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Final Report

EFFECTS OF DEPENDENCIES AMONG ELEMENTS OF LUMINANCE MICROSTRUCTURE UPON VISUAL FORM DISCRIMINATION

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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 the detection and identification distances of military targets seen on the ground 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 target-background relationship to facilitate experimentation. It is quite probable, however, that these earlier studies have left out important factors which are essential in predicting accurately the visibility of ground targets seen from the air.

In relatively few studies of detection and identification of visual forms have investigators employed targets with nonuniform luminance patterns, viewed against nonuniform backgrounds. Naturally, most practical targets will have such nonuniform luminance patterns. The present study has used targets and backgrounds both of which have specified degrees of internal organization of the black and white elements (the luminance microstructure) of which they are composed. This research illustrates an approach to the problems of detection and identification of complex targets viewed against complex backgrounds which may produce more valid data for those problems than previous approaches. It suggests a method for specifying one characteristic on nonuniform targets and backgrounds which influences the detectability and identifiability of these targets.

ABSTRACT

Targets and backgrounds were constructed using three degrees of dependency between the adjacent black and white elements (units of luminance microstructure) of which they were composed. These dependencies were 50, 75, and 100%. Generally, frequency of detection and recognition of the target forms was greatest when the difference between the microstructure dependencies of target and background was greatest, and least when this difference was smallest.

When the background dependencies were unspecified, less dependency within the target produced a lower probability of target detection. When the target dependencies were unspecified, 75% dependency in the background produced fewest target detections and 100% dependency in the background produced most target detections.

For target recognition, when either the target or background dependencies were unspecified best recognition occurred when the target or the background had greatest internal dependency, and least accurate recognition occurred when the target or background contained intermediate dependency.

I. INTRODUCTION

Most practical aerial visual reconnaissance missions involve detection and identification of complex targets of nonuniform luminance viewed against backgrounds of nonuniform luminance. Even when the luminance nonuniformities (units of luminance microstructure) of the target and background are both sufficiently large and contrasting to permit their detection, the complete target may still not be detected or recognized because its luminance pattern may not be sufficiently different from that of the background. Very little systematic study has been directed at the problem of specifying the luminance patterns of targets and backgrounds for application to this problem. The purpose of the present study was to discover an informational measure for specifying luminance nonuniformities so that the visibility of targets of a given luminance pattern can be predicted when viewed against backgrounds with specifiable luminance patterns.

The writer has previously proposed a neural perceptual scan across the visual field to apply to the assimilation of linear binary patterns.[1,2] This idea is apparently quite similar to the "post-exposure process" proposed for tachistoscopic perception of letter targets by Heron[3] and the "auto-correlation mechanism" suggested by Blackwell.[4] These processes imply a spatial correlation mechanism analyzing excitation from point to point across the cortical representation of the visual fields.

Attneave[5] has suggested that a spatial auto-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 targets of various forms presented against backgrounds of uniform luminance were determined by Kristofferson.[6] 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 auto-correlation over space of excitation, as well as the maximum amount of excitation, contributes to target detection. Kristofferson called this phenomenon "linear facilitation." An analogous situation with respect to visual acuity is the greater resoluability of a line when it is lengthened, without increasing its width.

Work by Swets[7] and Kincaid[8] has emphasized the importance of a decision-making mechanism for detection of targets. According to this concept, 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 target is detected.

In recent experiments, Green[9] demonstrated that whenever the probability for a cell in a matrix to be white or black is different within the target from that within the background by a criterion amount, then the target is detected.

For applications in photography, it has been demonstrated[10] that the size of the units of luminance microstructure (i.e., graininess) resolvable on film surfaces is related to the detection thresholds for targets photographed on that film.

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 is influenced by a complex decision process based on the available information.

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

II. STATEMENT OF THE PROBLEM

The present problem is to determine whether there is an effect on target detection and recognition attributable to the dependencies existing among the units of luminance microstructure within the targets and within the backgrounds. The hypothesis to be tested is that the greater the difference between the interdependencies of degrees of excitation at adjacent small areas within the target and the interdependencies of excitations at adjacent small areas within the background, the greater the likelihood of detection and recognition of the target. In other words, the greater the "dependency contrast," the more easily will targets be detected and identified.

III. APPARATUS AND PROCEDURES

The experimental luminance patterns (microstructures) 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 constructed was the one immediately adjacent on the right of the 30th cell. The cells vertically down the matrix were then determined. Then the bottom cell in the third column was determined, etc. Of course, 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 from the preceding cell. The completed field thus looked like a black and white checkerboard. For the 75% dependency 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."

To increase the size (i.e., number of cells) in the above fields, four copies of the same field were joined together to create a new field four times as large. To avoid repetitive patterns, each of the four samples was rotated to a different orientation with respect to horizontal before they were joined. To eliminate interruption of the fields at the center of the new field, a fifth copy of the field was placed over the center. Figure 1 is a composite photograph illustrating these experimental luminance patterns along with several others which had originally been constructed for study. The four field samples placed together are considered the background in this figure. The fifth field sample added at the center is considered the target. Of course, the three cases in which the target and background are composed of the same dependency illustrate the three backgrounds described above for use in the present study. The other pictures illustrate the cases in which a field with a given dependency is superimposed against a background composed of cells with a different microstructure dependency. No formal experiment was done using the target-background conditions shown in Fig. 1 because the targets, if of different dependency from that of the background, are obviously visible.

The 75% field is different from the 50% and 100% fields since the luminance microstructure is not isotropic relative to the horizontal and vertical dimensions. The above construction technique produced horizontal bands when the black and white cells were in "phase." This phasing is broken up with the different rotations of the four fields. Also, the juncture of the field samples is more disrupting than in the 50% and 100% fields in which the addition of the new field actually does not change the character of the microstructure dependencies across the junction.

The eight forms shown in Fig. 2 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 surface dependency for each form is shown in Fig. 2. The forms were equated in size according to area, maximum dimensions, 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. From the above dimensions, one can see that the target forms were small enough to fall well within the area of the central overlaid fifth copy of the test background. Therefore, presumably the disruption of the internal dependencies at the edge of this central field did not disturb the relation between target face and background luminance patterns at the interface.

