The effects of area and perimeter on detection rates¹

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The detection of luminance increments in a homogeneously lighted field was studied as a function of the area and perimeter of the luminance increment. Sixteen targets representing all possible combinations of four values of area and four values of perimeter were forcibly presented. Exposure durations were short (25 to 40 msec). Results of both an analysis of variance and linear discriminant analysis indicated that detection probability increases as area increases, but neither variations in perimeter nor perimeter-area combinations produced effects that were significant over the experiment as a whole. The linear discriminant analysis revealed individual differences in the effects of perimeter and area on detection probability. Results were contradictory to Kristofferson's (1957) "element contribution theory" and gave only slight support to Hecht's (Lamar, Hecht, Shlaer, & Hendley, 1947) "border-quantum theory."

If a portion of a field of homogeneous luminance is given a luminance increment and S is asked to detect this luminance increment, his probability of doing so has been shown to be a function of the luminance values involved, exposure duration, retinal locus, and percentage of area associated with each value of luminance. In addition to these variables, previous research suggests that the shape of the contrasting areas may be a relevant variable. The exact relationship of this latter variable to the probability of detection is still uncertain and two contradictory theories have been advanced to explain obtained results.

Physiological studies of the eye have shown interaction effects among retinal receptors. The reception of light in a given receptor affects the reception of light in other receptors of the retina (Hartline & Ratliff, 1958; Ratliff & Hartline, 1959). Two types of interaction effects have been discovered, inhibition and enhancement. Hartline and Ratliff (1958), on the basis of their investigations of inhibition in the eye of *Limulus*, concluded that the function of inhibition seemed to be the accentuation of contours. This finding suggests that variations in perimeter or shape for a given area might effect the probability of detection.

One of the earliest visual detection theories was formulated by Graham, Brown, and Mote (1939). The total area of detection target is considered to be composed of many unit elements of area with the contribution of each of these elements a function of their distance from the center of the target. The relative contributions of elements is a power function of their distance from the center of the target with those elements at the center contributing the most and those farthest from the center the least.

Kincaid, Blackwell, and Kristofferson (1960) have modified Graham et al's (1939) theory slightly. Instead of making the arbitrary assumption that the element contribution function obeys a power law they empirically derived the function. This theory is called an "element contribution theory."

Lamar, Hecht, Shlaer, and Hendley (1947) proposed a "border-quantum theory" which stresses the importance of boundary dimensions rather than area per se in determining detection thresholds. They developed an equation involving measures of perimeter and a concept they called "useful area" (UA). For background intensities (I) of 17.5 ft-L UA was found empirically to be the area within 1.5 min of visual angle of the detection target. Their data fit the following equation fairly well:

$$\frac{\Delta I}{I} = \frac{C \times P^{2/3}}{UA}, \quad \begin{array}{l} C = \text{a constant} \\ P = \text{perimeter} \end{array}$$

The experiment upon which this theory is based is not a pure detection study however. The Ss were required to recognize the

orientation of the rectangles. The theory is also not a pure border theory for it was found that increases in the total area were always accompanied by increases in UA.

According to the element contribution theory, for targets of a given area the circle will have the lowest detection threshold; the less circular a form the higher the detection threshold. The border-quantum theory, on the other hand, predicts that increasing perimeter with area held constant should lower the detection threshold, that is, the less circular the detection target the greater the probability of detection. Both theories predict that increasing area with perimeter held constant will increase the probability of detection.

Nachman (1957) attempted to test the incompatible predictions of these two theories and found the border-quantum theory to be more compatible with his data. He concluded that detection thresholds are determined by boundary dimensions rather than area. However there are some aspects of this experiment which make his rejection of the element contribution theory seem a bit hasty. The exposure duration used was 3 sec. When this is compared with the .01 sec value used by Kristofferson (1957), it is questionable whether the results of Nachman (1957) and Kristofferson (1957) can be compared. Nachman (1957) also used only rectangles as did Hecht and his associates (1947). Kristofferson (1957) used various figures and found that the data for rectangles fit his theory less well than data for other figures. Perhaps if Nachman (1957) had used an exposure duration comparable to Kristofferson's (1957) and any form other than a rectangle, his results might have been more consistent with the element contribution theory.

