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EFFECTS OF THE SHAPE AND DEGREE OF STRUCTURE OF THE
VISUAL FIELD ON TARGET DETECTION AND LOCATION

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EFFECTS OF THE SHAPE AND DEGREE OF STRUCTURE OF THE
VISUAL FIELD ON TARGET DETECTION AND LOCATION

by

Raymond E. Reilly

Thesis Submitted in Partial Fulfillment of the
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INTRODUCTION

In the visual search situation where the observer must detect the presence of a target, often against a noisy surround, the design of the display is critical. In a recent symposium on visual search, Teichner (1960) noted that search performance is a complex function of observer and target-display variables. He suggested that this be viewed as an interaction since the search media place restrictions on the types of observer strategy applicable. For example, Miller and Ludvigh (1960) studied the time required for the detection of stationary and moving targets as a function of size in large homogeneous and partially structured fields. They noted that in the absence of differential retinal stimulation subjects (Ss) appeared disoriented spatially and that S's visual disorientation was directly proportional to the amount of time exposed to a uniform field. No difference was found between the detection times for stationary and moving targets. With systematic search a fixed target should on the average be found sooner than a moving target; thus it was concluded that Ss were not able to search as systematically as desired. In a recent study by White and Ford (1960) eye movements of Ss monitoring simulated radar displays were recorded. They found that search patterns, and spatial distribution and duration of fixations were related to the internal dynamics of the display (radial sweep-line).

They noted further that search behavior when using a sweep line was greatly curtailed as opposed to search patterns observed under a "free-search" situation.

In addition to the constraints on performance imposed by the display characteristics, there is evidence that observers have preferred search tendencies which are independent of the display. Enoch (1960) recorded eye-movements of experienced photointerpreters who viewed aerial photographs varying in scale and verticality. He also recorded eye-movements of non-experienced observers who viewed simulated aerial photos. He found that the distribution of fixations was markedly concentrated at the center of the display with the peripheral regions essentially ignored. This finding was independent of the display quality, size and content, and experience of the observers. Enoch suggested that this central bias might be overcome by special training and/or the use of some automatic scanning device. The latter possibility was investigated by Townsend and Fry (1960). They found that use of an automatic scanner resulted in more uniform display coverage than with free search. The device increased search efficiency at low contrast levels but not at high levels where the target could be seen peripherally even before the mechanism was turned on. It was concluded that future research should determine precisely where changes in scanning procedures must be made and that this will depend not only upon the physical characteristics of the display

(size, blur, content, etc.) but also on the time allowed for search and the type of object sought.

Another type of scanning system was investigated by Baker (1958). To compensate for poor peripheral detection on a radar scope a green light was used to indicate the time during which the Ss were to search the outer half of the screen. The resulting improvement in performance was attributed to a biasing of attention to the periphery. In a further study Baker and Boyes (1959) demonstrated that probability of detection may be increased by utilizing existing bias in search behavior. Through the use of a B-scanner (square radar-like screen with vertical sweep line) which was designed to open like a book, so that one side was the mirror-image of the other, brief events of greatest importance were made to occur in the center of the area being searched. The probability of detection was greater than when the events occurred in relatively peripheral regions.

Thus even "natural" search tendencies appear to be differentially affected by the type of display. In this regard, Gottsdanker (1960) investigated the relation between the nature of the search situation and the effectiveness of alternative strategies of search. He used two search situations, one characterized by "competition" (search objects plus similarly constructed distractors), the second characterized by "imbeddedness" (search objects dissimilar to background but with "background broken up

so as to make detection difficult"). Two types of strategy were used: (1) sequential strategy in which Ss had to find all objects in a given class before going on to the next class; (2) free search in which the Ss could use any method desired. The latter strategy was found to be superior in both search situations.

Another characteristic of the search situation which affects search strategy was demonstrated by Baddely (1958) who found that irrelevant objects in the visual field were interpreted by Ss to be cues. The Ss oriented their search in relation to these "cues" and were thus distracted from a possible optimal searching method. Erikson (1955) studied detection time for a constant number of signals using a display varying in number of grid lines and irrelevant signals. Both of these variables increased search time directly.

