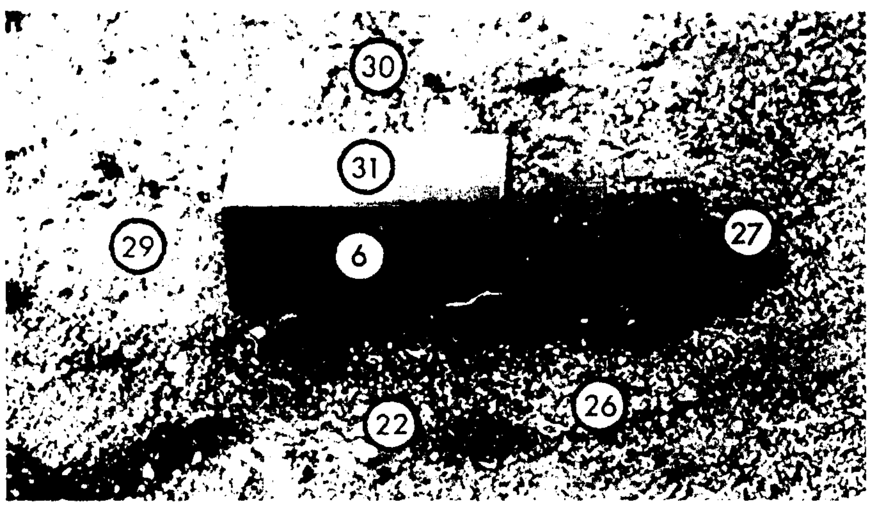

FIG. 29. Luminance Measurements on Photograph of Truck and Van. Numbers indicate luminance in footlamberts.

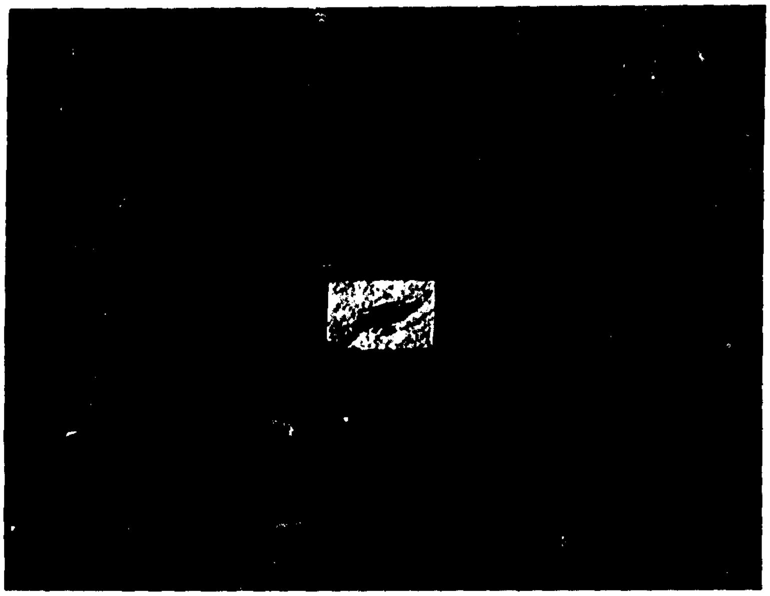

FIG. 30. Photograph of TV Monitor Displaying Fuel Tank Target.

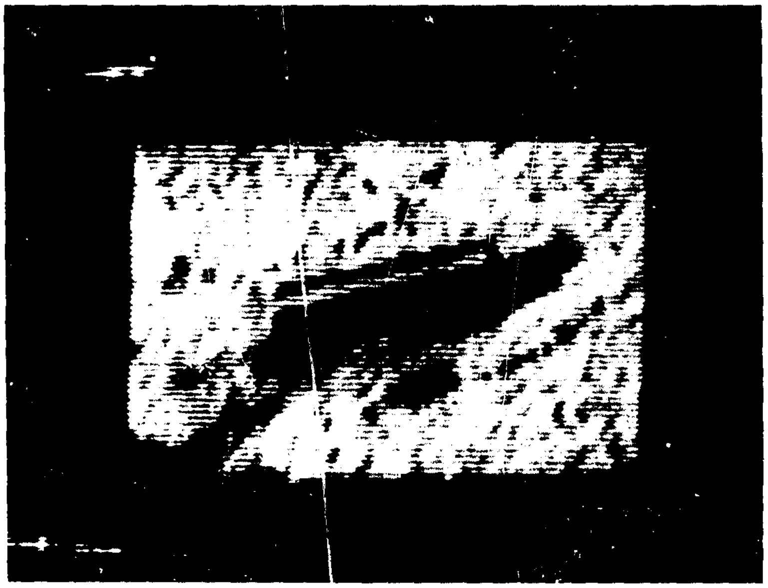

FIG. 31. Enlargement of Central Part of Fig. 30.

