Eye-movement parameters and pattern discrimination[1]

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Pattern discrimination was studied in a visual-search task by recording an O's eye movements while he determined how many of eight patterns, arranged in a square around a standard pattern, matched the standard pattern. The results demonstrate the role of eye movements in visual search and human pattern discrimination. The mean duration of an eye fixation on a pattern, the probability of fixating it, the probability of refixating it, and the sequence in which patterns were fixated were all systematically related to various pattern measures. Multivariate analyses showed modest correlations between the duration of individual eye fixations and various pattern measures. Relative characteristics of patterns influenced performance more than absolute characteristics of patterns. Patterns that matched a standard were fixated more often and longer than patterns that did not match a standard. The order in which patterns were fixated depended upon their relative characteristics. The results were consistent with a model of pattern discrimination consisting of two stages in which (1) features of a fixated pattern are abstracted and encoded, and (2) these features are then compared with the features of another pattern.

This research used eye-movement recordings to provide insights into how people discriminate among a set of visual patterns in a visual search task. Three eye-movement parameters—the duration, number, and location of eye fixations—are intrinsically involved in visual perception. Systematic correlations of these three eye-movement parameters with changes introduced into the shapes of patterns shown to human Ss have been previously established (Gould, 1967; Gould & Schaffer, 1967). These experiments concluded that the duration of an eye fixation on a pattern correlates with the length of time needed to process it; that whether or not a pattern is fixated foveally depends upon the "similarity" of that pattern to a standard pattern; and that refixation of a particular pattern indicates the need to obtain more information about it.

The general purpose of the present research was to extend these previous findings, which were based upon visual patterns that were essentially histoforms of asterisks generated from 4 by 4 matrices. In this study, a stimulus consisted of a standard pattern surrounded by eight other patterns, all simultaneously presented (Fig. 1). Some of the eight surrounding patterns, called targets, matched the standard, and the remainder of the eight, called nontargets, did not match the standard. The task for S was to determine the number of targets present; his eye movements were recorded while he did this.

The study investigated seven problems.

First, the temporal and spatial variations in S's sequence of eye fixations on the patterns were evaluated to determine what could be learned from them that might lead to a better understanding of human pattern discrimination. Analyses of the temporal variations were based upon the durations of eye fixations on individual patterns. Such measures are finer than the traditionally used response latency measure based upon total time to do a task. Analyses of spatial variations were based upon the sequential order of eye fixations and the probability of S fixating, or refixating, a particular pattern. The results of the present study showed that both analyses led to some similar conclusions, but that each type of analysis provided conclusions not obtainable from the other.

Second, the effects on eye-movement parameters of the size of the matrix from which patterns were generated was assessed. Patterns were generated from 4 by 4, 6 by 6, 8 by 8, and 10 by 10 matrices. The larger the matrix size, the larger the average number of elements in a pattern. The results of this study showed clearly—perhaps surprisingly—that pattern discrimination was not affected by these variations in matrix size.

Third, the effect on eye-movement parameters of the variations in the number of elements in a pattern of a particular matrix size was evaluated. The results of the study showed that variations in the number of elements in target patterns of a particular matrix size affected eye movement parameters differently than did variations in the number of elements in nontarget patterns of the same matrix size. A target pattern was nearly always fixated foveally, whereas the probability of looking directly at a nontarget pattern depended upon its "similarity" to the standard pattern. Duration of fixation on a pattern, however, was determined both by variations in target patterns and by variations in nontarget patterns.

Fourth, an attempt was made to identify the features or variations in patterns, in addition to those specifically manipulated in this experiment, that most affect human pattern discrimination. There presently exists no universal psychophysics of pattern perception. That is, although the three physical variables of intensity, wavelength, and purity account well for the perception of homogeneous visual fields, the physical variables that account for the perception of patterned visual fields have not been satisfactorily identified. This is true even though 100-200

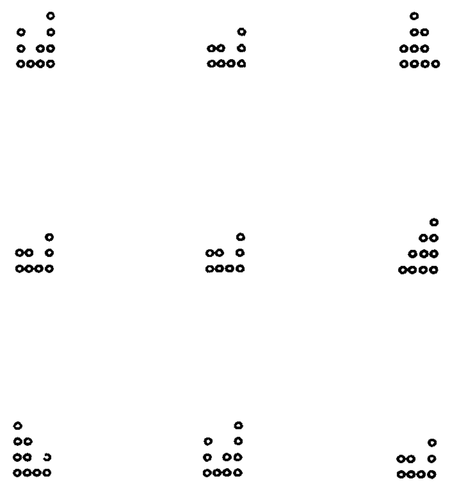

Fig. 1. Schematic of stimulus. Stimuli always contained a center standard pattern surrounded by eight other patterns of asterisks, some of which matched the standard (called targets) and some of which differed from the standard (called nontargets).

different measures of pattern features have been analyzed (Arnoult, 1960; Attneave, 1957; Brown & Owen, 1967; Gould, 1967; Michels & Zusne, 1965; Stenson, 1968; Silver, Landis, & Messick, 1966) in attempts to identify a few measures that are independent of each other and account for most of the variations in patterns and/or in human reaction to them. The results of the present study are consistent with these behavioral studies, as well as neurophysiological ones (e.g., Hubel & Wiesel, 1968), in suggesting that the visual system responds to a large number of different pattern features, rather than to a few "primary" features, as in the case of homogeneous fields.

Fifth, the degree to which the features of patterns that determine one S's eye-movement parameters also determine other Ss' eye-movement parameters was investigated. The significance of this test lies in its implication for identifying measures of basic pattern features that transcend individual differences. The results showed that all Ss were similar with regard to the pattern features that mainly determined their eye movements.

Sixth, the influence on eye-movement parameters of the "absolute" vs "relative" characteristics of patterns was evaluated. Several investigators (Chase, 1968; Egeth, 1966; Gould, 1967; Smith, 1968; Sternberg, 1967) have concluded that pattern discrimination involves two general processes (although different investigators differ on their exact description of the two): (1) abstraction-encoding of pattern features and (2) comparison of these features in the fixated pattern with those features in another (generally "memorized") pattern. Neurophysiological evidence (e.g., Hubel & Wiesel, 1968) relating to the first stage, along with behavioral evidence (Sternberg, 1967), demonstrates that *absolute* features of patterns are abstracted by the visual system. Behavioral evidence based upon errors or latency of the entire discrimination process (i.e., both stages) indicates that *relative*, rather than absolute, characteristics of patterns are the main determinant of pattern discrimination (cf. Garner, 1962; Rappaport, 1957). The present results showed that relative pattern features affect eye-movement parameters more than absolute pattern features do.