The present experiment was designed to determine the effects of both the perimeter and area of constant luminance increment on detection probability. It avoided some of the weaknesses of Nachman's (1957) experiment by using shorter exposure durations (.025 to .040 sec as opposed to 3 sec) and targets similar to ellipses rather than rectangles.

METHOD

Apparatus

The equipment was similar to that used by Kristofferson (1957) and Nachman (1957). An electronic timing device controlled the duration of an electric pulse delivered to a Sylvania F4T5/CWX fluorescent bulb, used because of its rapid onset-offset characteristics. Light from the bulb passed from one end of the light tunnel through an Alphax diaphragm opened to a diameter of about 1 cm, through an achromatic collimating lens with a focal length of 561 mm and a diameter of 130 mm, through a 1/8 in. thick milkglass screen, to the eye of the S. The interior of the light tunnel was painted flat black to minimize light reflection. The milkglass screen had the same dimensions as the cross-section of the light tunnel, 5½ x 6 in., and was centered in a frame of white cardboard 26 in. high and 32 in. wide. Two 25 W bulbs directed toward the screen, one to the right and one to the left of the S, provided background illumination. Each bulb was positioned at the same height as the milkglass screen and 45 in. from its center. Imaginary lines from the bulbs to the screen made a 58 deg angle with the plane of the screen with the vertex at its center. The bulbs provided a luminance of 2.22 ft-c measured at a distance of 13 in. from the center of the screen. The S sat facing the screen at a distance of 84 in. measured from the bridge of his nose.

The detection targets were inserted in a slot in the light tunnel ½ in. behind the milkglass screen. When the bulb was illuminated a well defined image of the form appeared on the screen as a light increment. The luminance of the image was 2.48 ft-c, representing a luminance increment of .26 ft-c.

Ellipselike forms composed of four circular arcs, two of a given radius and two of a smaller given radius, were used as targets. Such forms can be constructed having specified areas and perimeters with the restrictions that for a given area there is a minimum value of perimeter possible and for a given perimeter there is a maximum value for area. These restrictions were considered when values of area and perimeter were selected for the experiment.³

A pilot study was conducted to check equipment and procedure and to determine area values to be used in the experiment. Circular forms of various areas were used as stimuli. One S was run on all area values using a constant light duration of 65 msec. The circle detected accurately 60% of the time had an area of 4.0 cm², and was chosen as the smallest area for any form used in the experiment. The circle detected accurately 80% of the time had an area of 16.0 cm², the largest area to be assigned a form. Areas corresponding to these levels were chosen because at 60% accuracy S is operating slightly above chance but with an 80% or more accuracy rate he may become complacent and inattentive.

To determine the effects of perimeter on detection rate, the maximum possible range of perimeter values was used. The smallest perimeter value, 14.1 cm, was that of the circle having an area of 4.0 cm². An upper limit on perimeter value was imposed so that all forms would lie within a visual angle of 3 deg, thus limiting the maximum dimension of a form to 10.1 cm (perimeter is always greater than or equal to twice the maximum dimension).

Values of area and perimeter were increased in equal steps. The areas used were 4.0, 8.0, 12.0, and 16.0 cm² and the perimeters 14.1, 16.4, 18.7, and 21.0 cm. Each value of area was paired with each value of perimeter, resulting in 16 different forms. After solving the set of equations expressing the parameters to be used in constructing the ellipselike forms as functions of their areas and perimeters, they were drawn on black construction paper, cut out, pasted in the center of a piece of white cardboard, and photographed. Negatives of the photographed forms were made on Kodalith, tri-acetate base high contrast film. Cardboard frames having outer dimensions the size of the cross section of the light tunnel, enclosed the films. Thus only the light passing through the transparent form appeared on the milkglass screen as a light increment.

A temporal interval forced-choice technique was employed. On

each trial the sequence was as follows: 1-sec tone, 2 sec of silence, 1-sec tone. The light pulse was randomly contingent with the onset of either the first or the second tone. The purpose of the tone was to identify the two 1-sec intervals, during one of which the light pulse occurred. The tone system and lamp timer were connected. They in turn were connected to a switch, thus permitting E to control the tone-light contingency.

