
The relative roles of vertices and sides in determining perceptual centres within shapes

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Abstract. In the main experiment, subjects estimated the centre of five polygons in three variants: whole contour, only sides, or only corners. The perceived centre was closer to the area barycentre than to any other mathematical centre. Errors decreased as the number of sides of the figures increased. Larger mean deviations and variability were observed for the corner-only variant. Errors did not differ between the other two variants. However, this could be due to the fact that in the side-only variant only a small portion of the sides was erased, making in this way this variant to be similar to the complete contour. To exclude this possibility, in a Control Experiment side-only figures with different lengths erased around the corners were used. Since there was no worsening of the performance with longer erasings, it is concluded that, in finding the centre, the visual system relies mainly on the information provided by the sides, while a role of the corners is not evident.

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INTRODUCTION

Though the majority of works on visual perception is directed at investigating immediate aspects of visual stimulation, such as brightness, colour, contrast, texture or edges, other less evident aspects of visual shapes have also been studied. Symmetry, orientation and centres are examples of less salient features of the objects.

Some attempts have been made to understand how the two sets of characteristics might be inter-related. These studies have been concerned mainly with the influence of brightness distribution (Proffitt et al. 1983) and of some phenomenological aspects of visual figures on the location of perceptual centres (Gatti 1924, Humphries 1960, Davi 1989, 1991). Having this in mind, in the present study we investigated the relative role of vertices and sides in the process of finding the centre of flat figures.

Though never directly investigated, the importance of the vertices or the contour of a figure has been stressed by different authors (Gatti 1924, Beghi et al. 1983, Proffitt et al. 1983, Davi 1991). Even the first study on the perceptual centre of flat figures (Gatti 1924) provided an example of attributing (indirectly) different saliencies to these two components of figures. Gatti (1924), studying the location of the perceptual centre in three kinds of regular figures (equilateral triangles, squares and circles), found an upward displacement of the perceptual centre with respect to the geometric centre, in triangles and squares. Though not directly stressing the importance of the sides, the explanations proposed by Gatti (1924) point to a greater importance of the sides than of the vertices in perceiving the centre of figures.

If sides provide important information on the position of a figure's centre, a relationship between the systematic error and the number of sides should be expected. The error in determining the centre of figures with more sides should be smaller due to the greater amount of information available. In Gatti's (1924) study, a hint in this direction came from the fact that the systematic error is greater for triangles than for squares. Davi (1991) has found a signifi-

cant interaction between number of sides and rotational symmetry in determining the perceptual centre of flat figures, but to our knowledge an effect of number of sides on a reasonably wide range of variations of this factor has not been demonstrated so far.

Probably the best example of the importance of the sides is given in the study by Beghi et al. (1983). In this study the "figures" were represented only by dots marking their vertices. With an equilateral triangle depicted in this way, the authors obtained a systematic error larger than the error observed by Gatti (1924) with contour equilateral triangles. This result seems to point directly at the importance of the sides for finding the centre. When the sides are missing a larger error is observed. Unfortunately, a similar comparison cannot be made for the other shapes used by Beghi et al. (1983), because these shapes were employed only in their point-of-vertex version. Furthermore, in Beghi et al.'s study not only the sides of the figures were missing but also the corners of the shapes; only the points which were supposed to represent the vertices of a shape were given.

From a theoretical point of view, neither Beghi et al. (1983) nor Proffitt et al. (1983) distinguished between the relative roles of vertices and sides in the process of finding the centre of a shape. In fact, in both studies the authors emphasized the importance of the contour, which, obviously, includes both vertices and sides.

In this paper we describe an experiment aimed at revealing: (1) the relative importance of sides vs. vertices in determining the perceptual centre of a figure; and (2) whether the systematic error decreases as the number of sides increases.

EXPERIMENT I

Five shapes were used: two isosceles triangles and three irregular polygons with 4, 6, and 7 sides respectively. We expected the systematic error to diminish as the number of sides increased. Each shape was depicted in three variants: (1) as a complete contour drawing; (2) as a contour drawing

with corners omitted; and (3) as a drawing consisting of the corners only (see Fig. 1). We were interested in determining which of the two latter variants would give results similar to those of the complete contour drawing, knowing in this way which of the two components of figures was mainly utilized for finding the centre of the shape when the whole contour was present. To this end we analyzed not only the position of the mean perceptual centre (the mean systematic error), but also the variable error, which could give a measure of the relative difficulty of finding the centre in the different variants. Stimuli were shown in four different orientations. Based on our earlier data (Davi 1989, Yakimoff et al. 1990), we did not expect an effect of orientation *per se*. An interaction of orientation with the different variants could, however, be present.

