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FIGURAL AFTER-EFFECTS AND APPARENT SIZE*

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Sutherland (1954) obtained results which suggest that when the retinal size of test and inspection figures is equal, the direction of the FAE may be determined by the relative apparent sizes of the two figures. Other investigators have reproduced this result when exactly the same conditions were used: when the conditions were changed the result was not obtained. In the present paper these results are discussed and an attempt is made to determine why the effect is not obtained with small variations in the experimental conditions. It is further shown that some FAE phenomena cannot be explained by the two main existing theories; these phenomena could be explained if some analysis of the stimulus is being performed before the stage of the nervous system at which the process underlying FAEs occurs. Some recent physiological evidence (Hubel and Wiesel, 1959) supports this hypothesis. If this hypothesis is correct, it is likely that further work on FAEs determined by apparent size may help to throw light on the physiological mechanisms underlying size constancy, and some further experiments are suggested.

INTRODUCTION

Three of the papers published herewith attempt to confirm some findings of mine on FAEs (Sutherland, 1954). In this experiment it was found that, when the retinal sizes of test and inspection circles were equal, the test circle appeared smaller after inspection of a figure further away, and larger after inspection of a figure nearer than itself. I interpreted the results to mean that when the retinal sizes of two figures are equal then the direction of the FAE is determined by their relative apparent sizes, i.e. a test figure will look smaller after inspection of an apparently larger figure, larger after inspection of an apparently smaller figure. I shall refer to this effect as the A-effect. Of subsequent experiments reported on this topic only two have reproduced exactly the conditions used in this experiment. Story (1961) and Day and Logan (1961) both obtained the A-effect when (i) binocular viewing conditions were used; (ii) the distances of the figures from the eye were 144 and 57·6 in.; (iii) the size of the near circle was 4 in., and of the far circle 10 in.; (iv) the circles were outline circles. Under these conditions, if the far circle is inspected, the near (test) circle appears smaller than usual; if the near circle is inspected, the far (test) circle appears larger. In five experiments (including other experimental conditions used by Story and by Day and Logan) in which conditions were not exactly the same as those I used, the A-effect was not obtained. Thus the original result appears to be reproducible under the conditions of the original experiment: it is not reproducible if these conditions are varied. This calls into question the interpretation which I originally gave. In the first half of the present paper, I shall examine what happens when the conditions of the experiment are varied and consider whether the results obtained preclude the interpretation suggested. In the second half I shall attempt to set out some theoretical considerations which affect the interpretation of these experiments and which may be of some interest in their own right. Inspection, test and comparison figures will be referred to respectively by the letters I, T and C. Table I summarizes the results obtained on this problem by different investigators using different experimental conditions.

* This paper was prepared at the request of the Editor.

Apparent Versus Retinal Size

Binocular vision

Using identical stimulus objects to those employed by Sutherland (1954), Story under binocular viewing conditions confirms the result I obtained, but finds that with monocular vision the T-figure falling on the same area of the retina as the I-figure tends to be seen as larger than the C, irrespective of whether the T-figure is nearer or further away than the I. She suggests that the effect found when both eyes are used may occur because under these conditions the visual angles subtended at the two eyes by the circles in each of their four possible positions are different: also since the angle between the fixation point and the centre of the circle will differ, test and inspection circles will no longer be exactly concentric. There are four reasons why this does not seem a very plausible explanation. (i) The relative displacement of the positions occupied on the retinae by different circles will be maximal for the point on each circle lying furthest from the fixation point (i.e. the outermost point on each circle). In terms of relative displacement at the retina the effect even here is very small. I have calculated the visual angle subtended at each eye by the distance between the outermost edge of each circle and the fixation point. These calculations give the following results for the circles in the four possible positions relative to the eyes: by "same eye" is meant the eye on the same side of the head as the side occupied by a circle in relation to the fixation point. (*a*) Far circle, same eye: $4° 51' 56''$. (*b*) Far circle, opposite eye: $4° 51' 31''$. (*c*) Near circle, same eye: $4° 52' 3''$. (*d*) Near circle, opposite eye: $4° 51' 4''$. Thus it will be seen that under no condition does the amount of displacement exceed $1'$ of arc, and it may be doubted if this would have any effect particularly since the contours used by Story were themselves $2' 24''$ in breadth. Furthermore, if the distance of the near shapes from the eye varies from 57·6 in. by 0·1 in., this produces a $30''$ change in the visual angle subtended by the circle. It is doubtful if in any of the experiments reported the distance of the shapes from the eye was controlled to within a tenth of an inch. (ii) As Story herself states, the same effect should occur with monocular viewing provided that the alignment of the eyes and cards are the same under these conditions. When one eye alone is being used, if both the T- and I-figures are exposed on the opposite side to the eye, there will be a difference of over $20''$ in their visual angles: the direction of the distance will depend upon whether the I-figure is near or far, and we might expect that when it is far, the T-figure should be seen as smaller than it is; when I