Subjects

Four paid Ss were used, two graduate students, GR, a female, and HW, a male, and two female undergraduates, DG and MS. All Ss had had previous experience in perception experiments. Each S worked five consecutive nights per week. GR ran at 6:30, HW at 7:30, DG at 8:30, and MS at 9:30. Sessions, including rest periods, lasted about 50 min.

Each S was given three practice sessions to familiarize him with and correct any misconceptions about the task. Using a forced-choice technique an exposure duration was selected for each S that yielded 65% accuracy in the detection of the smallest form to be used in the experiment. By equating Ss' performances on the same form, effects of individual differences were minimized. The exposure durations selected were 25 msec for GR and HW, 41 msec for DG, and 34 msec for MS. These durations were held constant throughout the experiment.

Before each experimental session S was allowed 5 min to adapt to the level of illumination in the room and to practice. At least 10 nonrecorded trials were given and if S felt he had not yet adapted to the setting and procedure, he was allowed additional trials. The detection targets were presented in random orders constructed from tables of random numbers. At the conclusion of the 5-min warm-up period S was run through 20 trials of approximately 20 sec per trial duration, and allowed 2 min of rest, followed by 20 more trials, etc., until five blocks of 20 trials were completed. Each S completed 16 experimental sessions during which each detection target was presented a total of 100 times.

RESULTS

The proportion of trials in which S correctly identified the light-tone contingency was determined for the 50 odd trials and 50 even trials for each combination of area and perimeter. No corrections for guessing were made. The data are presented in Table 1.

Table 1
Proportion of Correct Detections on Odd and Even Trials

	GR perimeter				DG perimeter			
	14.1	16.4	18.7	21.0	14.1	16.4	18.7	21.0
4.0	60	64	66	70	62	68	52	64
	64	66	68	58	66	66	72	68
8.0	62	58	68	78	72	76	78	70
	70	72	70	72	82	76	68	66
area					area			
12.0	72	62	70	68	70	80	86	88
	62	52	64	70	82	86	82	86
16.0	70	62	78	72	88	88	94	86
	70	66	62	86	98	82	90	96
	HW perimeter				MS perimeter			
	14.1	16.4	18.7	21.0	14.1	16.4	18.7	21.0
4.0	60	46	72	58	62	62	70	54
	58	62	68	58	48	60	74	66
8.0	65	88	56	64	70	74	71	78
	69	72	64	78	74	68	67	86
area								
12.0	56	74	78	70	80	78	84	88
	74	68	64	76	70	70	84	78
16.0	82	70	80	80	74	76	94	94
	90	86	78	86	76	74	90	92

Fig. 1. Linear discriminant functions.

A three-way mixed model analysis of variance with area and perimeter treated as fixed factors and Ss treated as random factor was performed. The main effect for area yielded an $F(3,9)$ of 10.6, $p < .01$. The $F[(3,9) = 2.97]$ for Perimeter was not significant at the .05 level nor was the Area-Perimeter interaction [$F(9,27) = 1.9$].

Also, the data for each S were analyzed separately using linear discriminant analysis (Hake, Faust, McIntyre, & Murray, 1967; Cooley & Lohnes, 1962). With this analysis it is useful to assume that S sorts the detection targets into two different categories; the correct one when he identifies the light-tone contingency and the incorrect. If perimeter and area affect the detection rate of S then he should differentially sort the various perimeter-area combinations into the correct and incorrect categories. The linear discriminant, estimated by the distance between centroids of the correct and incorrect categories, is a measure of the extent to which this occurs. The centroid is obtained by weighting each value of area (perimeter) by the number of times it is sorted into the category and determining the weighted average. If there is no appreciable correlation between area and perimeter within the categories, then the distance between the two centroids in standard score is a very close estimate of the linear discriminant.⁴

The plots of the linear discriminant functions for each S are shown in Fig. 1. Correlations between perimeter and area within both correct and incorrect categories were close to zero for each S (GR, $-.002$; HW, $-.002$; DG, $-.001$; MS, $-.012$) so the linear discriminant was estimated by the distance between centroids for the response classes. The values of the linear discriminants were GR, $.126$; HW, $.212$; DG, $.242$; and MS, $.240$. The linear discriminant provides a measure of differential accuracy but not

accuracy per se. For example, if S was either correct or incorrect all of the time on all of the detection targets, the linear discriminant would be zero. If S was inaccurate on targets at one end of the stimulus dimension(s) but became increasingly accurate as the other end of the dimension(s) was approached, the linear discriminant would be non-zero.