Method

STIMULI AND PROCEDURE

An IBM-compatible computer was used to display the figures and to record subject responses. The figures were displayed on a graphics display (resolution 320x200 pixels). From the viewing distance of 0.57 m the figures subtended about 5.5 to 14.5 deg of visual angle; the size of the screen being 26x19 deg of visual angle. Five figures in four orientations, obtained by rotating the figures in steps of 90 deg, each one in three variants, formed the 60 stimuli used (see Fig. 1). The first variant (V1) was the shape itself with its complete contour. The second variant (V2) was obtained by erasing the sides and leaving only a length of 0.5 cm at the two ends of each side (this was the "corner-only" variant). The third variant (V3) was exactly the opposite of the second, in which the middle part of each side was displayed, lacking 0.5 cm of length at each of its two ends (this was the "side-only" variant). The number of sides for shapes 1 through 3 (S1, S2 and S3) was 4, 7, and 6, respectively; shapes 4 and 5 (S4 and S5) had 3 sides. The last two figures were isosceles triangles, one on a short base (S4) and one on a long base (S5). Shapes 1, 4 and 5 had

almost identical areas, while the other two shapes (especially S2) were somewhat larger. The figures were displayed eccentrically on the display. A small dot was also displayed, which could be moved in vertical, horizontal and diagonal directions on the screen.

The subject sat in front of the monitor screen. The figures were presented as white lines on a black background. The subject had to adjust the dot in the centre of each figure, which was continuously presented during the performance of the task. When satisfied with his/her performance, the subject had to press the "Enter" button to store the estimated position and to initiate the next figure presentation. The 60 stimuli were displayed in a random order and in random positions on the screen. Each stimulus was presented once to every subject. No fixation point was given, because of the prolonged presentation of the stimuli. The coordinates of the estimated centre were automatically monitored for further analysis.

SUBJECTS

Twelve subjects took part in the experiment. All had normal or corrected-to-normal vision.

Results

A problem arises when, as in the present experiment, irregular forms are used. It is connected with the fact that within a shape four mathematical centres can be specified: the geometric centre, the vertices barycentre, the contour barycentre, and the area barycentre (Beghi et al. 1983). Clearly, analyses have to be performed on distances computed from the mathematical centre which proves to be the nearest to the mean perceptual centres in the given set of figures. For most of the figures used in this experiment the mathematical centre nearest to the mean perceptual centre was the area barycentre. We used it as a reference point for measuring the errors. The positions of the mean perceptual centres were therefore converted into distances from the area barycentre and standardized according to Proffitt and

TABLE I

Friedman's tests for the influence of Shape, Variant and Orientation on the standardized distances between the mean perceptual centre and the area barycentre. Mean ranks and corresponding *chi-square* and confidence level (*P*) values are presented

Shape	S5(3)*	S4(3)	S1(4)	S3(6)	S2(7)
Mean rank	4.33	3.67	3.42	1.92	1.67
		$\chi^2(4)=25.7$		$P<0.0001$	
Variant	V1		V2		V3
Mean rank	2.05		2.25		1.70
		$\chi^2(2)=3.1$		$P=0.2122$	
Orientation		0°	90°	180°	270°
Mean rank		2.47	2.70	1.90	2.93
		$\chi^2(3)=5.3$		$P=0.1511$	

*The number of sides of each particular shape is given in parentheses

O'Brien's (1982) standardization procedure, which for accounts the differences in shape and size among the figures within which the distances have been observed, so that the resulting standardized distances can be compared. Three Friedman's non-parametric tests were performed on the standardized distances, to examine the influence of Shape, Orientation and Variant on the deviation of the mean perceived centre from the area barycentre. The results are summarized in Table I. Only Shape was found to influence significantly the distances between the mean perceptual centres and the area barycentres. Furthermore, the values of the mean ranks clearly point to the fact that this distance diminishes significantly with the increase of the number of sides in the shape. The influence of the three factors on mean standardized distances was also tested by a three-way (5x4x3) ANOVA, which allowed us to look for interaction effects. It was again the effect of Shape which proved to be significant [$F(4,24)=37.4, P<0.00001$] but the Shape*Variant interaction also appeared to be significant [$F(8,24)=11.6, P<0.00001$]. There were no other significant effects.