TABLE I

Summary of Results on Effects of Retinal and Apparent Size

Experimenter	*Size of circles*		*Distance of circles*		*Outline/disc*	*Binocular/monocular*	*Results* Whether I-figure judged larger or smaller than C			
	Far	*Near*	*Far*	*Near*			*T Near I Far*	*T Far I Near*	*Both far*	*Both near*
Sutherland	10·0	4·0	144	57·6	O	B	smaller*	larger*		
McEwen	2·4	0·6	118	29·5	O	B	smaller*	same		
Oyama	3·2	1·6	118	59·0	O	B	smaller	smaller		
Day and Logan	3·2	1·6	144	72·0	O	M	smaller	smaller	same	smaller*
					D	M	smaller*	smaller*	smaller*	smaller*
	10·0	4·0	144	57·6	O	B	smaller	larger*	larger	same
					D	B	smaller	same	larger	same
Story	10·0	4·0	144	57·6	O	M	larger*	larger*		
					O	B	smaller*	larger*		
Terwilliger	4·0	2·0	96	48·0	O	B	same	same	same	same

N.B. All sizes and distances are given in inches.
* Result significant at better than the 0·05 level of confidence.

is near it should be seen as larger. Unfortunately, Story does not break down her data for monocular viewing according to whether T- and I-figures were on the same or opposite sides as the eye used so that this prediction would only apply to half the trials she reports. Nevertheless, there is no sign of this trend in her results for monocular viewing. (iii) The effects to be expected due to the different spatial positions of the two eyes should be even more striking when the distance between shape and eye is less than in Story's experiment, and when the I-figure is shown to one eye and the T to the other: although these conditions have often been used in experiments on FAE no effects of this sort have been reported. (It might, however, be worth looking for them in future experiments.) (iv) Finally, although Story suggests that the different visual angles subtended by the figures at the retinae might be the explanation of the effects obtained under binocular viewing, she does not show in detail how these effects would be predicted by the geometry of the situation, and it is difficult to see how the effects found could in fact be produced in this way. Nevertheless, the suggestion is an interesting one and could be followed up by experiments in which the figures are placed closer to the eye and conditions of alternating monocular viewing are employed.

It is possible that the reason why the A-effect is obtained only when both eyes are used is that binocular vision itself provides a cue to the distance of the figures and thus to their relative apparent sizes (*v.* below): thus, the fact that the effect only occurs with binocular viewing does not necessarily conflict with the hypothesis that under some conditions the FAE may be determined by apparent size, and indeed can be interpreted within the framework of this hypothesis.

Size of circles

If *smaller* circles than those used by Sutherland are employed, the A-effect does not occur (Day and Logan, 1961; Terwilliger, 1961; McEwen 1959; Oyama, 1956): the usual result under these conditions is that the T-circle looks smaller than C whether I is nearer or further away. (It should be noted that Terwilliger did not obtain this result: when the retinal size of T and I was the same, he found no change in the apparent size of T.) This effect is also found when T and I shapes are the same distance away as one another (Day and Logan (1961), cf. also Köhler and Wallach (1944)). Day and Logan make the interesting suggestion that this shrinkage may resemble a time error effect though they do not discuss the details of how this might occur. Unfortunately, from what is known about time errors, one might expect the opposite effect with small circles. When a series of stimuli are being judged, there is usually a point in the middle of the series where (after practice) there is no constant error: above this point, time errors tend to be negative, below it, positive. We shall call this point the "adaptation point." Subjects will have an adaptation point at the start of an experiment and it will usually be shifted in the course of the experiment: now when a *small* circle is shown as I-figure this should shift the adaptation point downwards. If it shifts it downwards further for that part of the visual field on which the I-figure is shown than for other parts, we would expect the T-figure to be judged *larger* than the C-figure: the T-figure is less far away from the adaptation point at that part of the visual field than is the C-figure from the adaptation point at its part of the visual field. Day and Logan obtained exactly the opposite result to this.