Seventh, the serial vs parallel nature of both stages of pattern discrimination was evaluated. Several previous investigations have concluded that serial processing of visual information is involved in pattern discrimination (Chase, 1968; Corcoran, 1967; Egeth, 1966; Gould, 1967; Lindsay & Lindsay, 1966; Neisser, 1963; Sternberg, 1967). The nature of the abstraction-encoding stage was investigated by determining how long S looked at a standard pattern as a function of the number of elements in it. The results of this study were not conclusive. The nature of the feature-comparison stage was investigated by comparing the fixation durations on target patterns with fixation durations on nontarget patterns. The longer fixation durations on targets led to the conclusion that the process of comparing the features of a fixated pattern with those of a standard pattern was serial, and that this process terminated upon the detection of a difference between a standard pattern and a nontarget pattern.

METHOD

Subjects

The Ss, run individually, were 10 paid volunteers from a nearby college.

Procedure and Design

A stimulus consisted of a set of nine patterns arranged in three rows and three columns, as shown schematically in Fig. 1. The Ss were instructed to determine as rapidly as possible, subject to being accurate, the number of target patterns on a stimulus. Target patterns were positioned randomly and varied in number from two to six. Following a ready signal, an overhead projector projected a stimulus on a screen in front of S. Upon completing his scan S pressed a microswitch that closed the solenoid-controlled shutter and stopped a clock, and he then indicated his count of target pattern frequency. The standard pattern was not included in this count.

Table 1
The Number of Filled Cells in a Target or Nontarget Pattern at Each Level of Four Matrix Sizes

Matrix Size	Levels				
	1	2	3	4	5
4 by 4	6	8	10	12	14
6 by 6	11	16	21	26	31
8 by 8	17	27	36	45	55
10 by 10	25	40	55	70	85

All patterns were essentially computer-generated histoforms of asterisks. Every pattern on a particular stimulus was of the same matrix size, i.e., either 4 by 4, 6 by 6, 8 by 8, or 10 by 10. The bottom row of each pattern was always filled; the column heights of patterns varied and the position of different column heights in a pattern was random. These patterns were similar to those of Attneave and Arnoult's Method 3 (1956), Chase (1968), Fitts et al (1956), Gould (1967), and Polidora (1966). For each matrix size, five levels of the number of asterisks in target patterns and five levels of the number of asterisks in nontarget patterns were studied (i.e., a 4 by 5 by 5 design).

The following procedure was used to arrive at these five values, shown in Table 1, for each matrix size. The number of elements contained in the bottom row of each matrix size (4, 6, 8, or 10) was subtracted from the total number of cells in each matrix size (16, 36, 64, or 100). This left remainders of 12, 30, 56, and 90 cells, respectively. Then 1/6, 2/6, 3/6, 4/6, or 5/6 of these remaining cells was added to the number of cells on the bottom row of a matrix to determine the total number of cells to be filled for a particular level and matrix. For example, the fourth level of a 6 by 6 pattern (Table 1) was $6 + 4/6(30) = 26$.

Stimuli were arranged in blocks of 100, corresponding to the 100 experimental conditions (four matrix sizes by five target pattern levels by five nontarget pattern levels). After some initial practice, each S scanned, over a period of seven to nine sessions, two blocks of stimuli. Results are based upon eye-movement records obtained on the second block. When a record was unusable, the record from the first block was substituted.

Five hundred stimuli, one for each of the five target pattern frequencies at each of the 100 experimental conditions, were used. Each stimulus was a photographic negative of a computer-printout, and consisted of nine patterns of light asterisks (about 25 mL) on a darker background (about 1 mL). The angles, subtended at S's eye, by the center-to-center distance of adjacent patterns were approximately constant for each matrix size, about 7 deg horizontally and about 8 deg vertically. Consequently, the size of asterisks and the size of patterns varied somewhat with matrix size. The center-to-center angular subtense of asterisks was between 15-23 min horizontally and 28-37 min vertically. Angular subtense of the asterisks was between 12-20 min.

Apparatus

The eye-movement recording system has been previously described (Gould & Schaffer, 1965). Filmed records of the stimulus field and the positions of the S's fixations within it were obtained using a modified closed-circuit television, corneal reflectance, eye-marker system (Mackworth & Mackworth, 1958). The duration of each fixation (recorded at 20 frames per second) was read from filmed records and, together with a code describing the particular pattern fixated, punched into an IBM card. This

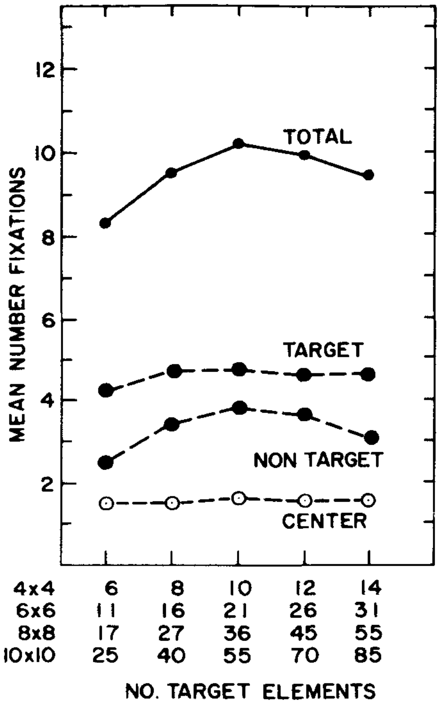

Fig. 2. Mean number of eye fixations on each stimulus as a function of the number of elements in target patterns of each matrix size. Each data point of upper three curves is based upon 200 scores. Each score was the mean from a search trial.

process was repeated for each additional fixation on that trial, resulting in an ordinal record suitable for computer processing of the duration, location, and number of fixations on each trial.

RESULTS AND DISCUSSION

The results showed that mean scan time for each stimulus was 3.48 sec, mean number of fixations was 9.49, and mean duration of fixation was .32 sec. Errors occurred on 68 of the 1,000 records; these records were included in all subsequent analyses.

