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Final Report

VISUAL DETECTION AND RECOGNITION OF TARGETS OF NON-UNIFORM LUMINANCE VIEWED AGAINST UNIFORM BACKGROUNDS

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PREFACE

This investigation, conducted in the Vision Research Laboratories of The University of Michigan, represents a part of the effort supported by BuAer, U.S. Navy, aimed at the discovery of basic principles determining detection and identification distances for military targets located on the ground as viewed from vantage points in the air. Many of the large number of relevant variables involved in such detection and identification have previously been investigated under laboratory conditions which necessitated impoverishment of certain aspects of the task to facilitate experimentation. In general, studies have previously involved targets and backgrounds of uniform luminance. It is quite probable that these earlier studies have left out important factors which are essential in predicting accurately the visibility of most military targets.

The present study has used targets composed of black and white elements which have specified degrees of internal organization of the units of luminance non-uniformity (microstructure). Most practical targets will have non-uniform luminance patterns, which resemble the targets studied in a general way. This research illustrates an approach to the problems of detection and identification of complex forms which may produce more valid data for these problems than previous approaches. It suggests a method for specifying one aspect of target luminance non-uniformity and, in so doing, aids in predicting the detectability and recognizability of military targets.

ABSTRACT

Targets with three degrees of dependency between adjacent black and white elements of luminance non-uniformity microstructure were presented against black and gray backgrounds of uniform luminance, in two experiments.

For four observers, detection thresholds were progressively higher for targets having greater degrees of organization of the elements of the luminance microstructure when the targets were presented both against black and against gray backgrounds of uniform luminance.

No general statement is possible concerning the relation between the pattern of luminance non-uniformity and recognition thresholds, as this depended both on the particular observer and on whether the background was black or gray.

I. INTRODUCTION

Most practical aerial visual reconnaissance missions involve detection and identification of complex targets of non-uniform luminance viewed against backgrounds of non-uniform luminance. Often the elements in the non-uniform luminance pattern of the target and background are both sufficiently large and contrasting to permit their detection, but the target is not detected or recognized. Very little systematic study has been directed at specifying the characteristics of the luminance patterns of practical targets and backgrounds for application to this problem. The purpose of the present study was to discover an informational measure for specifying patterns of non-uniform luminance so that the visibility of non-uniform targets can be predicted when viewed against backgrounds of uniform luminance.

Although the luminance microstructure within the present targets is rather gross compared to the size of detail which the eye can resolve, the present targets may perhaps be thought of as models for illustrating neural information-analysis mechanisms for the detection and recognition of complex targets. The general thesis of this research is that this type of form discrimination is affected by the correlation over space of loci of heightened or decreased cortical excitation produced by the target, as well as by the difference between the average amount of excitation within the target compared to the average amount of excitation over an equivalent area of the background.

The writer has previously proposed a neural perceptual scan across the visual field when linear binary patterns are assimilated.[1] This process implies a spatial-correlation mechanism analyzing excitation from point to point across the cortical representation of the visual field. Such an analysis or correlation of excitations over space in visual acuity and detection tasks was first suggested to the author by Blackwell some years ago.[2]

Attneave[3] has suggested that a spatial-correlation mechanism is important in form discrimination. Conceiving a target and background as a matrix of cells of different brightnesses or colors, he was able to specify the information contained in the target form. This informational measure was directly related to the likelihood that observers would perceive the form of the target.

Detection thresholds for uniform targets of various forms viewed against backgrounds of uniform luminance were determined by Kristofferson.[4] He discovered that certain targets with a large dimensionality (i.e., length-width ratio) such as long, thin rectangles, are more easily detected than would be predicted from the contribution of each part of the target to a point of maximum excitation on the cortex. In other words, the correlation over space of excitations, as well as the maximum amount of excitation, contributes to target detection. Kristofferson called this phenomenon "linear facilitation." An analygous situation with respect to visual acuity is the greater resolvability of a line when it is lengthened without increasing its width.

Work by Swets[5] and Kincaid[6] has emphasized the importance of a decision-making mechanism for detection of targets. If the distribution of quantities of neural excitation generated by the target differs by a criterion amount from that formed by the background, then the presence of the target is detected.