Teichner (1960) has suggested that there may be kinds and quantities of display structure some of which may be more conducive to patterning eye-movements than others. He suggested further that the geometry of structuring be referred to as "visual geography" and noted the importance to visual search performance of studies attempting to relate search strategy and detection to the geographical properties of the display. This study is considered to be a step in this direction.

From the studies reviewed, two main points are clear:

(1) In some situations Ss exhibit search behavior which is

biased and maladaptive in terms of optimal performance;

(2) This performance can be altered by changes in the characteristics of the visual display and/or instruction plus some cue. Any systematic relationship between visual geography and induced search behavior remains to be determined.

The present study was designed to test the effects of

- (1) two general forms of search area: circular and square;
- (2) five levels of structure of the search area; and
- (3) three levels of search (exposure) time: 3, 6, and 9 seconds, on the detection and location of low visibility targets. The experimental structures were of two types, concentric circles for the circular field and vertical grid lines for the square field. These appear to be similar to the natural search patterns reported by Enoch (1960).

METHOD

Apparatus

Ten negative slides were made by photographing black on white drawings of the visual displays. There were 5 for the circular field and 5 for the square field (see appendix, fig. A). The 5 levels of structure for the circular field ranged from 0 (plain circular field, no concentric circles) to 4 (four concentric circles dividing the area into 5 equal parts). The square area also had levels of structure ranging from 0 (plain square field, no grid lines) to 4 (4 vertical lines dividing the area into 5 equal parts). The slides were projected onto a special screen. The projected image of the circular figures was 24 inches in diameter giving a search area of 452.16 square inches. The image of the square figures was 21.27 inches on each side with an area of 452.41 square inches. The difference of .25 square inches was considered negligible.

The screen was constructed of ground glass backed by sheet metal painted flat black. Twenty holes, .031 inches in diameter, were drilled in the metal in randomly assigned locations within the area described by the projected slides. Each hole was placed so that no line from any of the 10 slides would fall directly on it. A lamp mounted behind each hole provided a point source of light when viewed from the front of the screen. The selection of particular lights

(targets) was accomplished manually by means of a selector switch. Only one target at a time was used. The lighting of targets and the exposure of slides was synchronized by a Hunter interval timer.

For the purposes of this study it was desired to have the target-surround contrast ratio such that the target would be visible under foveal fixation but not visible peripherally. As noted by Townsend and Fry (1960) high contrast targets were detected peripherally and defeated the purpose of the scanning device. Six graduate students served as judges to obtain this contrast ratio. A variac was used to set the intensity of the target which was constant throughout the experiment. A Macbeth illuminometer was used to determine the photometric values which were: (a) general room illumination level of 2.00 ft. candles; (b) point source (target) intensity of 1.13 candlepower; (c) screen brightness of .016 ft. candles. The target-screen contrast ratio was computed to be 98.3% at the surface of the screen and 49.0% six feet away at the eye of the observer.

Each S was supplied with 10 data sheets, one for each slide presented. Each sheet was a replica to scale of the projected display. The circular figures were 4 inches in diameter and the square figures were 3.54 inches on each side. The data sheets were prearranged in order corresponding to that of the slides. A questionnaire was also used a copy of which is included in the appendix.

Subjects

The Ss were 30 male and female undergraduates enrolled in basic psychology at the University of Massachusetts. All had normal or corrected to 20/20 vision.

Procedure

The 30 Ss were randomly assigned to 3 groups of 10 each. Each group had the slides presented in the same predetermined random sequence for either 3, 6, or 9 seconds. Each slide was shown 5 times in succession with the corresponding 5 targets occurring in random locations. Thus each S searched for a total of 50 targets.