Given the lack of significance of Orientation and of its interactions with the other two factors, the results were pooled over all orientations. Mean estimated centre positions for all shapes and variants are presented in Fig. 1 by crosses. Small squares depict the area barycentres of the shapes. The Figure clearly illustrates the influence of shape on percep-

tual centre displacement with respect to area barycentre. The displacement increases with the decrease of the number of sides of the shape.

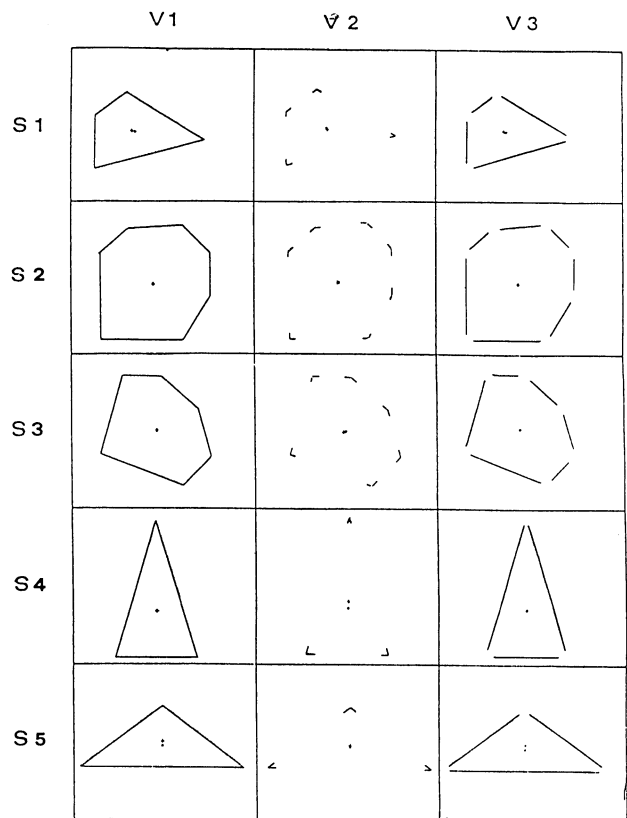


Fig. 1. The five shapes used in Experiment I, each in its three variants. Crosses represent the mean perceptual centre, and squares represent the area barycentre.

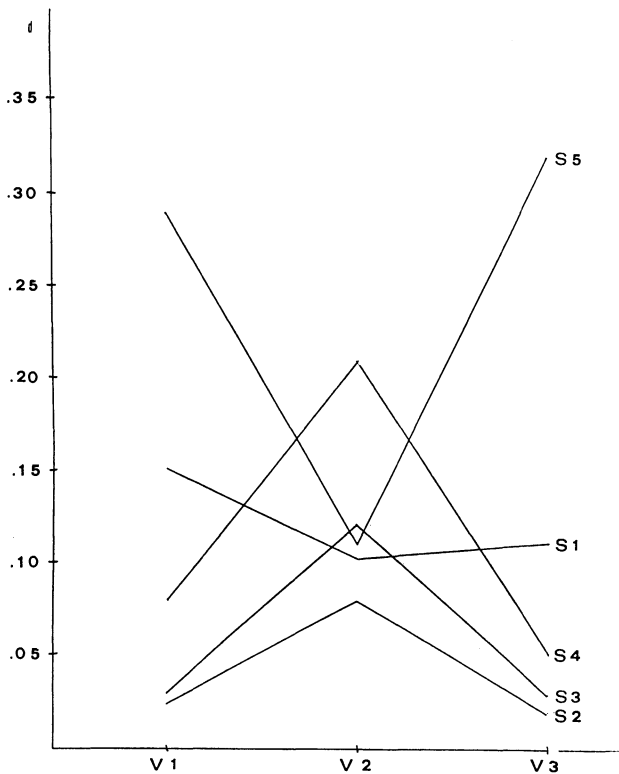


Fig. 2. Standardized distance *d* of the mean perceptual centre from the area barycentre depending on the variant for the five shapes.

In order to further investigate the Shape*Variant interaction, five two-way (3x4) ANOVAs were performed, with Variant and Orientation as factors, for the five individual shapes. The Orientation factor and the Variant*Orientation interaction were not significant in any case. The effect of Variant was significant for three shapes, namely S3, S4 and S5 [$F(2,6) \geq 13.1, P \leq 0.007$]. As can be seen in Fig. 2, the mean for the "corner-only" variant (V2) was always different from the others, but while in S3 and

S4 its mean was larger than those for V1 and V3, in S5 it was smaller. This difference explains why the main effect of Variant was not significant in the general analyses (it becomes null when averaged over shapes), while the Shape*Variant interaction was significant in the general ANOVA.