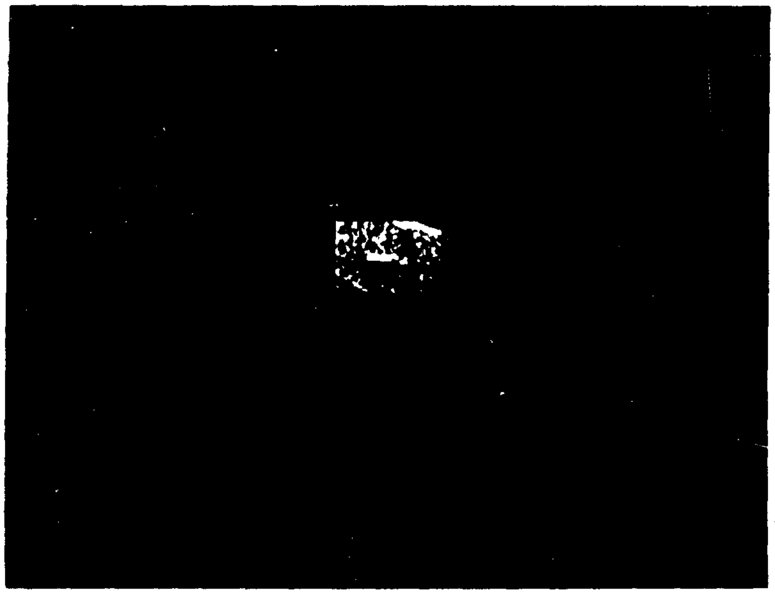

FIG. 32. Photograph of TV Monitor Displaying Truck Target.

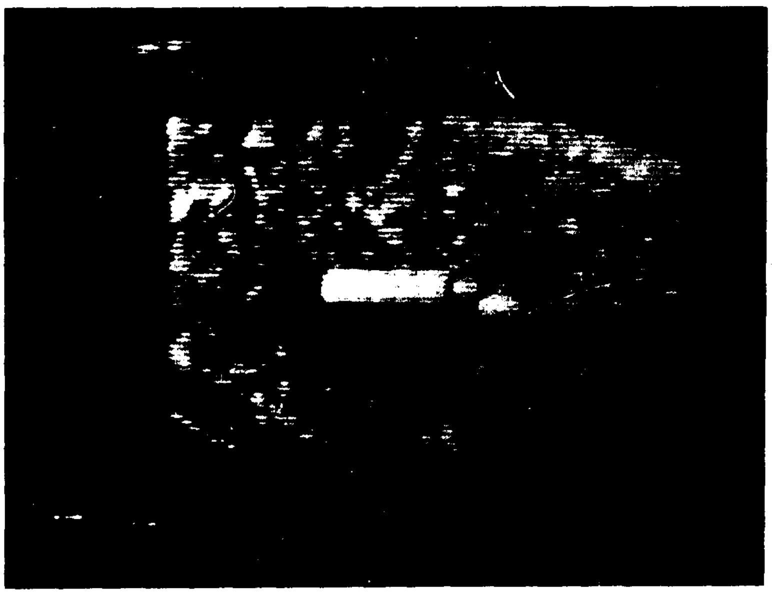

FIG. 33. Enlargement of Central Part of Fig. 32.