At the start of each experimental session the Ss were seated 6 feet in front of the screen. A practice target was presented to insure that the Ss understood the task and that the contrast used was above individual thresholds. All Ss were able to see the target although it was necessary for some that it be pointed out. Ss were told that their task was to find the target which would always be present and always lie within the perimeter of the projected figure. They were instructed further that each slide would appear 5 times in succession and that each time they were to find the target. Upon detecting the target, Ss were to place a dot on their data sheets corresponding as accurately as possible to the actual location of the target on the screen. For each slide the targets were numbered in sequence from 1 to 5. Ss were instructed to write the proper number next to each to avoid

confusion in scoring.

The interval between slides was approximately 15 seconds. This was determined by the experimenter (E) who saw that all Ss had completed marking the data sheets and that their attention was on the screen. A "click" made by the Hunter timer 3.9 seconds prior to the onset of target and slide served as a warning signal to further insure attention.

After completing the 50 trials Ss filled out a brief questionnaire concerning the possible effects of the stimulus characteristics on their search performance. This questionnaire was intended to obtain two general types of information: (1) an expression of preference for searching particular displays; (2) a verbal account of the effects of the displays on search patterns and strategies.

RESULTS

Two scores were obtained from the data: (1) percent targets detected; and (2) accuracy of target location. The accuracy with which Ss reported target location was determined by placing over the data sheet a transparent overlay on which the target was correctly located. The distance between the true point and the S's point was measured to the nearest .025 inches. Distances under .025 inches were assigned a value of .025 inches. Targets in error greater than 1 inch were considered to be guesses and were treated as 'undetected'. Undetected targets were arbitrarily assigned a linear error value of infinity. Reciprocals were taken for the error scores ranging from 0 ($1/\infty$) to 40 ($1/.025$). Tables of means and standard deviations of results are included in appendix.

Percent detection measures

Analysis of variance was performed on the frequency of detection data. As shown in Table 1 the main effects of time, form (circle vs. square) and levels of structure were significant at the .01 level while the interaction of form x time was significant at the .05 level. Figure 1 presents percent targets detected as a function of levels of structure for both squares and circles. A slight increase in the functions from the first to the second level followed by a more pronounced decline suggests the presence of an optimum degree of structure at level 1 (division of the search area into two equal partitions). Performance for squares is seen to be

higher than that for circles over levels 0 to 3 with no difference occurring at level 4. While both graphs show the optimum at level 1 the plot for circles has a reversal at level 3 and increases again to level 4.

Figure 2 shows percent targets detected as a function of search time for square and circles. While detections increase with time for both forms, the performance for squares starts out at a higher level and reaches 85% detection at a slower rate than does that for circles.

Location-error measures

Analysis of variance was performed on the reciprocals of the error scores. As seen in Table 2 the main effect of time was significant at the .01 level while the main effects of form and levels of structure were significant at the .05 level. None of the interactions reached significance. Figure 3 presents mean reciprocal error as a function of levels of structure for squares and circles. Both forms show an optimum point; the one for squares is at level 2 (division of search area into 3 equal parts) and the optimum for circles is at level 1. The performance for squares is superior to circles at all levels of structure.

Figure 4 shows mean reciprocal error as a function of search time for circles and squares. Although the performance for squares is better at all search times, it increases rapidly from 3 to 6 seconds and then begins to level off. The plot for circles increases linearly over the three search times and

Table 1

Summary of Analysis of Variance For Percent Targets Detected

Source of Variance	df	MS	F
Time (T)	2	73.93	8.51**
Ss/T	27	8.69	
Form (F)	1	9.01	9.01**
Levels of Structure (L)	4	8.82	10.05**
F x L	4	1.05	1.85
F x T	2	3.42	3.42*
L x T	8	0.19	0.22
F x L x T	8	0.88	1.54
Ss x F/T ^a	27	1.00	
Ss x L/T ^b	108	0.88	
Ss x F x L/T ^c	108	0.57	

a Error term for F, F x T

b Error term for L, L x T

c Error term for F x L, F x L x T

* Significant at .05 level

** Significant at .01 level

Fig. 1. Percent targets detected for circular and square fields as a function of levels of structure.