A measure of the relative effects of area and perimeter on detection rate is provided by determining the linear combination of area and perimeter used in sorting detection targets into the correct category. When area and perimeter are measured in terms of their respective standard deviations, for area 4.47 cm^2 and for perimeter 2.57 cm , Ss used the following linear combinations: GR, $.94(\text{perimeter}) + .35(\text{area})$; HW, $.08(\text{perimeter}) + .99(\text{area})$; DG, $.00(\text{perimeter}) + 1.00(\text{area})$; MS, $.47(\text{perimeter}) + .88(\text{area})$. These values were determined by measuring the cosines of the linear discriminant function plotted in the area-perimeter space. The positive values of all coefficients indicate that detection rate increases as perimeter or area increases for all Ss except DG whose perimeter coefficient is zero. The relative contributions of area and perimeter, when *not* measured in terms of their respective standard deviations, to the discriminant function is given by multiplying the coefficient for perimeter in the linear discriminant function by the standard deviation of perimeter values in the experiment, and multiplying the coefficient for area by the standard deviation of area (Cooley & Lohnes, 1962, p. 118). These relative contributions were as follows: GR, $2.42(\text{perimeter})$, $1.56(\text{area})$; HW, $.21(\text{perimeter})$, $4.42(\text{area})$; DG, $.00(\text{perimeter})$, $4.47(\text{area})$; and MS, $1.21(\text{perimeter})$, $3.94(\text{area})$. The detection rates of HW and DG are almost entirely determined by area and variations in perimeter have negligible effect. The detection rates

of MS are predominantly determined by area but perimeter does have some effect. For GR perimeter affects detection rate more so than does area.

DISCUSSION

For three of the four Ss variations in perimeter have small or negligible effects on detection rates relative to the effects produced by variations in area. For these Ss as area increases the detection rate increases while an increase in perimeter results in a small or negligible increase in detection accuracy. Neither the analysis of variance nor the linear discriminant analysis showed interaction effects between area and perimeter for these Ss. The performance of GR differed considerably from that of the other Ss in two respects: (a) the linear discriminant was about half that of the other Ss implying less differential accuracy, i.e., very little increase in detection accuracy on the "easy" targets, and (b) perimeter variations had a very appreciable effect (relative to area effect) on detection rates.

No simple explanation of why GR's performance differed so markedly from that of the other Ss is apparent. In the absence of other explanations the hypothesis of true individual differences in elementary perceptual processes must be considered. This hypothesis implies failure for attempts to develop a theory of *how* the process of simple detection works since there may be many different simple processes of detection. Perhaps this is why Kristofferson (1957) and Hecht and his associates (Lamar et al, 1947) have developed contradictory theories to account for detection. A sufficient number of Kristofferson's Ss may have used a detection process which supported his theory, while Hecht's Ss may have yielded data supporting his position.

The results obtained in this study do not agree with predictions based on Kristofferson's (1957) theory which assumes that if area is held constant and perimeter increased the detection probability should decrease. In fact, for GR, and to a small extent for MS, as perimeter increased with area held constant the detection probability increased rather than decreased. The present study and that of Nachman (1957) are the only known experiments that tested Kristofferson's theory and both of them failed to support it.

This study provides but little support for Hecht's (Lamar et al, 1947) theory which implies that if area is held constant and perimeter increased the detection probability should increase. This result was obtained for only two of our Ss, for GR and to a small extent for MS.

The findings suggest that further research is desirable to determine the extent of individual differences in detection processes.

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NOTES

1. This investigation was supported by Public Health Service Research Grant MH-1206 and a Public Health Service Research Career Program Award, K6-MH-22,014.
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3. The authors wish to thank Professor L. R. Tucker for suggesting this alternative to true ellipses and for suggesting a computing routine that provided a solution for the three parameters used in constructing the figures.
4. Personal communication from Professor H. Hake.

(Accepted for publication August 9, 1968.)