The technique for constructing the test slides was to cut out patches of each form from copies of each of the three field luminance microstructures and photograph them superimposed at the center of one of the three test fields. The cells in the target and in the background always registered as closely as possible with one another. Each frame of the 35-mm film was then mounted in 2-by-2-in. slides. In all, 147 slides were made. Three of these slides consisted of the three backgrounds without targets. The remaining 144 slides were derived from all possible conditions using two samples of each of three target dependencies against each of three background dependencies for each of eight forms. In the case of checkerboard (i.e., 100% dependency) targets or backgrounds, care was taken that the two samples were displaced horizontally with respect to one another against the background by a space one cell broad. This was particularly important when both target and background were checkerboards. In one case, in which the checkerboard patterns of target and background registered with one another, the target virtually disappeared. But in the other case, the edge of the form was quite visible where the checkerboard patterns did not match.

The target slides were presented in an apparatus which permitted tachistoscopic or indefinitely long exposures. The transilluminated slides were viewed monocularly at a distance of 24 inches without magnification. Three exposure conditions were used: high contrast and indefinitely long exposure (H:L); high contrast and tachistoscopic exposure (H:T), and low contrast and tachistoscopic exposure (L:T). In the H:L condition, considering the dark portions of the target as background, the contrast was about 36.5 and the target was exposed for as long as the observer wanted. For the H:T condition the contrast was not changed, but the target was exposed only once for .14 second. In the L:T condition the contrast was reduced to about 2.3 and the exposure duration was again .14 second. These three conditions were employed on different days to provide evidence concerning whether changes in contrast, total luminance, or exposure duration would have a large or differential effect on the results, even though individual cells in the target or field were suprathreshold if viewed directly. The observers verified that they could resolve individual cells under each condition. Each matrix cell in the slide measured 1.6 minutes and the total field measured 1.6 degrees.

After each target exposure the observer indicated on a dittoed response sheet for that presentation either his best guess concerning which of the eight target forms had been presented, or if he had seen none at all. If he was certain of the accuracy of his response he marked an "X" in the appropriate space. If he was not certain, he marked an "O" in the space. Either an X or an O in a space under one of the eight forms indicated that the observer was certain that he could detect a target.

The observers were thoroughly familiarized with the apparatus, target forms, and backgrounds before experimentation. A practice session was held before the experiment proper began. So that the observers would be fully aware of the target forms to be presented, sample slides of each form with checkerboard dependencies presented against a uniformly black background were placed on the experimental table near the observer for handy reference at any time. He could, in fact, under the H:L conditions look back and forth from the sample slide to the test slide as often as he desired.

Each of the 147 slides could be presented to the observer in two orientations. These orientations were different for the different slides. The real targets (airplane, truck, tank) could be presented with the vehicle pointed toward the left or toward the right. The triangle could appear with apex pointed up or down. The rectangle, ellipse, cross, and morph could appear with the long axis horizontal or rotated 90° counterclockwise. The no-target fields were presented 'normal' or rotated 90° counterclockwise. In a 2-hr experimental session, each of the 147 slides was presented in haphazard order in each of the two aspects. The observer was permitted to rest after 147 observations.

Two observers were used in this study. One observer, D.E., was presented the conditions in the following daily sequence: H:T, H:L, and L:T. The other observer, W.D., observed the reverse sequence.

IV. RESULTS

Neither of the observers ever indicated that a target was present when there in fact was no target. Observer D.E. was always certain that there was no target and W.D. was certain 14 out of the 18 instances.

The frequency of responses in the various categories, for each target-background relation under each experimental condition, are shown for Observer D.E. in Table I and for Observer W.D. in Table II. These results are summarized for no-target responses in Table III. In Table III the frequency of "no-target" responses is shown to be generally maximal when the dependencies in the target and background are equal, and minimal when these dependencies are most different. The differences among these cell entries for both observers are highly significant. Nondetections are least frequent when the target has the greatest internal organization. The 75% background with the intermediate degree of organization produces most frequent observations in which the target is not detected. The mean numbers of certain target detections under each experimental condition are illustrated in Fig. 3 for Observer D.E. and in Fig. 4 for Observer W.D. The close correspondence of results for each day with different viewing conditions is apparent in these figures and in Tables I and II.

Table IV shows that the dependency within the targets affects the certainty of the "no-target" response. The certainty decreases as the targets become more ordered. For the backgrounds, the certainty is least with the 75% field for Observer D.E. and unaffected by background dependency for Observer W.D.

In Table V, the frequency of correct target recognitions is shown to vary significantly under the various target-background situations for each observer. Although tests of significance for the column and row totals were not performed, the results, which are quite similar for the two observers, indicate that recognition accuracy is highest when the target or the background contains 100% dependency and lowest when the target or background has 75% internal dependency.

The recognition results for the nine target-background conditions are illustrated by the dashed lines in Fig. 5 for Observer D.E. and in Fig. 6 for Observer W.D. The solid lines in these figures represent the number of correct recognitions expressed as a percentage of the total detections. The number and percentage measures produce the same conclusions, except for the 100% targets observed against 100% backgrounds. The large increase at this point on the percentage curve for both observers illustrates that, if a 100% target is placed against a 100% background so that the patterns do not register, the contour of the target becomes quite obvious and recognizable.

Table VI presents the frequency of certain and uncertain recognition responses for different dependencies in the background and in the target, for each observer. The proportion of certain responses changes with background dependency for both observers. The 75% background produces the smallest percentage of certain recognitions and the 100% background yields the largest percentage of certain recognitions. For Observer D.E. the relative number of certain responses is dependent also upon the dependency in the target. An interesting point is that for Observer W.D. the dependency within the target does not influence significantly the proportion of certain responses. For detection the reverse effect was seen. That is, the dependency in the background did not affect the certainty of detection, but it did affect the certainty of recognition. Conversely, for this observer the dependency within the target affected the certainty of detection but did not affect the certainty of recognition.

The frequency of responses for the various forms under each experimental condition are shown in Table VII for Observer D.E. and in Table VIII for Observer W.D. These results are summarized in Table IX. Table IX shows different proportions between the frequencies of incorrect and correct target recognitions for the various target forms. These differences are highly significant for both observers. This effect is in contrast to the almost equal numbers of total detections among the eight forms for each observer.