Matrix Size

Matrix size did not affect mean scan time, errors, mean number of fixations, or mean duration of fixation ($p > .10$ in all cases). This was true even though there were, on the average, about six times as many elements in patterns constructed from 10 by 10 matrices as in patterns constructed from 4 by 4 matrices. Matrix size did not interact with any other independent variable ($p > .10$). This combined absence of a significant matrix effect and interaction suggests that total number of pattern elements per se does not influence eye movements during visual pattern discrimination.

Number of Elements in Target Patterns

Whereas matrix size did not affect the number of eye fixations, variations in the number of elements in patterns within a given matrix size did. Figure 2 shows the significant effect of the number of elements in target patterns of each matrix size on the overall mean number of eye fixations on a stimulus [curve labeled "Total"; $F(4,36) = 22.30$; $p < .001$] and on the mean number of fixations on nontarget patterns [$F(4,36) = 24.98$, $p < .001$]. Data presented below show that these two curvilinear relationships were due to relative pattern characteristics, i.e., similarity between target and nontarget patterns. Number of target elements did not affect number of fixations on target patterns ($p > .05$).

The division, in Fig. 2, of total number of fixations into those on targets, those on nontargets, and those on the center standard (dashed curves) was accomplished, as explained previously (Gould, 1967), by determining the pattern that S was looking at most directly. Of course, other patterns were simultaneously imaged in the periphery of the retina. Since matrix size had no effect on any eye-movement parameter, the curves of Fig. 2 (as well as of Figs. 3-5) are the same for each matrix size.

Whereas Fig. 2 showed the mean *numbers* of eye fixations, Fig. 3 shows the mean *durations* of eye fixations as a function of the number of asterisks in target patterns of a particular matrix size. The number of asterisks in target patterns at each matrix size significantly affected the mean duration of all eye fixations (solid curve), of fixations on targets only, of fixations on nontargets only, and of the initial fixation on a standard pattern (labeled "First") (all $p < .001$). All four curves of Fig. 3 had both significant linear and significant quadratic components (all $p < .01$).

Durations of fixations on target patterns were longer than durations of fixations on nontarget patterns [$F(1,9) = 87.45$; $p < .001$]. Initial fixations on standard patterns were longer than subsequent fixations on target patterns, identical to the standards [$F(1,9) = 41.4$; $p < .001$].

Number of Elements in Nontarget Patterns

The number of elements in nontarget patterns of a particular matrix size (Fig. 4) had about the same effect on the *number* of eye fixations as did the number of elements in target patterns of a

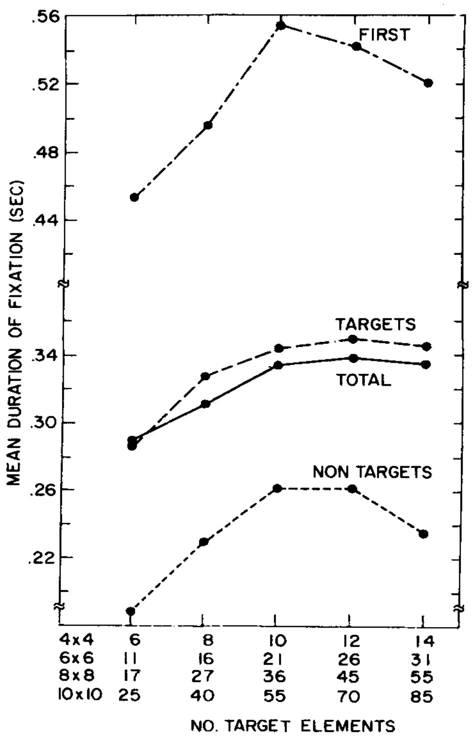

Fig. 3. Mean duration of eye fixations on each stimulus as a function of the number of elements in target patterns of each matrix size. Each data point of all curves except those of the "center" curve is the mean of the mean fixation durations from 200 search trials.

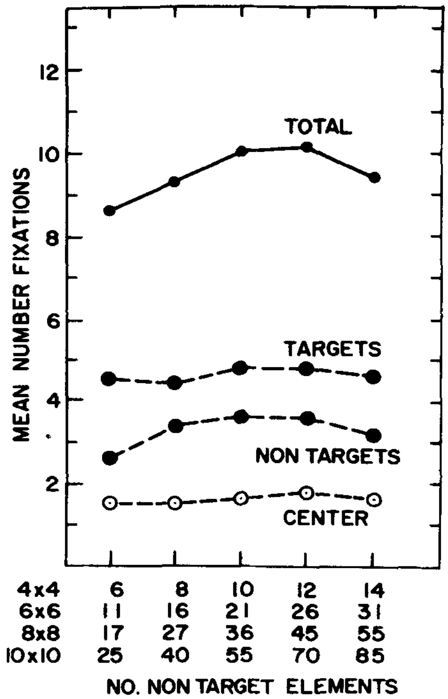

Fig. 4. Mean number of eye fixations as a function of the number of elements in nontarget patterns of each matrix size.

particular matrix size (Fig. 2). Number of fixations on nontarget patterns was significantly affected [$F(4,36) = 34.19$; $p < .01$], whereas number of fixations on target patterns was only slightly, but significantly [$F(4,36) = 4.21$; $p < .01$] affected.

The number of elements in nontarget patterns of a particular matrix size had about the same effect on the *durations* of eye fixations on target patterns and on nontarget patterns (Fig. 5) as did the number of elements in target patterns (Fig. 3). The mean durations of fixations on target patterns were modified slightly, but significantly [$F(4,36) = 4.36$; $p < .01$]. The mean durations of fixations on nontarget patterns showed a curvilinear relationship (significant quadratic component, $p < .001$). The durations of fixations on standard patterns were not significantly affected by the number of nontarget elements, whereas they were curvilinearly related to number of target elements (upper two curves of Fig. 3).

Interaction Between Target and Nontarget Elements

If fixation durations were influenced mainly by absolute characteristics of patterns, then they would be independent of any combined effect of target and nontarget patterns and dependent upon only the individual characteristics of a fixated pattern. The combined effect of the level of target elements and the level of nontarget elements on fixation duration shown in Fig. 6 demonstrates the dominance of relative pattern characteristics, however. Note the systematic nature of this interaction [$F(4,36) = 30.26$; $p < .001$]. Fixations were longest when the level of target elements equalled the level of nontarget elements, and they were nearly always shortest when the absolute difference in the level of target elements and level of nontarget elements was largest.