In addition to analyzing the mean position of the perceptual centre, we also wanted to have a measure of the relative difficulty of finding the centre in the different variants. This was accomplished by analyzing all the responses provided by the subjects under the form of standardized distances from the area barycentre. A three-way (4x3x5) repeated measures ANOVA, with Orientation, Variant and Shape as factors, was performed. In this analysis, the main effect of Variant [$F(2,654)=14.1, P < 0.001$] and Shape [$F(4,654)=78.5, P < 0.0001$] was significant, along with the two two-way interactions Shape*Variant [$F(8,654)=4.5, P < 0.001$] and Orientation*Variant [$F(6,654)=2.9, P=0.008$]. No other effect was significant.

Five separate repeated measures two-way (4x3) ANOVAs were then performed, one for each shape, with Orientation and Variant as factors, in order to determine the origin of the significant effects. Because each analysis was concerned only with the data from a particular shape, non-standardized distances were used. The interaction between Orientation and Variant was due to shape 2 only, in which it was significant [$F(6,130)=2.9, P=0.012$]; Variant, however, was a significant main factor in three shapes, namely S2, S3 and S4 [$F(2,22) \geq 5.4, P \leq 0.013$]. In these analyses, again, it was always V2 that was different from the other variants, but here

TABLE II

Mean variable error *e* from the area barycentre depending on variant, for the five shapes (values are not standardized; comparison between rows is not allowed)

Shape	Variant		
	V1	V2	V3
S1	5.81	6.18	4.83
S2	2.88	5.22	2.55
S3	2.30	4.15	2.54
S4	6.81	10.75	7.38
S5	4.74	4.22	5.14

its mean was always greater than that of the other variants (see Table II), pointing to a wider and more disperse distribution of responses around the mean estimated centre location for this variant. Finally, the fact that the Variant factor was significant only in three out of the five shapes, explains the significance of the two-way interaction Shape*Variant in the general ANOVA on this same variable.

Discussion

The finding that the area barycentre appeared to be the nearest to the perceptual centre was unexpected in view of previous studies. In fact, Beghi et al. (1983) claimed the contour barycentre to be the barycentre nearest to the perceptual centre, while Davi (1989) found that it was the vertices barycentre, although in some of his figures, as in the case of the isosceles triangles in the present study, the area and the vertices barycentre were coinciding. Data provided by Yakimoff et al. (1990) seem to be in agreement with the present findings. Perceptual centres were considered to be close to the area barycentre in irregular quadrangles, without, however, taking into consideration other barycentres. A systematic investigation of the perceptual centre-barycentre correspondence was beyond the scope of the present study, but needing a common reference point for data analysis, area barycentre appeared to be the best choice.

Concerning the positions of the mean perceptual centres, the following also emerged: the mean perceptual centre was always located on one of the two main axes of the "image ellipse" of the stimuli, which, according to the general theory of moments, represents the orientation and the size of the figure (Teague 1980). These two axes, computed via the second order moments of a shape, are orthogonal. They intersect at the area barycentre, and the angle between the abscissa of the reference system and the major axis can be considered a mathematical representation of the shape's orientation. Subsequent review of the literature showed that this positional feature of perceptual centres, although previously unnoticed, was present also in the aforementioned

studies (Gatti 1924, Davi 1989, Yakimoff et al. 1990). It could be speculated that the second order moments of perceived shapes are, in some unknown way, computed by the visual system, or, in other words, that a reference frame attached to the shape itself is established in the process of finding its centre. This possibility has already been considered by Davi (1989). He has observed that the direction of the systematic error does not change in triangles in different orientations, if the error is measured relative to the figure. The use of a stimulus-locked perceptual reference system can explain why the Orientation factor was not significant in the present experiment, as well as in those of Davi (1989) and Yakimoff et al. (1990).