V. DISCUSSION

The present evidence supports the hypothesis tested in this experiment. Tables I, II, and III, showing "no-target" responses, and Figs. 3 and 4, showing the mean number of certain detections under each experimental condition, indicate that, generally, the greater the difference between the dependencies of the target and the background, the greater the likelihood of detecting the target. An exception to this rule, however, occurs for both observers with targets against 75% backgrounds. The 50% target was not as easily detected by Observer W.D. as the 75% target against the 75% background. This reflects the fact that, for all backgrounds combined, targets with 50% internal dependency are least easily detected. From this result one can, perhaps, draw the conclusion that the best camouflage for a given target requires least internal organization of the luminance microstructure of the target, if the background is not specified. However, if the target luminance microstructure is not specified, the background best for hiding targets is one with an intermediate degree of internal organization, probably because being intermediate between the 50% and 100% fields in dependency, neither of the other fields is more than 25 dependency-percentage points different. But for the other fields targets have a greater possible range of difference (i.e., 50 dependency-percentage points).

Of course, the above conclusions apply only to the three degrees of dependency and target conditions used in this study. Further research is needed to establish whether other values not tested would provide other maxima or minima of functions, or different conclusions entirely. For example, in Fig. 1 the 50% field viewed against a 75% background is obviously detectable. However, Table III shows that the 50% field viewed against a 75% background is obviously detectable. However, Table III shows that the 50% target is virtually undetectable against a 75% background. Therefore, the number of elements in the target is of critical importance for the detection of the target against some backgrounds.

Another conclusion can be drawn from Table III and Figs. 2 and 3. The dependency-contrast relation must specify the direction of the contrast. For example, the threshold is not the same for a 100% and for a 50% target when viewed against a 75% background although the differences in percentage between the target and background is the same in both cases. For the same dependency contrast, the difference is always in the direction in which more detections occur when the target is closer to 75% organization than the background is to 75%. Also, the sensitivity in terms of detection thresholds is greater on the 100% dependency end of the scale than on the 50% dependency end.

Tables IV and VI suggest the tentative conclusion that the certainty of response is determined primarily by the target dependency when the observer reports that he cannot see the target. However, the certainty is determined primarily by the background dependency when the response involves identification of a target which is above the detection threshold. This somewhat surprising result is difficult to interpret. Perhaps the frame of reference is established by the background in the case of nondetection and by the target in the case of recognition. In the former case the target area is perhaps tested by the null hypothesis established by the background field. In the latter case, perhaps the target establishes a baseline from which the background field is judged to depart from or to conform to.

An effort was made to determine a stimulus dimension for the various forms which correlated sufficiently with the percent-correct recognition scores for each form. No single measure was found to be satisfactory. This is not surprising considering the heterogeneous nature of the present population of forms, which include geometric forms, "real" forms, and a "random" form. The best approach to this problem, with only the present information available, is probably an intuitive one in which the forms least apt to be confused with the other forms (i.e., airplane and triangle) are correctly recognized most often, etc. It is interesting to note that the nonmeaningful form (morph) is correctly recognized least often.

For explaining the effect on the detection and recognition of nonuniform targets viewed against nonuniform backgrounds attributable to the degree of difference between the spatial organization of the luminance microstructure within the target and within the background, the author proposes a neural perceptual scan of the peaks and troughs of excitation across the cortex which leads to the establishment of a baseline of parameters describing microstructure dependencies over area. Subsequent areas in the scan are analyzed and compared to the baseline. If the baseline of the new area differs by a criterion amount from the previous baseline, then the observer detects a target. If the baseline does not differ by a criterion amount, the observer does not detect a target and the new area is assimilated into and reinforces the old baseline. This argument explains why the area of the target (i.e., number of units of luminance microstructure) is important. The larger the target area and the background area, the larger are the dependency samples which are employed for establishing baselines, and the smaller are the differences in baselines which are perceived as significant by the cortical analysis mechanism.

From inspection of Fig. 1, one can see that, as the microstructure dependencies depart more from 100%, the average size of clumps of cells of the same luminance increase. Although there is no proof of it, probably the differential in size is a special case of dependency contrast. Obviously, the present theoretical approach requires much work in the determination of relevant variables and constants before it can be finally evaluated.

REFERENCES

1. Harcum, E. R., Visual Recognition Along Four Meridians of the Visual Field: Preliminary Experiments, Univ. of Mich. Eng. Res. Inst. Project MICHIGAN Rept. 2144-50-T, 1957.

2. Harcum, E. R., "Three Inferred Factors in the Visual Recognition of Binary Targets," in Form Discrimination as Related to Military Problems, edited by J. W. Wulfeck and J. H. Taylor, Proc. of a Symposium sponsored by the Armed Forces-NRC Committee on Vision, Tufts University, Medford, Mass. Nat. Acad. of Sciences - Nat. Res. Council Publication, 561, pp. 32-37 (April 4-5, 1957).

3. Heron, W., "Perception as a Function of Retinal Locus and Attention," Amer. J. Psychol. 70, 38-48 (1957).

4. Blackwell, H. R., Personal Communication.

5. Attneave, F., "Some Informational Aspects of Visual Perception," Psychol. Rev., 61, 183-193 (1954).

6. Kristofferson, A. B., Foveal Intensity Discrimination as a Function of Area and Shape, Univ. of Mich., Thesis, Unpublished, 1954.

7. Swets, J. A., An Experimental Comparison of Two Theories of Visual Detection, Univ. of Mich., Thesis, Unpublished, 1954.

8. Kincaid, W. M., Theoretical Models for the Discriminatory Process in Visual Detection, Univ. of Mich. Res. Inst. Rept. 2144-281-T (in press).

9. Green, B. F., "The Use of High-Speed Digital Computers in Studies of Form Perception," in Form Discrimination as Related to Military Problems, edited by J. W. Wulfeck and J. H. Taylor, Proc. of a Symposium sponsored by the Armed Forces-NRC Committee on Vision, Tufts University, Medford, Mass. Nat. Acad. of Sciences - Nat. Res. Council Publication,561, pp. 65-75 (Apr. 4-5, 1957).