The data of Fig. 6 support a previous finding (Gould, 1967) in which an index, called a "similarity" index for easy reference and based upon the absolute difference between the level of target elements and the level of nontarget elements, was one of the better predictors of the duration of an individual eye fixation. Figure 7 replots the data of Fig. 6 and shows the linear relationship of the mean duration of fixations on both targets and nontargets with this index; the smaller the value of the index, the greater the pattern similarity.

Underlying Pattern Measures

The features of visual patterns can be described by 100-200 other measures, in addition to those systematically varied in this research (Attneave & Arnoult, 1956; Brown & Owen, 1967; Michels & Zusne, 1965). Results based upon analyzing the duration and number of eye fixations in terms of about 40 such measures will now be given.

Measures based upon the *absolute* features of individual patterns, e.g., number of sides, perimeter, dispersion, or total number of elements (without regard to matrix size) in a pattern, generally showed no clear-cut, systematic relationship to the duration of an eye fixation.

Measures based upon *differences* between the features of a standard pattern and the features of a fixated pattern, e.g., differences in the number of sides, perimeter, or dispersion of a fixated pattern and a standard pattern, showed some systematic effect on the duration of the fixated pattern. However, the usefulness of these difference measures was usually affected by matrix size, since differences tended to be larger for larger matrices.

Measures based upon *ratios* of the features of a standard pattern and the features of a fixated pattern showed systematic relationships to the duration of an individual eye fixation. For example, Fig. 8 shows a general decrease in the mean duration of fixation with an increase in the ratio of the number of elements in a fixated pattern and the number of elements in its standard pattern ($r = -.29$; $p < .01$). This decrease in fixation duration occurred up to a ratio of 1.7. Patterns with ratios greater than 1.7 were fixated for only about 200 msec, which approaches the

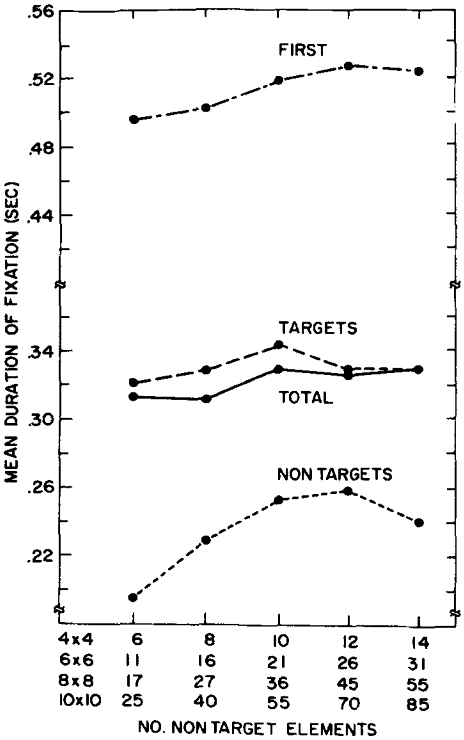

Fig. 5. Mean duration of eye fixations as a function of the number of elements in nontarget patterns of each matrix size.

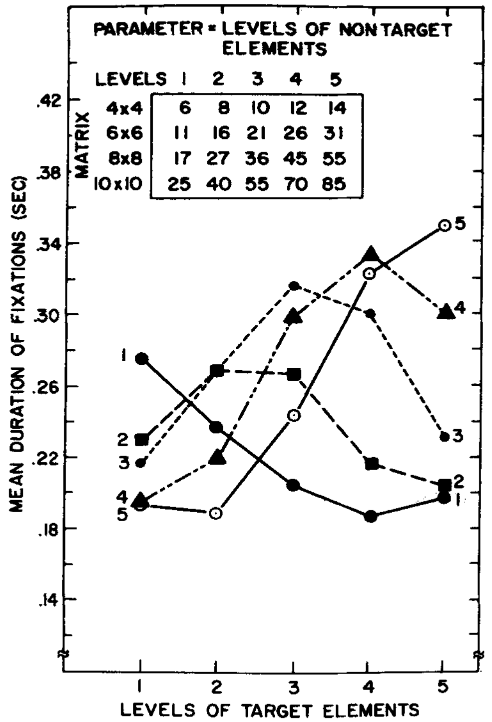

Fig. 6. Mean duration of eye fixations as a function of the level of asterisks (i.e., the number of asterisks at a particular matrix size) in target patterns (abscissa) and the level of asterisks in nontarget patterns (parameter of the curves).

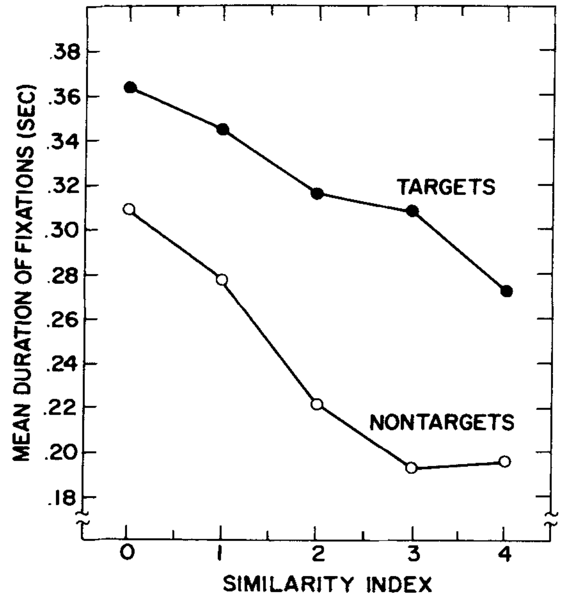

Fig. 7. Mean duration of eye fixations on targets and on nontargets as a function of the absolute difference between the level of target elements and the level of nontarget elements.

average reaction time of the eye (Luckiesh, 1937; Rashbash, 1961; Wheeless, Boynton, & Cohen, 1958). In computing this ratio, and all subsequent ones, the larger value is always in the numerator, resulting in a minimum ratio of 1.0. This was done to provide monotonic functions. When the ratio of a fixated pattern