In an earlier experiment, Smith[7] compared detection thresholds for square-matrix targets composed of black and white cells having three systems of internal organization. In one target, in which there was no ordering of the black and white cells, the individual cells were made randomly either black or white. Another target was completely organized so that it looked like a checkerboard. The third class of target was composed of alternate black and white bars. Smith found no significant differences in thresholds for the three classes of target in his first experiment. However, more recent experiments by Smith, using a wider range of experimental conditions, do indicate differences in basic detection thresholds for the three classes of target under some conditions.

The writer discovered that, whenever target matrices composed of black and white cells with three degrees of internal organization among the cells within the targets were presented against background matrices having the same three degrees of internal organization, larger differences between degree of organization of the target and that of the background produced greater likelihood of target detection.[8] When the results for all three backgrounds were combined, the target luminance pattern most easily detected was the one with complete internal organization, and the target pattern least easily detected was the one least organized internally. One cannot be sure whether the best prediction in the present experiment, in which backgrounds are of uniform luminance, can be derived from the previous results in which the background luminance patterns were unspecified or from the previous results in which the background luminance patterns were completely ordered. However, in the previous study with completely organized backgrouns luminance patterns, the best detection and recognition occurred for least organized targets. Therefore, both frames of reference would predict lowest detection thresholds for the targets with the least organization of the internal luminance pattern microstructure.

Thus previous research suggests that there is an analysis across space in the visual field of the information presented by the target and background, and that the detection and recognition of the target under some conditions is influenced by a complex decision process based on the available information. This method of thinking about the problem will be found fruitful in connection with the present study.

II. STATEMENT OF THE PROBLEM

The present problem is to determine whether there is an effect on target detection and recognition of the dependencies existing among the units of luminance microstructure within the targets when the targets are composed of black a and of white cells presented against uniform black or gray backgrounds and when the thresholds are obtained by an ascending method of limits.

The following hypotheses are tested in this study: a) detection thresholds are progressively higher for targets with greater degrees of internal dependency, and b) the "photocognitive interval" between detection and recognition thresholds decreases with greater internal dependencies of luminance microstructure within the targets. That is, for detection of a target the factor of primary concern is the contrast gradient of excitation at given points or cortex, which will tend to be greater for targets with less organized units of microstructure (given a constant unit size) because the bright areas will not be as evenly distributed over the target area. However, recognition thresholds will be higher for targets which lack internal organization of microstructure because information about the target form (i.e., contour) is lost. In some cases recognition thresholds are highest for targets least internally organized, and lowest for targets with the greatest amount of internal organization. Targets with no internal dependencies are often unrecognizable.

The above hypotheses were supported by significant results obtained in a preliminary study in which the author acted as the observer.

III. APPARATUS AND PROCEDURES

The experimental targets of non-uniform luminance were constructed on a 30-by-30 cell matrix in which the various cells were blackened or left white according to prescribed arbitrary rules. Whether a given cell was white or black was determined completely by the luminance of the cell immediately preceding it in a specified sequence. The sequence began at the lower-left cell in the matrix and proceeded upward. After the 30 cells in the first column were filled, the next cell to be determined was the one immediately adjacent on the right to the 30th cell. The cells vertically down the matrix were then determined. Then the bottom cell in the third column was determined, etc. The first cell in the sequence was made randomly either white or black. The three degrees of internal dependency chosen for this experimentation were 50, 75, and 100%. These values represent, respectively, no dependence, intermediate dependence, and complete dependence. In the 100%, or complete dependency, case the subsequent cell was always different in luminance from the preceding cell. The completed field thus looked like a black and white checkerboard. For the 75% dependence field, the subsequent cell was different in luminance from the preceding cell 75% of the time and the same 25% of the time. This was done by designating 75 cards of a

100-card deck as "different" and 25 cards as "same," and drawing a card to determine each cell. For filling in the 50%, or no dependency, surface 50 of the cards were designated "same" and 50 as "different." This field was, therefore, essentially "random."

The 75% field is different from the 50% and 100% fields since the pattern of non-uniform luminance is not isotropic relative to the horizontal and vertical dimensions. The above construction technique produces horizontal bands when the black and white cells are in "phase."

Eight target forms were chosen for this study. These forms represent geometric forms (rectangle, triangle, ellipse, cross), realistic targets (airplane, truck, tank), and a "random" form (morph). A sample of each element dependency for each form is shown in Fig. 1 against a gray background. Each single black or white cell in the targets subtended 1.6 minutes. The forms were equated in size according to area, maximum dimension, and perimeter, in that order. The area indicates the number of cells covered by the form. The maximum dimension indicates the number of cells in a horizontal or vertical straight line that can be included within the form at its greatest extent. The perimeter is measured by the number of sides of cells within the target that are adjacent to the background.