10. Levi, L., "On the Effect of Granularity on Dynamic Range and Information Content of Photographic Recordings," J. Opt. Soc. of Amer., 48, 9-12 (1958).

TABLE I

FREQUENCY OF RESPONSES IN THE VARIOUS CATEGORIES BY OBSERVER D.E.

Background	Target	Conditions	No Target			Incorrect Recognition			Correct Recognition		
			Sure	Uncertain	Total	Guess	Certain	Total	Guess	Certain	Total
50	50	H:L	32	0	32	0	0	0	0	0	0
		H:T	32	0	32	0	0	0	0	0	0
		L:T	32	0	32	0	0	0	0	0	0
		Total	96	0	96	0	0	0	0	0	0
	75	H:L	24	4	28	3	0	3	1	0	1
		H:T	22	4	26	6	0	6	0	0	0
		L:T	25	0	25	6	0	6	1	0	1
		Total	71	8	79	15	0	15	2	0	2
	100	H:L	0	0	0	3	4	7	8	17	25
		H:T	0	0	0	18	5	23	6	3	9
		L:T	0	0	0	11	6	17	10	5	15
		Total	0	0	0	32	15	47	24	25	49
75	50	H:L	30	2	32	0	0	0	0	0	0
		H:T	28	4	32	0	0	0	0	0	0
		L:T	32	0	32	0	0	0	0	0	0
		Total	90	6	96	0	0	0	0	0	0
	75	H:L	32	0	32	0	0	0	0	0	0
		H:T	32	0	32	0	0	0	0	0	0
		L:T	32	0	32	0	0	0	0	0	0
		Total	96	0	96	0	0	0	0	0	0
	100	H:L	0	0	0	10	4	14	13	5	18
		H:T	6	12	18	11	0	11	3	0	3
		L:T	2	7	9	10	2	12	7	4	11
		Total	8	19	27	31	6	37	23	9	32
100	50	H:L	0	0	0	5	4	9	4	19	23
		H:T	0	0	0	7	6	13	6	13	19
		L:T	0	0	0	4	9	13	2	17	19
		Total	0	0	0	16	19	35	12	49	61
	75	H:L	0	0	0	10	2	12	6	14	20
		H:T	0	0	0	12	3	15	4	13	17
		L:T	0	0	0	9	5	14	2	16	18
		Total	0	0	0	31	10	41	12	43	55
	100	H:L	16	0	16	0	2	2	2	12	14
		H:T	16	0	16	6	2	8	4	4	8
		L:T	16	0	16	2	3	5	1	10	11
		Total	48	0	48	8	7	15	7	26	33

TABLE II

FREQUENCY OF RESPONSES IN THE VARIOUS CATEGORIES BY OBSERVER W.D.

Background	Target	Conditions	No Target			Incorrect Recognition			Correct Recognition		
			Sure	Uncertain	Total	Guess	Certain	Total	Guess	Certain	Total
50	50	H:L	32	0	32	0	0	0	0	0	0
		H:T	32	0	32	0	0	0	0	0	0
		L:T	22	9	31	1	0	1	0	0	0
		Total	86	9	95	1	0	1	0	0	0
	75	H:L	20	9	29	3	0	3	0	0	0
		H:T	22	3	25	7	0	7	0	0	0
		L:T	4	12	16	12	1	13	3	0	3
		Total	46	24	70	22	1	23	3	0	3
	100	H:L	0	0	0	9	1	10	21	1	22
		H:T	1	0	1	12	0	12	14	5	19
		L:T	0	0	0	13	5	18	10	4	14
		Total	1	0	1	34	6	40	45	10	55
75	50	H:L	27	5	32	0	0	0	0	0	0
		H:T	32	0	32	0	0	0	0	0	0
		L:T	11	18	29	3	0	3	0	0	0
		Total	70	23	93	3	0	3	0	0	0
	75	H:L	28	4	32	0	0	0	0	0	0
		H:T	29	2	31	1	0	1	0	0	0
		L:T	13	15	28	3	1	4	0	0	0
		Total	70	21	91	4	1	5	0	0	0
	100	H:L	0	7	7	8	0	8	17	0	17
		H:T	1	0	1	16	1	17	13	1	14
		L:T	0	1	1	19	4	23	8	0	8
		Total	1	8	9	43	5	48	38	1	39
100	50	H:L	0	0	0	9	0	9	14	9	23
		H:T	0	0	0	10	2	12	15	5	20
		L:T	0	0	0	9	2	11	12	9	21
		Total	0	0	0	28	4	32	41	23	64
	75	H:L	0	0	0	12	1	13	11	8	19
		H:T	0	0	0	15	1	16	14	2	16
		L:T	0	0	0	11	2	13	9	10	19
		Total	0	0	0	38	4	42	34	20	54
	100	H:L	8	2	10	4	3	7	3	12	15
		H:T	4	4	8	9	2	11	3	10	13
		L:T	7	5	12	5	4	9	5	6	11
		Total	19	11	30	18	9	27	11	28	39

TABLE III

FREQUENCY OF NO-TARGET RESPONSES UNDER THE VARIOUS TARGET-BACKGROUND CONDITIONS

Dependency in Background	Observer D.E.				Observer W.D.			
	Dependency in Target			All Targets	Dependency in Target			All Targets
	50%	75%	100%		50%	75%	100%	
50%	96	79	0	175	95	75	1	166
75%	96	96	27	219	93	91	9	193
100%	0	0	48	48	0	0	30	30
All Backgrounds	192	175	75	442	188	161	40	389
Significance:	$\chi^2 = 274.54$; $p < .001$				$\chi^2 = 286.65$; $p < .001$			

TABLE IV

FREQUENCY OF CERTAIN AND UNCERTAIN NO-TARGET RESPONSES FOR THE THREE DEGREES OF DEPENDENCY WITHIN THE TARGET AND WITHIN THE BACKGROUND

Dependency	Observer D.E.				Observer W.D.			
	Background		Target		Background		Target	
	Certain	Uncertain	Certain	Uncertain	Certain	Uncertain	Certain	Uncertain
50%	167	8	186	6	133	33	156	32
75%	194	25	167	8	141	52	116	45
100%	48	0	56	19	19	11	21	19
All Dependencies	409	33	409	33	293	96	293	96
Significance:	$X^2 = 10.88$; $p < .01$		$X^2 = 41.96$; $p < .001$		$X^2 = 4.88$; $p > .10$		$X^2 = 18.02$; $p < .001$	