Fig. 2. Percent targets detected for circular and square fields as a function of search time.

Table 2

Summary of Analysis of Variance For Error of Target Location

Source of Variance	df	MS	F
Time (T)	2	331.45	10.17**
Ss/T	27	32.57	
Form (F)	1	80.35	5.29*
Levels of Structure (L)	4	51.10	3.13*
F x L	4	13.96	1.26
F x T	2	16.95	1.11
L x T	8	16.09	-
F x L x T	8	12.63	1.13
Ss x F/T ^a	27	15.18	
Ss x L/T ^b	108	16.31	
Ss x F x L/T ^c	108	11.09	

a Error term for F, F x T

b Error term for L, L x T

c Error term for F x L, F x L x T

* Significant at .05 level

** Significant at .01 level

Fig. 3. Mean reciprocal location error for circular and square fields as a function of levels of structure.

Fig. 4. Mean reciprocal location error for circular and square fields as a function of search time.

approaches that for squares at 9 seconds.

Results of the questionnaire

In response to the questionnaire all 30 Ss reported that the different ways of dividing the area affected their behavior. In answer to which type of slide they would prefer to search over long periods of time, 26 preferred square figures and 4 preferred circular figures. The exact tally is shown in Table 3. The total of 10 for the unstructured square may be due in part to the fact that some Ss merely preferred "the square". Whether or not this referred specifically to the undivided square or to square figures in general as opposed to circular figures was not clear.

In general the questionnaire results suggested a feeling on the part of the Ss that their search patterns were directly affected by the display structures. All but one subject indicated that they used an "up and down" pattern for the square figures and a spiral or S-shaped pattern for round figures.

Some Ss preferred searching with a particular pattern regardless of the type of display. They reported it to be disturbing when the search structure did not conform to the preferred pattern. Ss who desired to fixate in the center of the search area and scan the rest using peripheral vision objected to the dividing lines whereas those who wanted to search all of the field with foveal vision found the partitions a convenient way of eliminating certain sections with a degree of certainty before searching others.

Table 3

Summary of Ss Preference for Searching Particular Fields

	Levels of Structure					<u>Total</u>
	0	1	2	3	4	
Square	10	5	5	2	4	26
Circle	4	0	0	0	0	4

DISCUSSION

The results seem clear in showing that targets are more frequently detected and more accurately reported under intermediate levels of structure, with square rather than round figures and with longer search times. The optimum for both squares and circles occurred at level 1. With location error measures similar optima were found. However, the optimum for squares was at level 2 while the optimum for circles was at level 1.

For both dependent measures the search time function for squares starts off at a higher level and increases at a slower rate than that for circles, terminating in practically no difference between forms at 9 seconds. This suggests that with unlimited search time and ample time to record and check target locations no difference between forms would be found. Further, since all Ss were able to see the target prior to the experiment, 100 percent detection would be the theoretical upper limit of performance for this measure. As only 85 percent of the targets were detected within this restricted search area in 9 seconds, extended search times describing the function between 85 and 100 percent detection remain to be investigated.

In general, performance for the square figures was better than for circular figures. There was also the suggestion that this advantage disappears for detection at higher levels

of structure and at longer search times. This same trend is present for location error measures. However, as a function of degree of structure, location error is consistently less for squares.

In order to interpret the results it is necessary to consider what is involved in poor search behavior. According to the studies reviewed, the major source of difficulty in the search situation seems to be a failure of the observer to achieve a uniform coverage of the displays. The lack of uniform systematic search stems from (1) a biasing of search toward the central area of the display or about some irrelevant object in the field (Baddeley, 1958), and (2) a lack of visual reference stimuli in large homogeneous fields (Miller and Ludvigh, 1960). A central bias implies a limited visual field whose center is apparent to the observer. To the extent that the center is not evident, less bias to this region might be expected. Where differential retinal stimulation is absent, and searching is erratic, the introduction of reference points might improve performance (Miller and Ludvigh, 1960). However, as such stimuli are increased there is the possible risk of the behavior reported by Enoch (1960) and Baddeley (1958) who found that large portions of the area were left unsearched if targets were not found to be in immediate relation to objects interpreted by Ss to be clues. In either situation target detection is directly related to search