The technique for constructing the test slides was to cut out patches of each form from copies of each of the three non-uniformity patterns and photograph them superimposed at the center of a black or a gray background. Each frame of the 35-mm film was then mounted in 2-by-2-in. slides. In all, 40 slides were made of the targets against a black background and 40 were made with the targets against gray backgrounds about midway in luminance between the black and the white areas. Each group of 40 slides contained two samples of each of the 50% and 75% surfaces and one sample of the 100% surface for each of eight forms.

Since relative results for the three target dependencies were of primary concern, a method of limits was used as the psychophysical technique. This was achieved by having the observer turn a variac connected with the light source in the exposure apparatus. The variac-scale setting at threshold was recorded. Later the corresponding luminance levels of the clear (white) cells in the targets were calculated through calibration of the variac scale in foot-lamberts.

For each slide both detection and recognition thresholds were determined. In each experimental session for each observer, thresholds were obtained twice for each slide, except for the checker board targets which required four observations. To obtain a threshold, the observer slowly turned the variac to increase the luminance of the light source until he could just see that a target was present. He then read the variac-scale setting, which was recorded by the experimenter. The observer was not permitted to turn the luminance back to a lower level while obtaining a threshold. If he suddenly perceived the target at what seemed to be a suprathreshold luminance level, he did not turn the variac down, but made the threshold reading with the variac dial at that setting. Then the target luminance was increased still further until the observer felt that he could recognize the form of the target (i.e., which of the eight forms was presented). A threshold reading was taken at that point. The target luminance was then further increased until the maximum possible luminance was reached. If at any time the observer felt that his earlier recognition response was in error, he made another response and reported the scale reading. The last correct response was taken as the recognition threshold. The difference in luminance between the luminance at detection and recognition thresholds was calculated and identified as the "photocognitive interval."

Two groups of observers were used in this study. One group consisted of two graduate students, experienced in obtaining visual thresholds; the second was composed of two undergraduate students, relatively inexperienced in visual tasks of this kind. The experienced observers, S.W.S. and H.L., completed the experiment with the targets against the black background before observing the targets against the gray background. The inexperienced observers, D.E. and C.S., were presented the targets against the gray background before they were shown the targets against the black background.

IV. RESULTS

Because the thresholds for the different forms were not equal, allowances for these differences had to be made in assessing possible effects of the three microstructure dependencies used on detection and recognition thresholds. Also, in some instances recognition thresholds were not reached at the highest luminance levels, so that the recognition thresholds and photocognitive intervals were indeterminately high. Therefore, the thresholds for the three dependencies were tallied as above- or below-median threshold reached for that target form for that day of experimentation. Subsequently, chi-square tests of significance were performed on these results combined for all forms and both experimental days. These chi-square values and probability levels associated with the results are given in Table I.

In Fig. 2 the numbers of detection thresholds above the median threshold are plotted for the targets against black backgrounds. The four lines represent the four observers. For the 50% targets the thresholds were generally below the median for each observer. The thresholds were generally above the median for the 100% targets for each observer. Although these differences were more marked for the inexperienced observers (W.D. and C.S.), they were significant for each of the four observing. These differences are in the direction predicted by the hypothesis tested in this study.

The number of recognition thresholds above the median for targets against a black background, shown in Fig. 3, indicate no significant differences among the three tart dependencies for three of the observers. However, for Observer H.L. there are significant differences which are opposite in direction to the detection thresholds. That is, for this experienced observer the recognition thresholds for 50% targets are generally above the median and those for the 100% targets are usually below the median. This result is also in the direction predicted by the hypothesis.

In Fig. 4 the photocognitive intervals for the targets presented against a black background are seen to be generally largest for 50% targets and smallest for 100% targets. This result is significant for one experienced observer (H.L.) and one inexperienced observer (C.S.). Again this result corresponded to the hypothesis.

In Fig. 5 the differences for detection of these targets against gray backgrounds are more extreme than for the differences when black backgrounds were used. Again the 50% targets yield thresholds generally below the median and the 100% targets produce thresholds above the median. These differences are again significant for each observer and conform to the hypothesis.

Figure 6 is an illustration for targets against gray backgrounds of the numbers of recognition thresholds that are above the median threshold. For the two observers for whom these differences are significant (W.D. and S.W.S.), there is generally an increase in the number of thresholds above the median as the target dependency increases from 50% to 100%. This is generally opposite in trend to the recognition thresholds with black backgrounds.