TABLE V

FREQUENCY OF CORRECT RECOGNITIONS UNDER THE VARIOUS TARGET-BACKGROUND CONDITIONS

Dependency in Background	Observer D.E.				Observer W.D.			
	Dependency in Target			All Targets	Dependency in Target			All Targets
	50%	75%	100%		50%	75%	100%	
50%	0	2	49	51	0	3	55	58
75%	0	0	32	32	0	0	39	39
100%	61	55	33	149	64	54	39	157
All Backgrounds	61	57	114	232	64	57	133	254
Significance:	$\chi^2 = 121.72$; $p < .001$				$\chi^2 = 125.58$; $p < .001$			

TABLE VI

FREQUENCY OF CERTAIN AND UNCERTAIN CORRECT RECOGNITIONS FOR THE THREE DEGREES OF DEPENDENCY WITHIN THE TARGET AND WITHIN THE BACKGROUND

Dependency	Observer D.E.				Observer W.D.			
	Background		Target		Background		Target	
	Certain	Uncertain	Certain	Uncertain	Certain	Uncertain	Certain	Uncertain
50%	25	26	49	12	10	48	23	41
75%	9	23	43	14	1	38	20	37
100%	118	31	60	54	71	86	39	94
All Dependencies	152	80	152	80	82	172	82	172
Significance:	$X^2 = 40.21$; $p < .001$		$X^2 = 16.78$; $p < .001$		$X^2 = 33.74$; $p < .001$		$X^2 = 1.11$; $p > .50$	

TABLE VII

FREQUENCY OF RESPONSES FOR THE VARIOUS FORMS BY OBSERVER D.E.

Form	Conditions	Incorrect Recognition			Correct Recognition			Total Detections
		Guess	Certain	Total	Guess	Certain	Total	
Rect.	H:L	2	2	4	5	10	15	19
	H:T	7	1	8	5	4	9	17
	L:T	4	5	9	6	4	10	19
	Total	13	8	21	16	18	34	55
Airp.	H:L	2	0	2	8	9	17	19
	H:T	6	1	7	2	7	9	16
	L:T	2	1	3	2	12	14	17
	Total	10	2	12	12	28	40	52
Tria.	H:L	0	0	0	6	12	18	18
	H:T	7	0	7	2	6	8	15
	L:T	2	0	2	5	10	15	17
	Total	9	0	9	13	28	41	50
Truck	H:L	4	1	5	4	9	13	18
	H:T	5	1	6	2	8	10	16
	L:T	8	1	9	1	7	8	17
	Total	17	3	20	7	24	31	51
Tank	H:L	6	2	8	2	8	10	18
	H:T	7	2	9	5	2	7	16
	L:T	6	5	11	0	6	6	17
	Total	19	9	28	7	16	23	51
Cross	H:L	7	3	10	1	8	9	19
	H:T	7	6	13	1	4	5	18
	L:T	6	6	12	1	5	6	18
	Total	20	15	35	3	17	20	55
Elip.	H:L	5	1	6	5	7	12	18
	H:T	10	0	10	5	2	7	17
	L:T	3	2	5	5	8	13	18
	Total	18	3	21	15	17	32	53
Morph	H:L	4	6	10	5	4	9	19
	H:T	11	5	16	1	0	1	17
	L:T	12	5	17	2	0	2	19
	Total	27	16	43	8	4	12	55

TABLE VIII

FREQUENCY OF RESPONSES FOR THE VARIOUS FORMS BY OBSERVER W.D.

Form	Conditions	Incorrect Recognition			Correct Recognition			Total Detections
		Guess	Certain	Total	Guess	Certain	Total	
Rect.	H:L	7	0	7	9	3	12	19
	H:T	6	0	6	10	5	15	21
	L:T	11	2	13	3	7	10	23
	Total	24	2	26	22	15	37	63
Airp.	H:L	1	0	1	7	7	14	15
	H:T	7	2	9	5	3	8	17
	L:T	4	3	7	11	5	16	23
	Total	12	5	17	23	15	38	55
Tria.	H:L	3	0	3	4	11	15	18
	H:T	4	0	4	8	8	16	20
	L:T	5	1	6	7	7	14	20
	Total	12	1	13	19	26	45	58
Truck	H:L	8	1	9	6	2	8	17
	H:T	11	0	11	4	4	8	19
	L:T	13	2	15	3	0	3	18
	Total	32	3	35	13	6	19	54
Tank	H:L	6	2	8	10	0	10	18
	H:T	8	1	9	9	1	10	19
	L:T	11	3	14	6	1	7	21
	Total	25	6	31	25	2	27	58
Cross	H:L	4	1	5	11	3	14	19
	H:T	14	1	15	5	1	6	21
	L:T	14	6	20	4	0	4	24
	Total	32	8	40	20	4	24	64
Elip.	H:L	5	0	5	10	4	14	19
	H:T	5	0	5	13	1	14	19
	L:T	4	0	4	10	5	15	19
	Total	14	0	14	33	10	43	57
Morph	H:L	11	1	12	8	1	9	21
	H:T	14	2	16	5	0	5	21
	L:T	15	2	17	3	4	7	24
	Total	40	5	45	16	5	21	66

TABLE IX

FREQUENCY OF DETECTION AND RECOGNITION RESPONSES FOR THE VARIOUS FORMS

Form	Observer D.E.			Observer W.D.		
	Incorrect	Correct	All Detections	Incorrect	Correct	All Detections
Rectangle	21	34	55	26	37	63
Airplane	12	40	52	17	38	55
Triangle	9	41	50	13	45	58
Truck	20	31	51	35	19	54
Tank	28	23	51	31	27	58
Cross	35	20	55	40	24	64
Ellipse	21	32	53	14	43	57
Morph	43	12	55	45	21	66
All Forms	189	233	422	221	254	475
Significance:	$\chi^2 = 61.35$; $p < .001$			$\chi^2 = 58.01$; $p < .001$		