time. Thus, with any search area, given just enough time to search it once, and assuming that detection is equivalent to fixation, the unsearched portions are directly proportional to the redundantly searched sections, e.g., given just enough time to search four quadrants, covering one twice necessarily leaves one unsearched. Erikson (1955) investigated the effects of search time of varying the number of irrelevant objects in the field and the number of grid lines dividing the field. The fact that search time increased directly with both variables was explained tentatively as due to an increased number of fixations brought about by the increased complexity of the field. When eye movements are not taken directly, the explanation concerning number of fixations might be questioned. At least it would be valuable to know whether when searching such complex fields Ss actually make the maximum number of different fixations or whether they search redundantly by fixating too long at some points and search others more than once. In the case of Erikson's (1955) study with up to 70 irrelevant objects in the field or with 1024 cells to search (32 x 32 matrix) such behavior is not unlikely.

With a limited unstructured field, again assuming enough time to search it once, both search biases and random search produce non-uniform coverage through redundant search (Enoch, 1960). Thus, the problem is one of designing the display so as to minimize this redundancy.

The display characteristics should be such that natural search biases are overcome and the searcher is afforded the means to utilize a systematic strategy in which he knows what has been searched and what has not. A further desirable aspect would be to have the optimal search pattern for the display known and have the geography of the display induce such a pattern.

While the partitioning of the search area did not improve performance in Erikson's (1955) investigation it still seems a logical approach to the problem. If it can be assumed that some structuring is better than none, the question arises as to some optimum level. There are at least two reasons for expecting that too much structuring would result in poorer performance; (1) If the partitions become too numerous within a fixed area their width will be reduced to one smaller than that covered by foveal vision, and more than one partition at a time would be searched. Overlapping and redundant searching would occur in trying to cover each partition; (2) Increased structuring would eventually result in the searcher's inability to discriminate sections or even keep his gaze along one section and redundant search would occur again. There is the further possibility that increased structure would tend to obscure the target.

The results of the present study seem to agree with the above explanation. Thus, the significantly better overall performance with square figures suggests a reduction in

central bias due to the presence of the four corners. The corners may have had some "clue" value in the same sense that irrelevant objects were used by Ss in the above mentioned studies. This is not unreasonable in view of Baker and Boyes' (1959) finding that by altering the characteristics of a B-scanner so that more important events occur in the central region, performance is improved through capitalizing on an existing central bias. Here a similar effect seems possible regarding the corners or other aspects of the display.

In addition to the effects on search behavior of this type, there is the possibility of different strategies being available for square figures than for circles, e.g., search the four corners, then the center, etc. While the undivided areas in this study were defined as unstructured, the perimeter of the projected image and/or the boundaries of the screen may have played a part in the search sequence used. There is also evidence from the questionnaire results that the general shape of the search patterns varied directly with the form of the field.

The fact that targets were reported more accurately with square figures might be due in part to better horizontal-vertical orientation between slide and data sheet. It appears that errors in reporting target location, while fairly accurate with respect to radial distance from the center of the field, would be more prone to rotation either

clockwise or counterclockwise with the circular slides and data sheets. Initially, it might be assumed that increased structure would lead to more precision in reporting target locations. Given sufficient time to enumerate partitions and locate targets accordingly such an assumption seems reasonable. However, for the search times used in this study, location error was seen to increase with more structuring beyond certain optima. Further evidence contrary to the above assumption is the highly insignificant interaction of levels x time ($F = 0.98$) which suggests that performance at the various levels is not differentially affected by search time and therefore, it would be expected that with increased search time, the optima for levels of structure would remain the same.