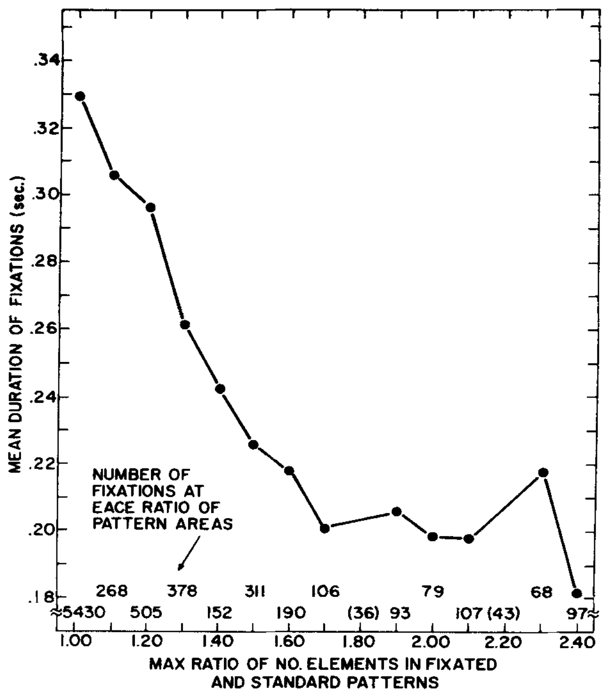

Fig. 8. Mean duration of fixations as a function of the maximum ratio of the number of elements in the fixated pattern and the number of elements in its standard pattern. A value on the abscissa corresponds to the upper bound of an interval. The number of fixations that each data point is based upon is given at the bottom of the graph.

to its standard (or vice versa) was plotted instead, fixation duration was symmetrical around a ratio of 1.0.

A measure based upon squaring the perimeter of a pattern and dividing this product by its area has been frequently used in pattern discrimination studies (cf. Behrman & Brown, 1968). In Fig. 9 the mean duration of an eye fixation is plotted against the maximum ratio of this measure (substituting number of elements for area) for the fixated standard patterns. Fixation duration decreases with increases in this ratio ($r = -.19$; $p < .01$).

Figure 10 shows a decrease in the mean duration of an eye fixation as the ratio of the third moments of areal dispersion (distribution of distances of each asterisk from the centroid of the pattern) of the fixated pattern and the standard pattern increases. This decrease tapers off at about 220 msec.

Figure 11 shows a linear increase in the duration of an eye fixation with an increase in a measure based upon the number of common filled cells contained in the fixated pattern and the standard pattern divided by the squared rank of the matrix ($r = .25$; $p < .01$).

It is clear from Figs. 7-11 that several pattern measures (and others not reported here) show systematic relationships with the *mean* duration of fixations. These measures do not, however, predict the duration of an *individual* eye fixation very well, as seen from the associated, small correlation coefficients based upon individual fixations (all $r < .30$; all $p < .01$). Of course, these coefficients increase when S's *mean* fixation durations are used (Gould, 1967). The relationships between fixation duration and relative pattern characteristics (Figs. 7-11) form the basis for the curvilinear relationships of Figs. 3-5 described earlier.

The results of Figs. 7-11 demonstrate that many pattern measures were related to fixation duration. In order to determine the pattern measures that, independent of other pattern

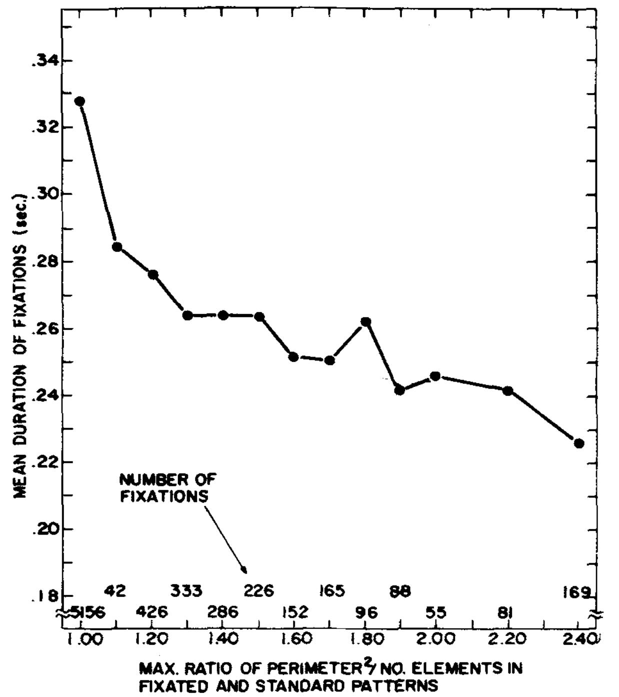

Fig. 9. Mean duration of eye fixations as a function of the maximum ratio of A and B, where A is the quotient of the squared perimeter divided by the number of elements in the fixated pattern and B is the same quotient for the standard pattern.

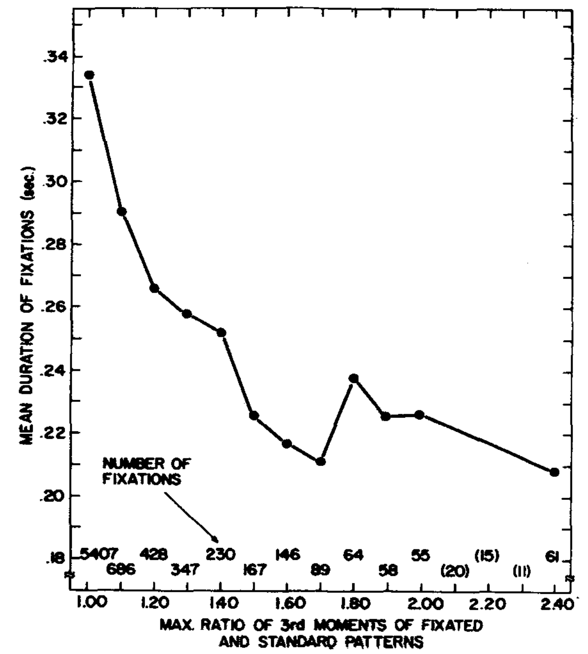

Fig. 10. Mean duration of eye fixations as a function of the maximum ratio of the third moment of areal dispersion of the fixated pattern and that of its standard pattern.

measures, best predicted the duration of an individual fixation, two statistical methods used in previous studies of pattern discrimination (Brown & Owen, 1967; Gould, 1967; Polidora,