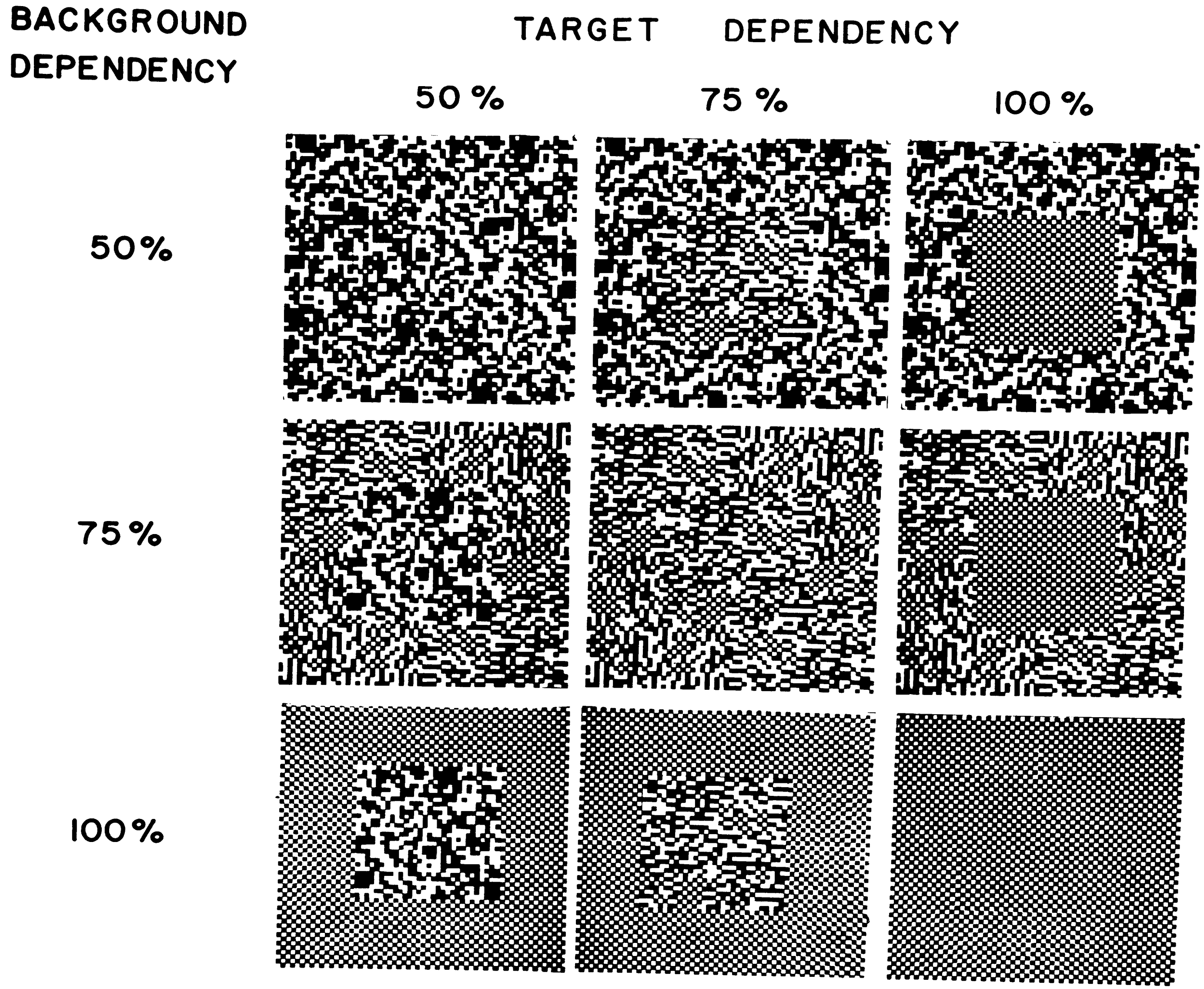
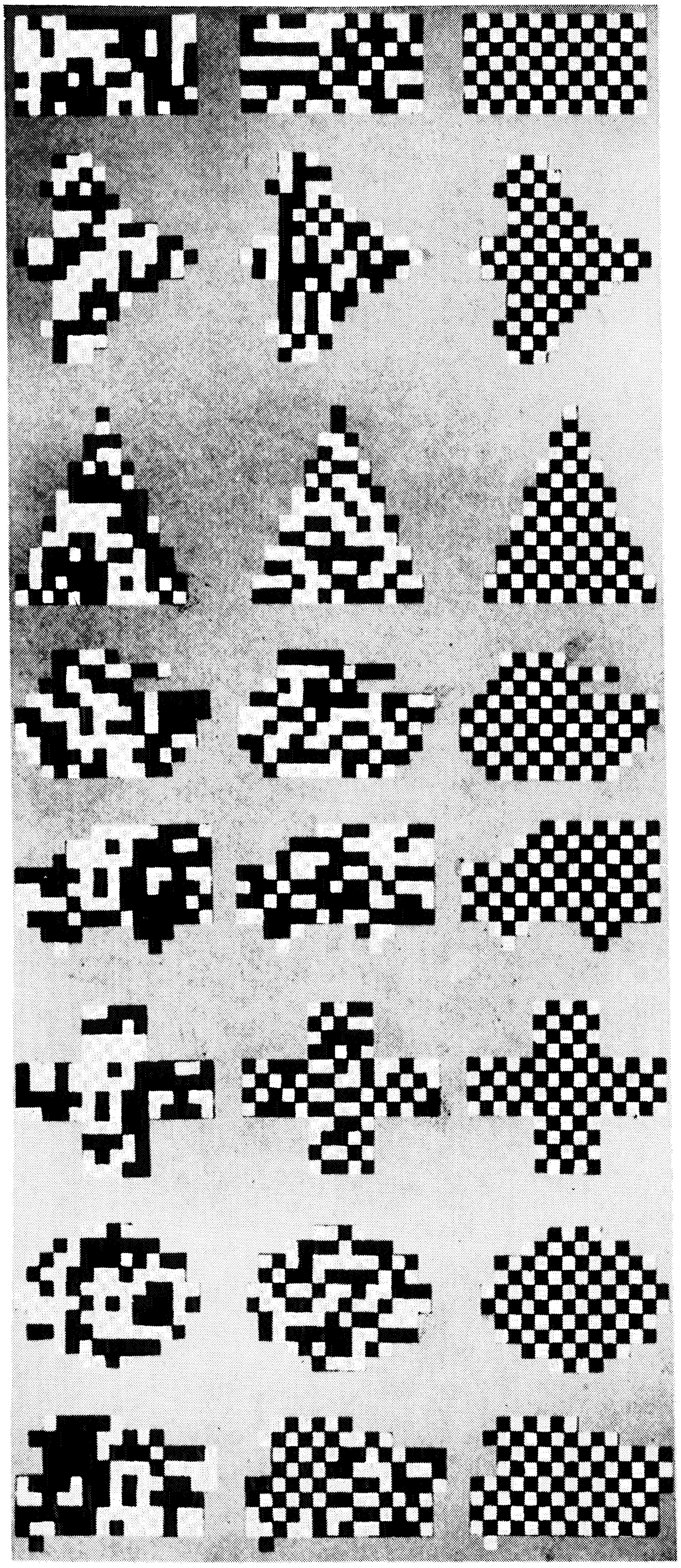