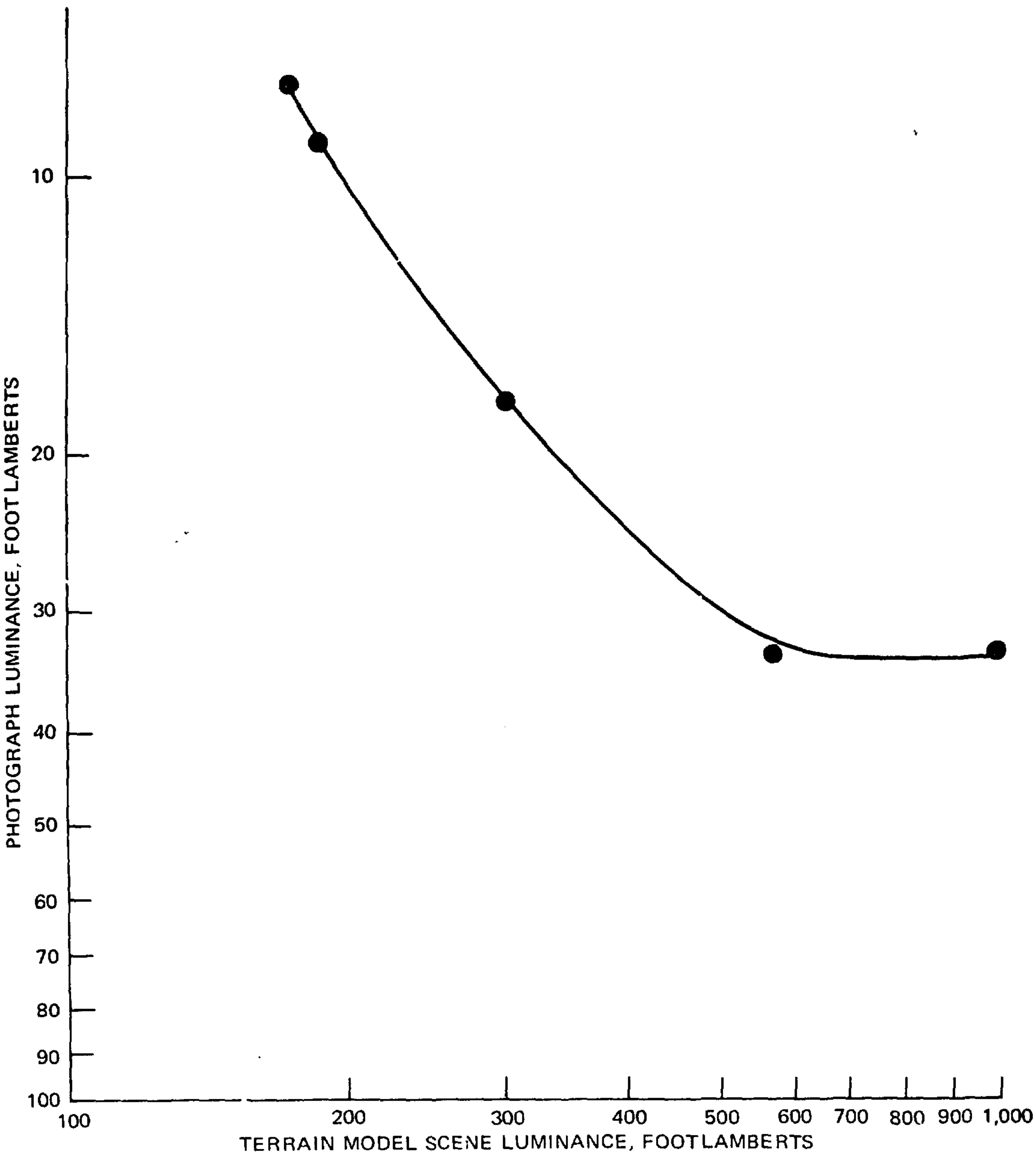

FIG. 34. Tone Reproduction in Photographs of a Terrain Model With a Sandy Background.

Appendix B

PERFORMANCE DATA ON EXPERIMENTS

TABLE 17. Experiment I Performance Data for Each Subject for Each Condition

	Number of correct responses (16 maximum)										
Lines per image	4.8			6.3			7.8			15.5	
Image subtense, minutes of arc	4.4	6.0	10.2	4.4	6.0	10.2	4.4	6.0	10.2	6.0	10.2
Subject											
1	12	9	13	11	16	13	12	15	16	16	16
2	12	11	10	14	14	15	11	15	16	15	16
3	11	13	10	13	15	15	11	15	16	15	16
4	11	10	9	14	15	12	14	15	16	16	16
5	11	14	12	13	15	16	11	15	16	16	16
6	9	11	5	9	13	12	11	13	15	15	16
7	7	11	11	12	14	12	11	13	15	14	16
8	12	15	14	12	14	16	9	15	16	16	16
Mean	10.6	11.8	10.5	12.3	14.5	14.0	11.3	14.5	15.8	15.4	16.0
% correct	66	73	66	77	91	88	70	91	98	96	100