The main factor which proved to influence the position of the perceptual centre was the Shape of the figures. As shown in Table 1 this influence seems to be related to the number of sides in the figures. It has to be remarked that S1, S4 and S5 had almost identical areas, while S3, and especially S2, had larger areas. The magnitude of the systematic error has been found to be directly proportional to the size of the shapes (Gatti 1924, Humphries 1960, Davi 1989). The area differences in the present stimuli would therefore have produced an effect opposite to the one obtained; hence this effect cannot be due to area differences. If any, the effect of the different areas in some of our stimuli may have been to reduce the effect of the number of sides. Nevertheless, number of sides remained a significant factor, and the fact that its effect is not nullified by area differences going in the opposite direction is probably a proof that the number of sides is much more important than the size of a figure. Beghi et al. (1983) and Proffitt et al. (1983) have stressed the role of the contour as the main source of information for finding the shape's centre. The present results confirm this conjecture; it seems that the side can be considered the fundamental information unit in the process, in the sense that adding sides diminishes the deviation of the perceptual centre from the area barycentre. This possibility has been suggested by Davi et al. (1992), but it is experimentally confirmed in the present study.

The significance of the number of sides in perceiving the centre of a shape does not provide an answer to our main question about the relative role of vertices and sides: increasing the number of sides equally increases the number of vertices in a shape. To answer this question, the effect of the Variant factor has to be considered. Firstly, through all analyses V1 and V3 (the complete contour and the "side-only" variant) yielded the same results. This is in agreement with results from eye movement studies. Božkov et al. (1982) have found that the distribution of fixations at different "angles" of a given polygon was not different between the closed and lacking-corners polygons, pointing to the fact that these two versions of a polygon represent a similar "Gestalt" for the subject.

The results obtained with the "corner-only" variant (V2) are significantly different from those obtained with V1 and V3 for some of the shapes. The systematic error was greater for S3 and S4, and it was smaller for S5. Beghi et al. (1983) have found larger systematic errors with "three-point-of-vertex" triangles, as compared with Gatti's (1924) results obtained with complete contour triangles. The smaller systematic error obtained with V2 for S5, which determines the significant interaction between Shape and Variant, is not in agreement with the other results. The differences in the perceived centre position in S4 and S5 (both figures are isosceles triangles) might be related to some peculiarities of their phenomenal shape. It could be argued that V2 is giving rise to a "Gestalt" different from that of the complete contour, but in this case, too, there are data in the eye movement literature showing this possibility to be unlikely. It has been shown that removing one side from a triangle or a square does not alter the mean fixation position (Kaufman and Richards 1969, Richards and Kaufman 1969), thus indicating similar cortical representations for the complete shapes and for the same shapes with one side removed.

The variable error of the estimates in the experiment was much greater in V2 for S2, S3 and S4 (Table II). This result can easily be interpreted as pointing to a greater difficulty in finding the centre in the "corner-only" variant.

As for the interaction between Variant and Number of sides, it seems that the mean systematic error tends to be different for the three variants in the shapes with a lesser number of sides. It could therefore be that in shapes with many sides the systematic error is too small to show any difference due to Variant. This argument is, however, only speculative, because this correlation between the two factors is not very strict.

As previously mentioned, when the corners are removed (V3) both kinds of error have the same magnitude as in the complete contour situation (V1). This leads us to hypothesize that the information from the vertices is not much utilized for finding the centre and so, when they are removed, there is no worsening of the performance. However, there is a second possibility: it could be that in V3 it was not very difficult for the subject to 'redraw' the vertices properly, reaching in this way the observed results. Some data show the existence of such a possibility: when observers are asked to determine the intersection point of two segments, they make small errors; for instance, when the 'true' intersection point is at 60 mm from the ends of the segments, a maximum error of less than 20 mm in one study (Weintraub and Virsu 1971), and of only about 9 mm in another study (Weintraub and Virsu 1972) was observed. In our case, being the intersection point at a distance of 5 mm from the ends of the segments (the sides) and assuming the occurrence of the largest error, an error of only 1.5 mm would be obtained. If this is the case, then it could be that the information from the vertices is also important in the process, and the result could depend on the fact that this information was in fact available, given the negligible errors occurring in this hypothetical reconstruction of the vertices.

This possibility was tested in the next experiment, in which we used examples of V3 varying in side length in order to determine whether larger errors are obtained when the sides are shorter.

EXPERIMENT II

The stimuli in this experiment can be considered as examples of V3 in which the possible operation of "redrawing" the vertices was rendered more dif-

difficult for the subject to perform. This was done by using different erased lengths at the ends of the sides. If the good performance obtained with V3 stimuli in the previous experiment was due to the fact that the erased length was too short to prevent those stimuli from resembling the complete-contour (V1) stimuli, it should be more difficult to locate the centre when a longer part of the side's end is lacking, and larger errors would therefore be obtained in those situations.