Fig. 1. Target patches with three degrees of dependency within the microstructure, superimposed on backgrounds composed of the same three surface dependencies.

FORM SAMPLE

50% 75% 100%



NAME	AREA	MAX. DIM.	PERIMETER
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. 2. Illustration of the eight target forms used in this study.

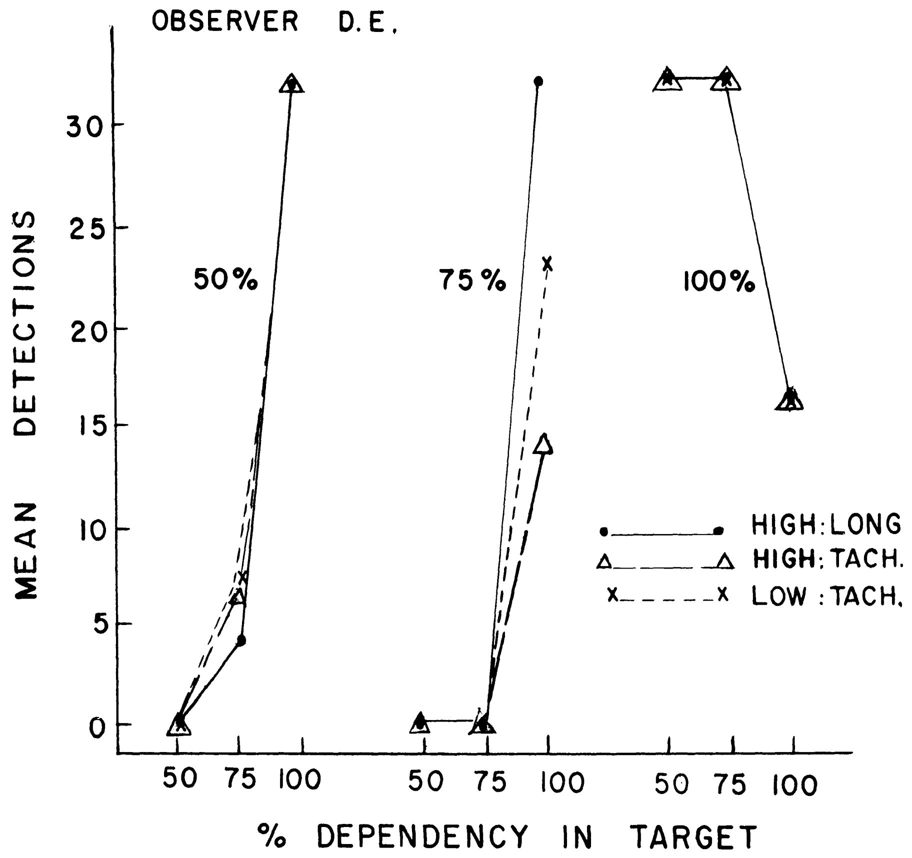


Fig. 3. Mean target detections with the nine target-background relations for Observer D.E.

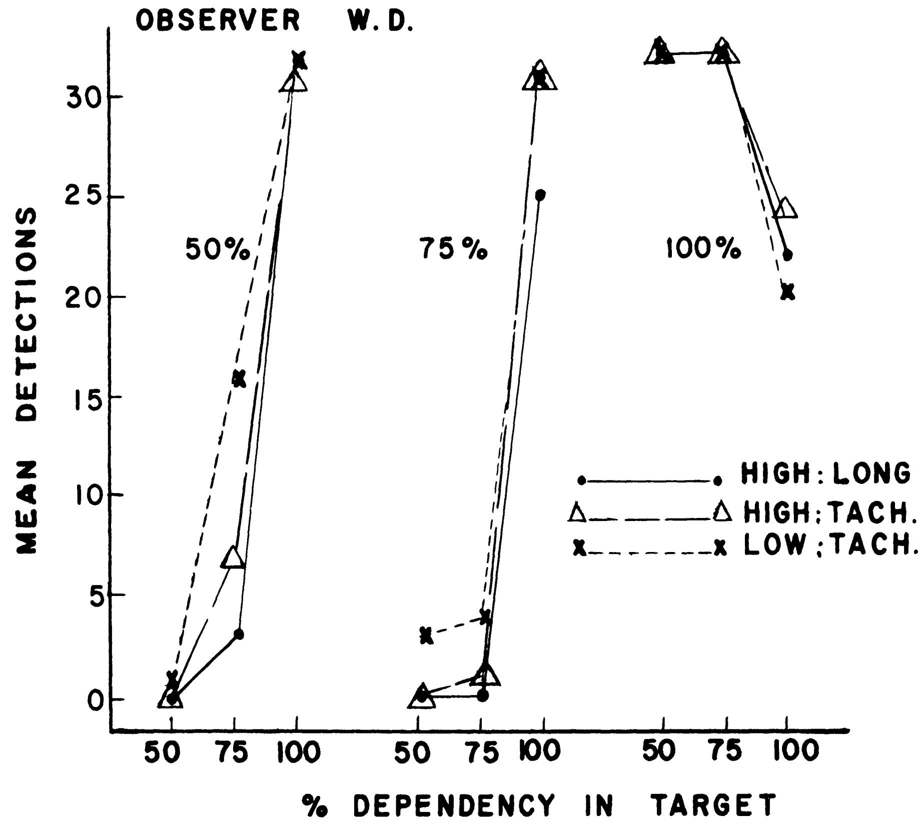


Fig. 4. Mean target detections with the nine target-background relations for Observer W.D.