TABLE 18. Experiment II Performance Data for Each Subject for Each Condition

	Number of correct responses (9 maximum)								
Number of active scan lines	3.7			7.0			10.8		
Image subtense, minutes of arc	4.4	6.0	10.2	4.4	6.0	10.2	4.4	6.0	10.2
Subject									
1	4	9	7	9	7	9	7	9	9
2	4	6	9	9	8	8	9	9	9
3	7	4	9	5	7	9	6	6	9
4	6	5	7	7	7	9	7	9	9
5	6	7	9	7	8	8	9	8	9
6	4	7	7	7	9	9	7	9	9
7	5	7	8	7	7	8	7	7	9
8	5	7	8	8	9	9	7	8	9
9	8	8	9	9	9	9	9	9	9
Mean	5.4	6.7	8.1	7.6	7.9	8.7	7.6	8.2	9.0
% correct	60	74	90	84	88	96	84	91	100

TABLE 19. Experiment III Performance Data for Each Subject for Each Condition (with Sandy Background)

	Number of correct responses (9 maximum)								
Number of active scan lines	6			10			15		
Image subtense, minutes of arc	6	10	14	6	10	14	6	10	14
Subject									
1	4	5	5	3	7	8	8	7	7
2	2	3	2	5	8	6	3	7	7
3	3	5	7	7	6	7	5	7	7
4	1	1	2	3	4	6	4	4	6
5	4	5	4	6	7	6	3	6	7
6	2	4	6	7	8	6	5	7	7
7	4	4	6	4	5	7	5	6	7
8	3	6	2	3	4	6	6	6	8
9	4	3	3	4	6	7	4	6	7
Mean	3.0	4.0	4.1	4.7	6.1	6.6	4.8	6.2	7.0
% correct	33	44	46	52	68	73	53	69	78

TABLE 20. Experiment III Performance Data for Each Subject for Each Condition (with Foliage Background)

	Number of correct responses (9 maximum)								
Number of active scan lines	6			10			15		
Image subtense, minutes of arc	6	10	14	6	10	14	6	10	14
Subject									
1	5	5	5	6	8	8	6	9	9
2	4	7	7	9	8	9	7	8	9
3	4	6	6	6	8	9	7	7	9
4	6	4	6	7	8	8	7	8	6
5	8	7	6	8	7	7	7	7	8
6	9	5	6	6	7	8	4	8	9
7	7	7	8	6	9	8	8	8	9
8	3	5	6	7	8	8	3	9	8
9	6	7	7	9	7	6	9	6	9
Mean	5.8	5.9	6.3	7.1	7.8	7.9	6.4	7.8	8.4
% correct	64	65	70	79	86	88	72	86	94

TABLE 21. Experiment IV Performance Data for Each Subject for Each Condition

	Number of correct responses (9 maximum)					
Image subtense, minutes of arc	6		10		14	
Background	Sandy	Foliage	Sandy	Foliage	Sandy	Foliage
Subject						
1	6	7	8	9	9	9
2	7	6	7	9	9	9
3	8	9	9	8	9	9
4	9	8	9	9	8	9
5	5	8	7	8	8	9
6	7	7	9	9	9	9
7	4	6	6	9	9	9
8	6	7	8	8	9	9
9	5	8	8	9	8	9
Mean	6.3	7.3	7.9	8.7	[illegible]	9.0
% correct	70	81	88	96	9	100

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13. ABSTRACT

Four experiments were conducted to measure identification of photographs of geometric symbols and military vehicles both on TV and by direct vision. The number of TV scan lines per image and image angular subtense were systematically varied. The background against which the vehicles were photographed was also varied.

The mean performance of symbol legibility on TV followed a constant-product rule: the symbol size multiplied by the number of scan lines per symbol was constant for a constant level of performance within a specified range of the variables.

The vehicle image required at least 10 scan lines per vehicle and an angular subtense of over 14 minutes of arc to ensure a high probability of identification. Vehicle identification performance also varied as a function of the type of background.

Direct-vision performance was used to estimate the degradation resulting by interposing the TV system between the observer and the photographs. The TV degradation did not vary with image size, but was a function of lines per vehicle and background type.

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
TV Image Identification Symbol Identification Vehicle Identification TV Imagery						

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