The photocognitive intervals of the targets against gray backgrounds, shown in Fig. 7, are significantly different for the three target dependencies for Observers W.D. and C.S. These two observers usually obtained smallest photocognitive intervals for 100% targets. This conforms both to the results with black background and to the results predicted by hypothesis.

V. DISCUSSION

The threshold for discrimination of the targets employed in these experiments is influenced in many cases by the internal organization of luminance microstructure within the target. However, the microstructure of the target that produces greater target discriminability depends upon the requirements of the visual task. For the method-of-limits detection thresholds obtained in both of these experiments, the progressively less organized target pattern produced progressively lower thresholds. The correct interpretation of this result is not necessarily that the lack of organization of the microstructure _per se_ produced the lower thresholds. Perhaps the lack of organization which produced larger irregular clumps of the black and the white cells, resulted in greater differentials in the peaks and trought of excitations representing these targets on the cerebral cortex.

New research might properly investigate whether the differential effect of microstructure dependencies operates directly or whether the effect depends upon the differential clumping of cells as a result of different dependencies. That is, one would normally expect larger clumps of the same luminance to produce lower detection thresholds. This point is currently being investigated by S. W. Smith.[7]

The relative lack of uniformity of results among observers for the phogocognitive intervals and recognition thresholds probably reflects the added importance of the target contour in those tasks in addition to the target luminance pattern. Since the target contour is more completely defined with increasing organization. of the microstructure, and since the contour is generally conceded to be the primary determinant of the recognition of form, it was predicted that greater organization of the mecrostructure would produce lower recognition thresholds and smaller photocognitive intervals. This result actually occurred for some observers under certain conditions. The differences in results among observers and the lack of differences among dependencies for individual observers may indicate different weightings of the two factors for individual observers under particular experimental conditions.

It may not be obvious why the target luminance pattern, apart from its edge against the background, is important in target recognition. First, a surface must be detected before an edge can be discriminated. Second, in recognition tasks of the sort used in this study in which only eight forms with equal area at known location are used, the perception of a surface at a given point provides evidence concerning the target shape. For example, compare in Fig. 1 the rectangle and airplane. If these two targets were superimposed, there would be a large surface area in common, but there would still be parts of the wingtips of the airplane which would not overlap the rectangle, and the corners of the rectangle would not overlap the airplane. Therefore, perception of any of these nonoverlapping surfaces would preclude that the other target was being presented. Thus, a factor such as lack of internal organization or average clump size of cells of the same luminance, which facilitates detection, might also aid in recognition.

Observers may differ in the relative use made of the luminance pattern and contour cues. Also, specific experimental conditions, such as the particular sample of the luminance pattern used, may force a change in the relative importance of the two cues. For example, the fact that the relation between microstructure dependency in the target and threshold is more marked for targets against the gray background may explain why the recognition thresholds increase for microstructure dependencies with gray backgrounds but the recognition thresholds are lower with increasing microstructure dependencies in the presnece of black backgrounds.