Along with studies such as Erikson's (1955) the presence of optimum points at levels 1 and 2 for both dependent measures, with declining performance at higher levels of structure, suggest that for limited visual fields of about 400 to 500 square in., increased structuring beyond observed optima may lead to performance poorer than that with no structure at all.

SUMMARY

The effects of the degree of structuring and the form of the visual field on target detection and target location were investigated for 3 different search times. Thirty undergraduate Ss searched for low visibility targets on a special screen and recorded the target locations on prepared data sheets. Each S searched for a total of 50 targets over 10 form-structure combinations for the visual field.

The results suggest that both target detection and location are related in a non-monotonic fashion to the degree of structure and to the form of the field. The structuring continuum was defined as the division of the search area into two or more partitions of equal area. Optima for both measures occurred at the low end of the continuum.

Of the two forms investigated, performance with square fields was generally superior to that for circular fields. In answer to a questionnaire after the experiment, Ss reported a preference for searching the square fields.

Both target detection and target location varied directly with amount of search time. However, the functions tended to increase rapidly at first and then level off at the longer search times.

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APPENDIX

Questionnaire

Do you think the different ways of dividing the area made any difference concerning your search behavior? If so how?

If you had to search such areas over long periods of time, which slide would you prefer? (can refer to data sheet if necessary)

Consider the way in which your eyes moved over the search area (path of search). Try to sketch this path in the place provided. For example:

Was this path affected by the different kinds of lines? If so, how?

Fig. A. Search areas seen by Ss as white on black -
levels 0 to 4 for circle and square

Table 4

Means and Standard Deviations for Location Error Measures

Time	Level	Circle		Square	
		Mean	SD	Mean	SD
(3 sec.)	0	3.0	4.3	3.0	3.6
	1	3.3	6.8	4.1	3.3
	2	2.0	3.6	3.8	5.0
	3	1.8	3.7	3.8	5.5
	4	1.6	2.4	3.2	5.1
(6 sec.)	0	4.2	3.8	5.8	6.0
	1	6.1	6.6	6.1	5.8
	2	4.7	6.7	8.6	10.6
	3	4.6	7.3	6.8	8.5
	4	4.4	6.4	7.7	11.2
(9 sec.)	0	6.4	6.3	5.3	5.5
	1	7.4	7.3	7.9	7.9
	2	7.8	8.0	8.0	10.2
	3	7.5	10.6	8.1	9.3
	4	6.0	8.3	6.8	6.8

Time	Mean	SD	Level	Mean	SD
3 sec.	2.3	4.5	0	4.6	5.0
6 sec.	2.9	4.5	1	5.8	6.7
9 sec.	6.1	7.1	2	5.8	8.2
			3	5.4	8.2
			4	4.9	7.6

Form	Mean	SD
Circle	4.7	5.1
Square	5.9	7.6

Table 5

Means and Standard Deviations of Frequency Data

	Level	Circle		Square	
		Mean	SD	Mean	SD
(3 sec.)	0	2.6	1.3	3.1	1.8
	1	2.5	1.6	3.6	1.2
	2	2.0	.9	3.2	1.6
	3	1.7	1.4	2.5	1.6
	4	2.3	1.6	2.3	2.0
(6 sec.)	0	3.6	.8	4.1	1.0
	1	4.7	.9	4.2	.8
	2	3.4	.7	4.0	1.0
	3	2.8	.9	3.7	1.4
	4	3.5	1.4	3.7	1.7
(9 sec.)	0	4.5	.7	4.4	.9
	1	4.6	.7	4.8	.6
	2	4.2	1.0	4.1	1.2
	3	3.7	1.1	3.9	1.4
	4	4.3	1.0	4.0	1.0

Form	Mean	SD	Level	Mean	SD
Circle	3.3	1.5	0	3.7	1.3
Square	3.7	1.5	1	4.0	1.2
			2	3.4	1.3
			3	3.0	1.4
			4	1.9	1.9

Approved by:

Warren H. Feistner

J. L. Myers
Chief Clerk

Date: November 28, 1960