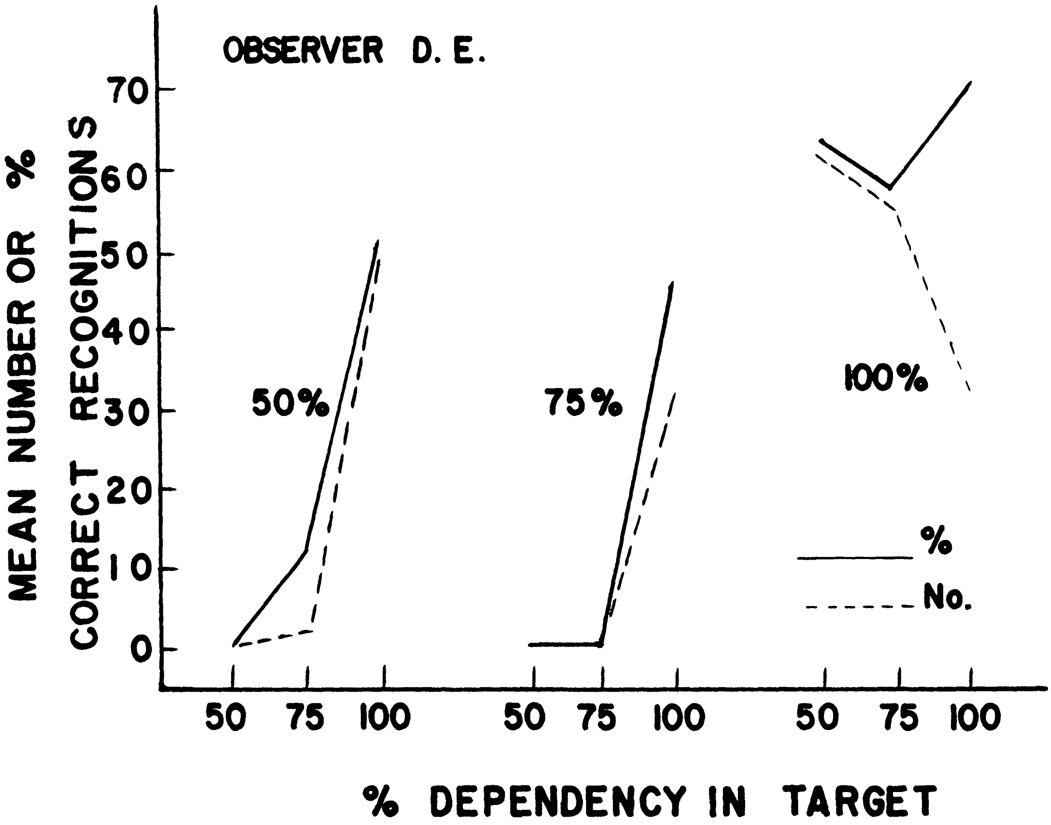


Fig. 5. Mean number and percent correct target recognitions with the nine target-background relations for Observer D.E.

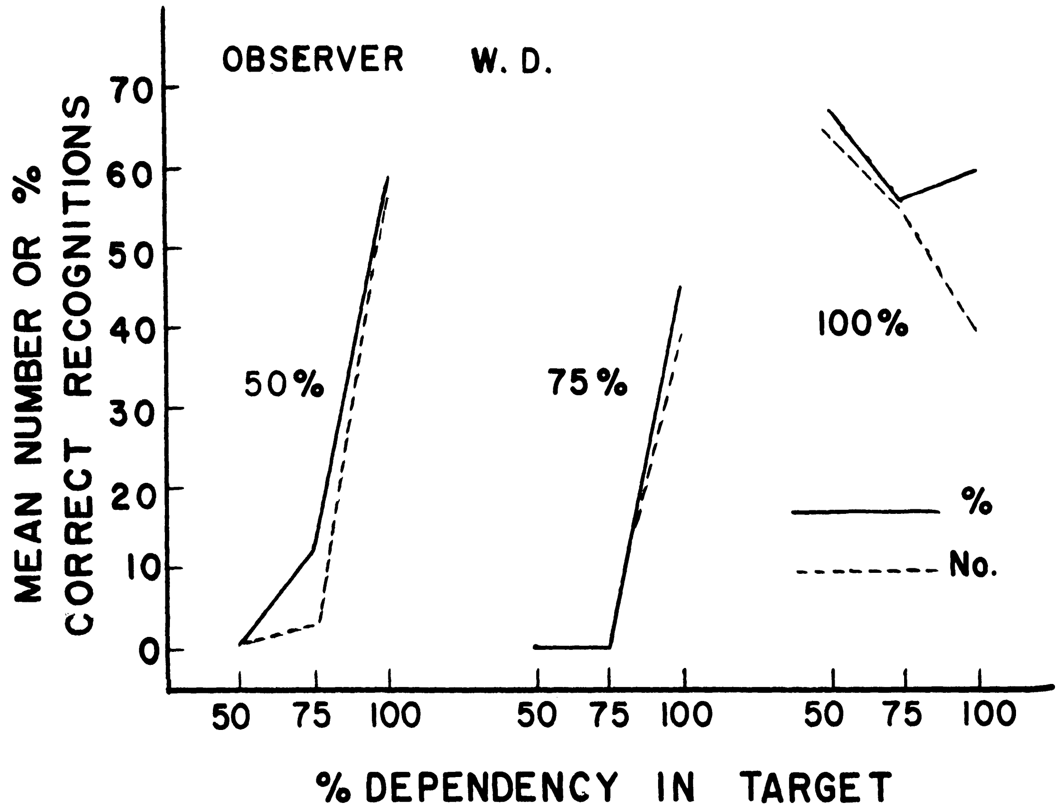


Fig. 6. Mean number and percent correct target recognitions with the nine target-background relations for Observer W.D.