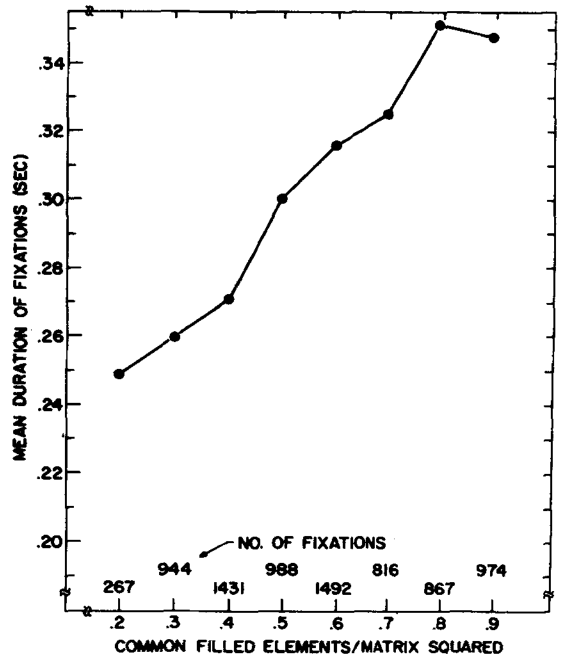

Fig. 11. Mean duration of eye fixation as a function of the measure based upon the common filled elements in a fixated pattern and standard pattern divided by the squared size of the pattern matrix.

1966) were applied to the data. Partial correlation coefficients provided the correlation between fixation duration and a particular pattern measure, with all other pattern measures in the analysis held constant. Factor analysis identified measures that "independently" predicted fixation duration through high loading on one dimension but low loadings on others.

The net results of these attempts to predict *individual* fixation durations were multiple r's between .35 to .45 ($p < .001$). This range reflects corrections, e.g., for each S's overall mean, transformations of the data, and various combinations of predictors, as well as additions and subtractions of pattern measures. The partial correlation coefficients of the better predictors were around .20 ($p < .01$).

The prediction equation and its weights for the four best predictors (multiple $r = .38$; $p < .001$) were similar to Gould, 1967:

$$\log_{10} \text{Dur} = .0554 \text{ Tar} - .0269 \text{ Sim} + .1407 \text{ Rcmfl} - .0762 \text{ Relem} - .5338$$

where Dur is the duration of an eye fixation in seconds; a 1.0 or 0.0 is assigned to Tar if the fixated pattern is a target or nontarget, respectively; Sim is the similarity index previously defined; Rcmfl is the number of common filled cells in the standard and target divided by the matrix rank; and Relem is the maximum ratio of the number of elements in the standard and fixated patterns. An uncertainty reduction measure, based upon the statistical probability of each pattern occurring in the population of patterns (cf. Garner, 1962) did not contribute to prediction accuracy.

Refixations

An S typically did not look back and forth in discriminating between a fixated pattern and its standard pattern. This suggests

Table 2
Summary of Performance of Individual Subjects

Subject	Scan Time (sec)	Mean No. Fixations	Mean Duration Per Fixation (sec)	Multiple r Based on Pattern Measurements
1	3.67	10.8	.31	.50
2	4.17	10.8	.33	.41
3	2.94	8.5	.32	.47
4	2.95	7.9	.33	.48
5	4.36	9.2	.44	.54
6	3.19	9.3	.30	.36
7	4.15	10.3	.35	.49
8	2.79	8.7	.29	.47
9	2.28	8.5	.22	.33
10	4.33	10.8	.34	.42

that in some sense the standard pattern was stored by S. Of the refixations that did occur, about twice as many were on targets as on nontargets. There were 675 refixations of the 4,000 targets and 360 refixations of the 4,000 nontargets. A standard pattern was refixated less than once per stimulus (601 refixations of the 1,000 standards).

Short Duration Fixations

Occasionally very short duration eye fixations were found. Of 9,545 fixations, 24 did not exceed 50 msec (one camera frame), an additional 316 did not exceed 100 msec, and an additional 798 did not exceed 150 msec. This finding is significant in showing that minimum reaction time for saccadic eye movements, which has been studied for other tasks (Luckiesh, 1937; Rashbash, 1961; Wheeless, Boynton, & Cohen, 1958), can be less than 150 msec in a search task.

Individual Differences

The same pattern measures that were the best predictors of one S's fixation durations were also the best predictors of other Ss' performance. Based upon an analysis of 21 pattern measures, at least two of the three best predictors for each S were shared in common by every other S. Multiple correlation coefficients, obtained for each S individually, were .33-.54 ($p < .001$). The three best predictors were Sim, Rcmfl, and Relem.

Individuals who tended to be fast scanners, in terms of overall time to scan, tended both to make fewer eye fixations and have shorter durations of these eye fixations that did Ss who tended to be slower scanners. Table 2 shows this and also indicates that the faster scanners have lower individual multiple r's, based upon the analyses of pattern measurements just discussed, than do the slower scanners. This latter result suggests that the better an individual is at scanning tasks, the less predictable are the stimulus characteristics to which he responds.

Conclusions from Fixation Durations

The data on durations of eye fixations lead to several conclusions, all consistent with previous work (Gould, 1967; Gould & Schaffer, 1967).

First, fixation durations tend to be longer when patterns of a particular matrix size contain more and more elements; fixation time per pattern element is not a constant, however. The longer overall fixation durations are due mainly, but not entirely, to longer fixations on nontarget patterns.

Any inference from the data of this study concerning serial vs parallel processing of patterns involves assumptions about two unknown relationships. First, since it is clear on logical grounds that individual elements of patterns are not processed by the visual system, the relationship between the number of elements in a pattern of a particular matrix size and the number of features in that pattern that are processed by the visual system must be assumed. Second, the relationship between fixation time and processing time must be assumed. The first relationship is assumed to be monotonic because of the positive correlations shown by Brown & Owen (1967) to exist among so many pattern features, and the second relationship is assumed to be monotonic because S is instructed to look at a pattern as briefly as possible. The next two conclusions are concerned with serial vs parallel processing during the abstracting-encoding stage and the feature-comparison stage of pattern discrimination, respectively.

Second, the durations of initial fixations on standard patterns (curves of Figs. 3 and 5 labeled "First") reflect their abstraction-encoding times. These durations are directly related to the number of elements in standard patterns (significant linear component in Fig. 3), are independent of the number of elements in nontarget patterns (Fig. 5), and are independent of the relationships between targets and nontargets (no Target Element by Nontarget Element interaction). But it cannot be concluded with certainty that pattern features are sequentially or serially abstracted and encoded. Data presented below will show that these fixation durations on standards also reflect the time for processing gross information about surrounding patterns.