Method

STIMULI AND PROCEDURE

Procedure was the same as in the preceding experiment.

The figures subtended about 6.5 to 10 deg of visual angle. All figures were constructed starting from an equilateral triangle with a side of 11.1 cm, and erasing part of each side at its two ends. There were three levels of erasure in steps of 1.2 cm, so that at each side's end it was erased a length of 1.2, 2.4, or 3.6 cm. This yielded three figures, each of which had all sides of the same length (all of them being long, medium, or short; see Fig. 3). Each stimulus was presented twice to every subject.

SUBJECTS

Ten subjects took part in the experiment. All had normal or corrected-to-normal vision.

Results

The positions of all the responses provided by the subjects were converted into distances from the

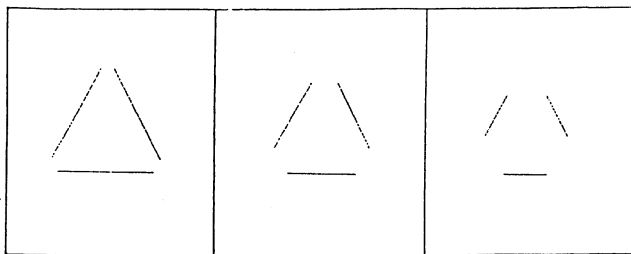


Fig. 3. Stimuli of Experiment II(see text).

geometric centre of the equilateral triangle from which the stimuli were derived. On these distances a one-way repeated measures ANOVA, using the three figures as levels of the Length factor, was performed. It did not prove to be significant [$F(2,57) < 1$].

Discussion

The results did not show larger errors when corners were more amputated. It seems that observers, looking for the centres of shapes lacking their corners, do not try to "redraw" the corners; this would be more difficult when longer ending portions of the sides are amputated. It seems, instead, that subjects rely mainly on the information provided by the sides, which here, as well as in the V3 stimuli of the previous experiment, were present.

In conclusion, the results of the present experiment confirm those of the preceding. For finding the centre the information from the sides is used, while that from the corners is not very important. The results of the present experiment show that the good performance with the "side-only" (V3) stimuli of the previous experiment was not due to the fact that the portion of side erased around the corners was too short. The importance of the sides is, instead, shown by the results of the previous experiment: when only the corners are present and the sides are lacking (V2) there is an increase both in the mean and the variable error.

GENERAL DISCUSSION

The main experiment was designed to address the issue of the relative roles of corners and sides in the estimation of perceptual centres, as well as the role of number of sides. For both of these issues there were only hints in the literature (Gatti 1924, Beghi et al. 1983, Davi et al. 1992), but no systematic study had been performed. We obtained larger mean and variable errors when the sides were erased, but not when the corners were, in comparison with the display of the whole contour. This result pointed to a greater importance of the information provided by the sides than by the cor-

ners, in finding a shape's centre. However, it was possible that the lack of a difference between the whole contour display and the side-only variant was due to the fact that only a small portion of the ends of the sides was erased in the latter variant.

For this reason, in Experiment II we erased larger portions of the sides' ends. If the result for V3 stimuli was due to the erasings being too small to produce a difference from V1, larger errors should be expected when larger portions of the perimeter around the corners are lacking. This, however, did not happen. The fact that we did not obtain larger errors with larger erasings around the corner is in agreement with Mitrani and Yakimoff's (1983) model for the extrapolation of the intersection-point of two converging segments. In fact, this model does not predict different errors in extrapolating the intersection-point with different distances of the segments from it. It instead states that the error depends on the size of the angle that the segments are forming, and it predicts an inward displacement of the intersection point with angles lesser than 120° . In our Experiment II the stimuli were constructed from an equilateral triangle, and so all angles were of 60° . According to this model we should therefore have obtained similar errors in all of our stimuli, and this is what happened. This result does not support the idea that the results for V3 stimuli in the main experiment were due to the erasures being too short, and hence confirms the arguments put forward there.

In conclusion, it was found that there are larger errors and greater variability in finding the centre of figures of which only the corners are shown than in finding those of the same figures when only the sides are displayed, or the whole contour is. Furthermore, errors decreased as number of sides increased. It seems therefore, that, for finding a shape's centre, the visual system relies more on the information provided by the sides than on that provided by the corners.

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