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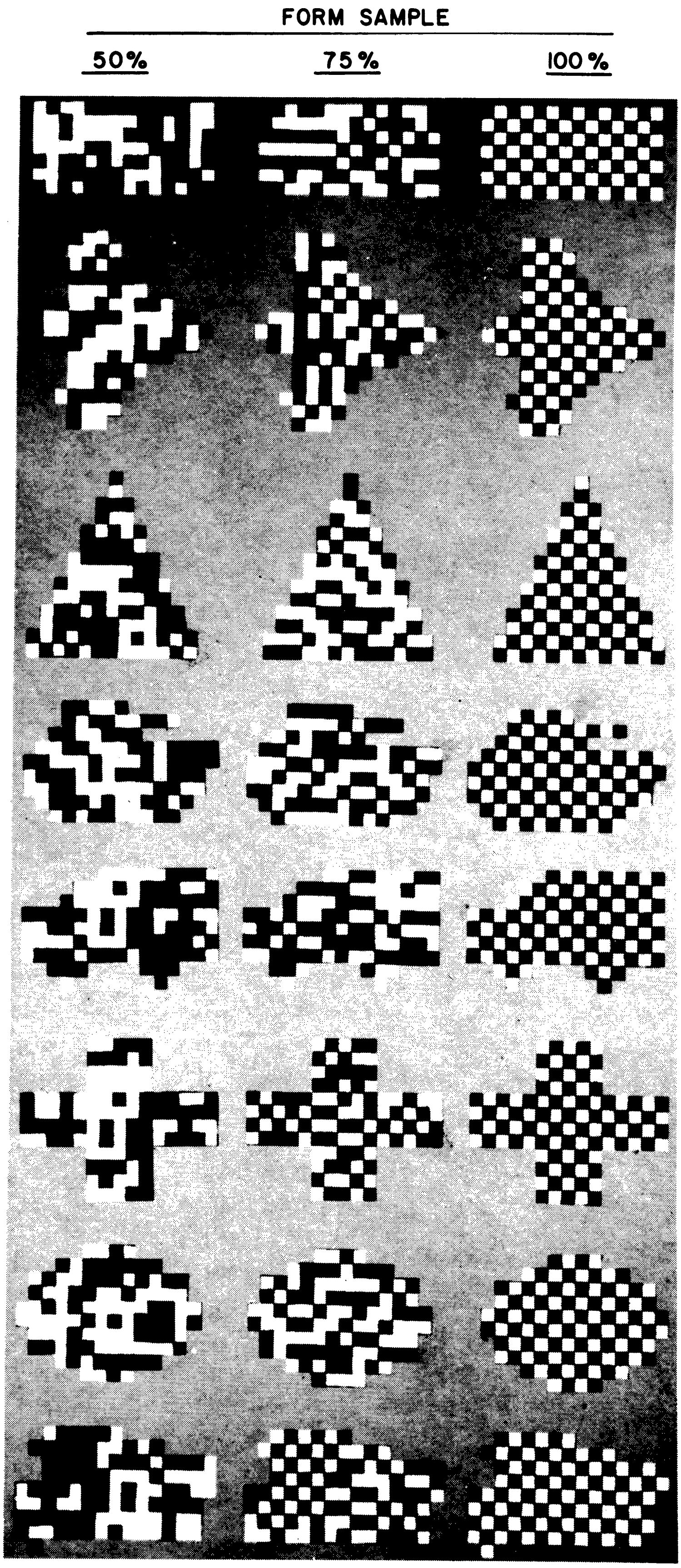
TABLE I

CHI-SQUARE VALUES ASSOCIATED WITH THE RELATION BETWEEN TARGET LUMINANCE PATTERNS AND THE NUMBER OF THRESHOLDS ABOVE AND BELOW THE MEDIAN THRESHOLD FOR EACH OBSERVER AND FOR EACH BACKGROUND

(Significance levels are given in parentheses)

Threshold	Background	Observers			
		W.D.	S.W.S.	H.L.	C.S.
Detection	Black	22.74 (.001)	14.24 (.001)	8.30 (.02)	27.74 (.001)
	Gray	54.24 (.001)	52.74 (.001)	42.40 (.001)	47.70 (.001)
P-C Interval	Black	9.52 (.01)	4.05	12.30 (.01)	2.31
	Gray	8.06 (.02)	0.00	2.27	24.14 (.001)
Recognition	Black	1.56	0.00	14.57 (.001)	0.24
	Gray	6.05 (.05)	6.74 (.05)	0.40	3.24



NAME	AREA	MAX. DIM.	PERI-METER
Rect.	98	14	42
Airp.	100	14	62
Tria.	98	14	54
Tank	100	15	54
Truk.	100	15	52
Cros.	100	15	54
Elip.	100	14	48
Morp.	100	15	50

Fig. 1. Illustration of the eight target forms against a gray background. A sample of each luminance pattern is shown for each form.

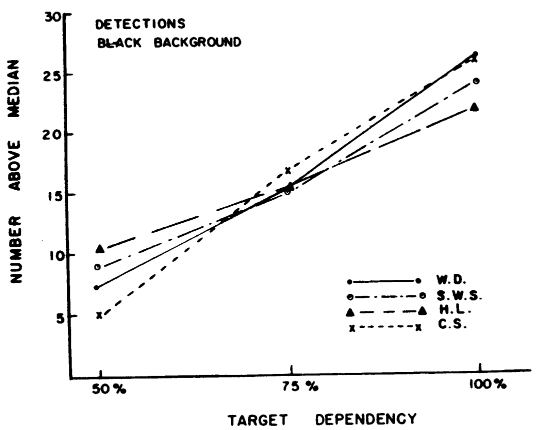


Fig. 2. Number of detections above the median for targets against the black background.