Third, Ss looked longer at target patterns than at nontarget patterns. This suggests that the features in a fixated pattern are compared with the features in a "memorized" standard pattern in a serial or sequential manner and that this comparison process terminates upon the detection of a critical difference between the two patterns. More feature comparisons, hence longer fixation durations, are needed to detect a target, or match of fixated and standard patterns, than to detect a nontarget, or difference in fixated and standard patterns. Egeth (1966) and Neisser (1963) also conclude that pattern discrimination involves a serial comparison process and that Ss do not examine all stimulus features exhaustively. With practice (Neisser, Novick, & Lazar, 1963), with highly codeable (i.e., "familiar") stimuli (Bindra, Donderi, & Nishisato, 1968), or with strong stimulus-response associations (Morin et al, 1965) these serial comparisons probably become parallel.

An alternative explanation, in terms of a parallel comparison process, would assume a set of parallel feature processors, all of which start simultaneously but terminate at different times, with the comparison time based upon the longest-lasting parallel feature processor (Sternberg, 1966).

Fourth, initial fixations on standard patterns were longer, often twice as long, as subsequent fixations on target patterns, even though a standard pattern and its targets were identical. One explanation of this result may be that the encoding of a standard pattern sensitizes the encoding of identical ones (targets) or related ones (nontargets) that are subsequently fixated foveally. This sensitization reduces their abstraction-encoding time. Alternatively, this difference may be due to extra-long fixations on the standard, rather than to a reduction in fixation time on targets. A third explanation might be that sufficient information about targets and nontargets was processed when they were originally fixated peripherally so as to reduce their minimum fixation times when they were subsequently fixated foveally.

Fifth, although the durations of eye fixations on standard patterns were determined mainly by *absolute* pattern characteristics, durations of eye fixations on the other patterns were determined mainly by *relative* pattern characteristics.

Sixth, the absolute features in target and nontarget patterns were not systematically related to fixation duration. Hubel & Wiesel (1968) have shown that the absolute features of a pattern are encoded by the visual system. Consequently, it appears that fixation duration may be independent of the *encoding* process in a comparison task. The relative features, on the other hand, did

Table 3
Proportion of Fixations on Targets*

	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	...	Nth	Over-All Means
					Order of Fixations								
Similarity Index**													
0	.00	.52	.47	.51	.43	.49	.45	.48	.55	.48	....		.47
1	.00	.59	.54	.48	.50	.53	.54	.47	.42	.43	...		.50
2	.00	.71	.61	.60	.58	.58	.54	.51	.44	.46	...		.57
3	.00	.79	.73	.60	.65	.62	.54	.57	.48	.52	...		.64
4	.00	.84	.77	.82	.70	.65	.68	.59	.82	.80	...		.75
													.54***

** Proportion* = $T / T + \bar{T} + C - 1000$
*** Similarity Index = Absolute Value of Target Level Minus Nontarget Level*
**** Weighted Grand Mean*

Table 4

	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	...	Nth	Over-All Means
					Order of Fixations								
Proportion of Fixations on:													
Targets	.00	.66	.59	.56	.54	.55	.53	.50	.48	.47	...		.54
Nontargets	.00	.34	.32	.36	.39	.37	.40	.45	.44	.45	...		.39
Center	1.00	.00	.08	.08	.07	.08	.07	.05	.08	.08	...		.07
Total Number of Fixations	1000	1000	1000	997	979	939	883	796	645	432	...		9486

determine how long a pattern was fixated. This suggests that variation in the length of time a person looks at a pattern is due, at least in part, to the process of *comparing* the absolute features of a fixated pattern with the absolute features of a standard pattern. Thus, variations in color, size, brightness, shape of stimuli may have little effect on encoding time, whereas similarity among stimuli may have a relatively large effect on comparison time, which in turn affects fixation duration.

Seventh, pattern features that significantly affect fixation duration, or other latency measures (Brown & Andrews, 1968) are many, not few. This is not surprising in view of Hubel and Wiesel's (1968) work showing the number of classes, and specialization within classes, of neural units sensitive to specific pattern features.

Eighth, the results of multivariate analyses do not account very well for individual eye fixation durations, or other latency data (Brown & Andrews, 1968). It is possible, although unlikely, that the lack of success with this approach was due to not including in the analysis the appropriate, albeit elusive, pattern measures. Alternatively, fixation duration may not be an appropriate dependent variable, either because it is not very well related to pattern discrimination or else because it reflects a number of other variables that have not been eliminated from it. A third possibility is that the recording accuracy of 50 msec resulting from recording eye movements at 20 frames/sec is so gross as to obscure the relationship that is sought.

Spatial Analysis

By analyzing the location of each eye fixation it is possible to make inferences about S's search process. Table 3 shows that there was a greater proportion of fixations on targets (54%) than on nontargets (39%), even though, overall, an equal number of target and nontarget patterns was presented to each S. The fixation immediately following the initial fixation of the standard, i.e., the second fixation, was about twice as likely to be on a target as on a nontarget pattern. Thus, while S was looking directly at the standard he was also processing information about peripheral patterns. This suggests that abstraction-encoding of the standard pattern is not necessarily completed prior to comparison of some of the features in it with features in a target or nontarget. Crovitz and Davis (1962) showed that the direction of an eye movement following offset of a tachistoscopically presented display correlated highly with the part of the display most accurately reported by S. Throughout the sequence of fixations, the tendency to fixate target patterns over nontarget patterns was progressively reduced, partly because there were fewer remaining targets to fixate.

Target patterns were usually fixated once, whereas the probability of fixating a nontarget depended upon its relation to target patterns. Of the 4,000 target patterns presented, 72 were not directly fixated, whereas of the 4,000 nontarget patterns presented, 1,078 were not directly fixated. As shown in the last column of Table 4, when patterns were quite similar target patterns were fixated about as frequently as nontarget patterns. However, as patterns became less and less similar, target patterns were fixated progressively more often than nontarget patterns. Indeed, at the level of least similarity (Level 4) three times as many fixations were on target patterns as on nontarget patterns. Thus, for high target-nontarget similarity, the feature analysis of both targets and nontargets must be precise and requires foveal fixation of each pattern; for low target-nontarget similarity the precise foveal feature analysis of targets operates in parallel with gross feature analysis of nontargets occurring in the periphery of the eye.