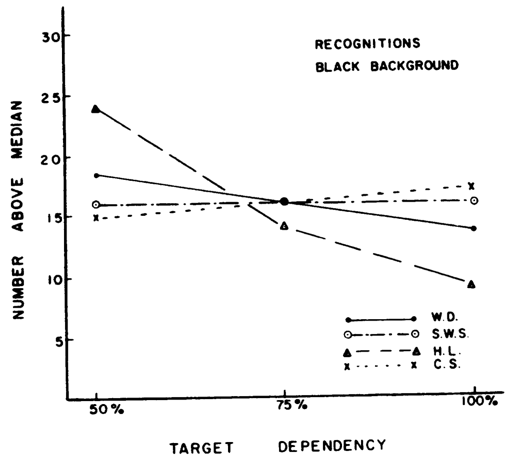


Fig. 3. Number of recognitions above the median for targets against the black background.

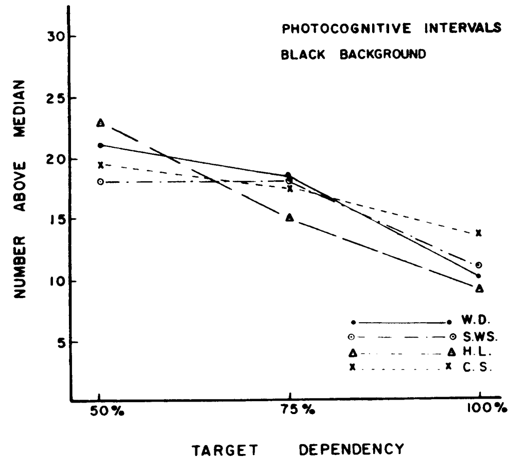


Fig. 4. Number of photocognitive intervals above the median for targets against the black blackground.

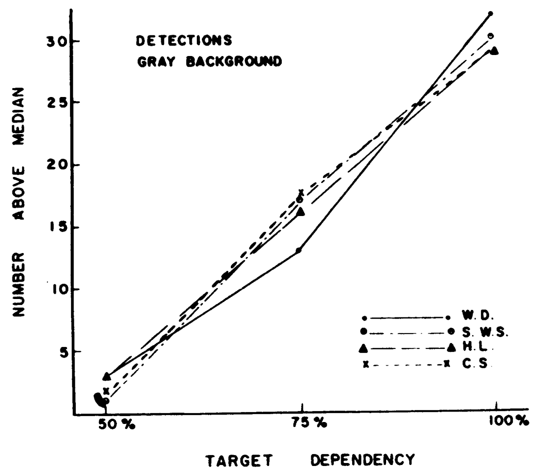


Fig 5. Number of detections above the median for targets against the gray background.

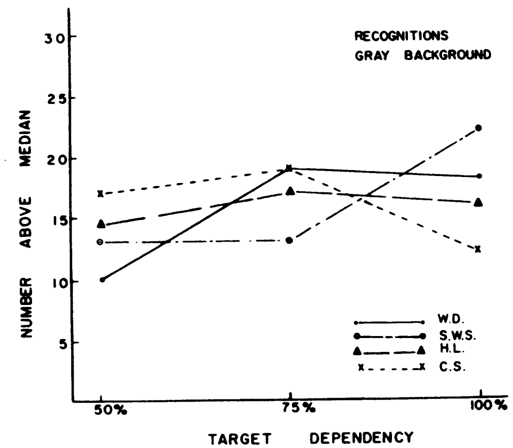


Fig. 6. Number of recognitions above the median for targets against the gray background.

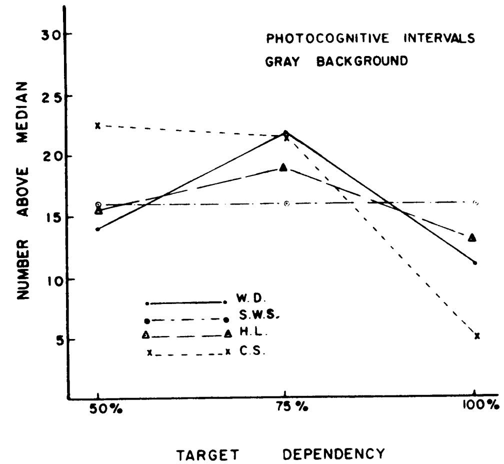


Fig. 7. Number of photocognitive intervals above the median for targets against the gray background.