The order in which patterns were fixated by individual Ss depended upon pattern similarity. On stimuli with highly similar patterns (Level 0), Ss tended to follow their own particular order of looking at them, regardless of where targets or nontargets were located. Although different individuals had different scan orders, each individual was fairly consistent within himself from stimulus to stimulus. The scan order of each S became more and more dependent upon the location of targets and nontargets for patterns that were less and less similar. Targets were still almost always fixated centrally but nontargets were not, i.e., they were sometimes "skipped" (Table 4). This suggests that peripheral fixation of a pattern is sometimes sufficient to indicate that a pattern is a nontarget, but central fixation is usually necessary to determine that a pattern is a target.

Pattern similarity affected refixations of nontargets, but did not affect refixations of targets. There were twice as many refixations of the standard and 25 times as many refixations on nontargets when patterns were most similar (Level 0) as when patterns were least similar (Level 4).

The final three figures show that the frequency or

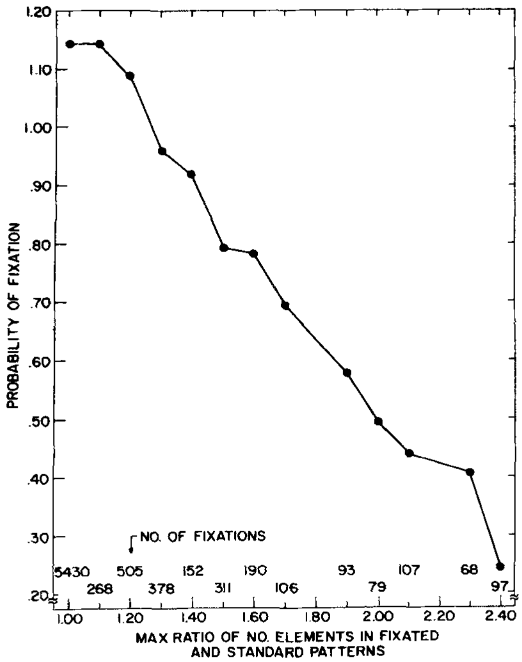

Fig. 12. The probability of fixating a pattern as a function of the maximum ratio of the number of elements in it and the standard pattern.

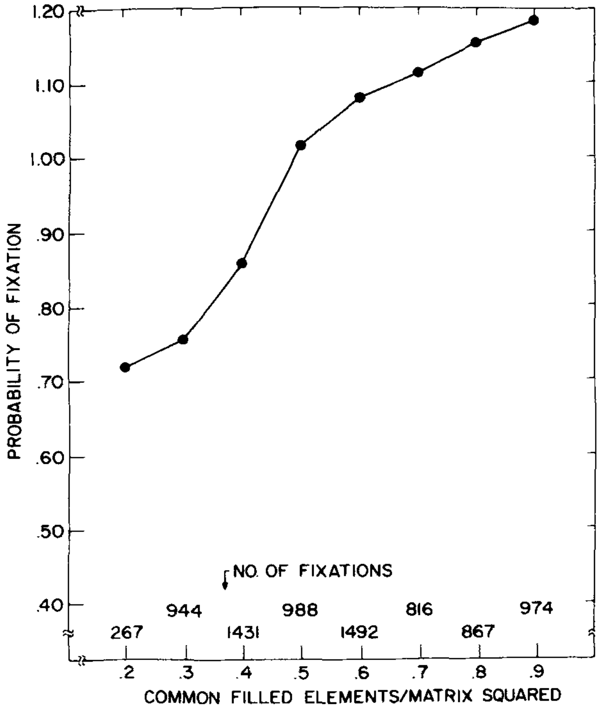

Fig. 13. The probability of fixating a pattern as a function of common filled elements in it and the standard divided by the square of the matrix rank.

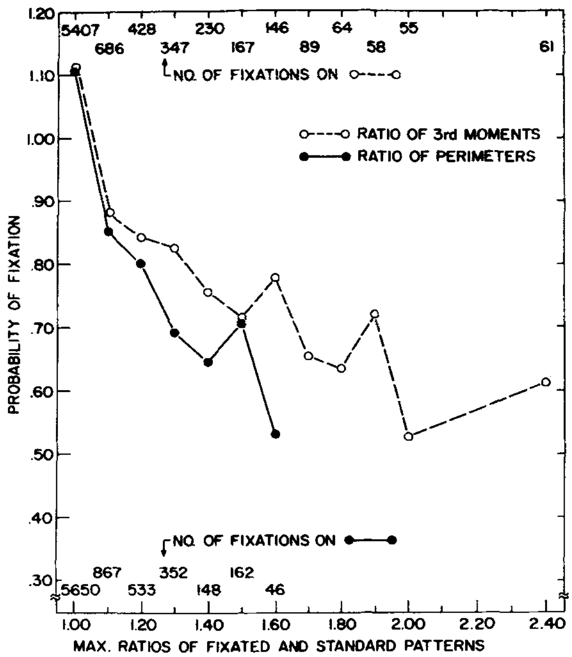

Fig. 14. The probability of fixating a pattern as a function of two different pattern measures. The dashed curve is based upon the ratio of the third moments of areal dispersion of the standard and fixated pattern; the solid curve is based upon the ratio of the perimeters of the two patterns.

"probability" of fixating patterns was systematically related to certain pattern measurements. In these figures, the "probability" exceeds 1.00 because refixations are included.

Figure 12 shows that the probability of fixating a pattern systematically decreased as the ratio of the number of elements in it and the standard pattern decreased. When one of these patterns had more than twice as many elements as the other, the probability of fixating it was less than 0.5. This suggests that for ratios larger than 2.00, S may reject a nontarget on gross features such as brightness or size.

Figure 13 shows that the probability of fixating a pattern systematically increased with increase in the measure based upon the number of common filled cells in it divided by the squared matrix rank. A pattern was always directly fixated when this measure exceeded 0.5. This suggests that the number of required feature comparisons increases with increases in the number of features that the two patterns have in common.

Figure 14 shows that the probability of fixating a pattern systematically decreased with either a decrease in the ratio of the perimeters, or of the third moments of areal dispersion, in the fixated and standard patterns.

In summary, Tables 3-4 and Figs. 12-14 emphasize that the fixation position of the eyes during visual search and pattern discrimination is systematically related to pattern characteristics. Williams (1967) has recently demonstrated this also.

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NOTES

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