Thus, there is some difficulty in applying this type of explanation, though the correspondence between the change in direction of the FAE with different sized circles (found by Day and Logan) and the change in direction of TE (found by Watson, 1957) is very suggestive. Nevertheless, Day and Logan's work does make it difficult to interpret the A-effect as due to differences in apparent size because of their finding that when *large* circles are used and both are far away, the T-circle appears larger than the C.

Outline and filled-in circles

Day and Logan show that the A-effect occurs with outline circles but not with filled-in circles: it is hard to see what explanation could be offered for this at present.

Further discussion

One very ingenious recent experiment has demonstrated in a most convincing way that an FAE determined wholly by apparent size does occur under certain conditions: Gregory (personal communication) has shown that if the apparent size of a figure is made to shrink continuously while the retinal size remains the same, when the shrinkage in apparent size is stopped suddenly there is a dramatic increase in the apparent size of the figure. This phenomenon is very striking and is seen by all observers. Since this shows that a FAE determined by continuous change in apparent size can occur, the question arises of why it is so difficult to demonstrate the effect with static figures. There are three possible answers to this.

(1) It may be that just as with FAE due to retinal size, the effect through apparent size only occurs if the difference between the apparent sizes of the T- and I-figures is optimal (cf. the distance paradox). If this is correct, we would only expect to obtain a FAE due to apparent size under limited conditions. This suggestion could be tested experimentally by keeping one circle a constant size and distance and varying the size and distance of the other keeping retinal size equal. We would expect an effect due to apparent size to occur only within a limited range of size and distance of the other figure. In Gregory's experiment, because the apparent size of the inspection figure changes continuously, these changes are bound to straddle the point which would be optimal for producing the effect.

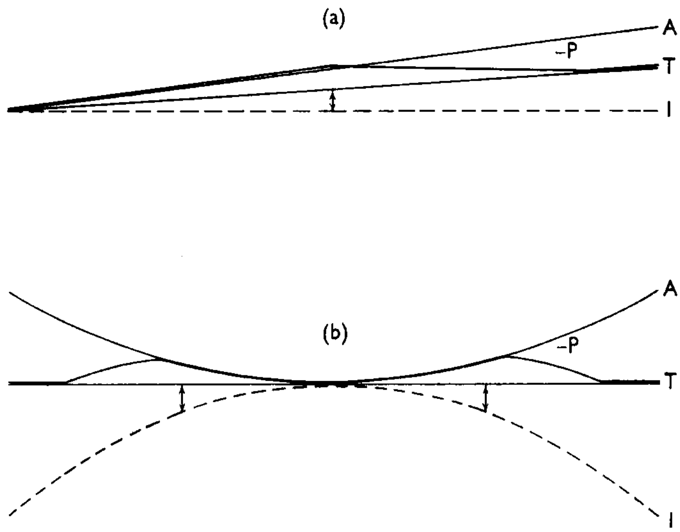
(2) The conditions of the experiments performed with static figures are such that there may be a temptation to judge in terms of retinal size: it is known that when two shapes of different real size are aligned side by side, subjects tend to make judgements in terms of retinal size (Joynson and Kirk, 1960). It would be interesting to test for the occurrence of the A-effect, using for T- and C-figures two shapes of the same physical size but different retinal sizes at different distances away from the observer and not aligned opposite one another. The T-circle could be kept the same retinal size as the I, and the C-circle would be a different retinal size: subjects would be asked to compare the *real* size of T- and C-figures. These experimental conditions should tend to favour judgements in terms of apparent physical size rather than apparent retinal size.

(3) It may be that apparent size only influences FAE when the apparent size has changed continuously, i.e. where there has been an apparent movement effect: if established this would be an important finding since it would reveal a difference in the mechanisms underlying apparent movement and judgements of apparent size (*v.* below). This could only be established by a thorough investigation of the static A-effect along the lines set out in (1) and (2) above.

Theoretical Considerations

The work of Hubel and Wiesel (1959) suggests a new theoretical approach to FAE problems. In order to see the experiments described above in perspective, it may be worth setting out briefly what this approach is: it has suggested itself independently to a number of workers in the field, and Papert is currently engaged on testing some of its implications. It must be stressed that a new approach is necessary since the sort of theory espoused by Köhler and Wallach (1944) and by Osgood and Heyer (1952) is unable to account for many of the phenomena of FAE. They both assume that inspection of a contour results in any contour subsequently falling near the second contour being seen as displaced away from it: the amount it is displaced is said to depend upon the distance separating the two contours on the retina, and there will be a point at which displacement is maximal. Three instances of well attested phenomena which this theory is unable to explain will be quoted. (1) In Figure 1, if the I-line is fixated, the T-line should appear as shown (P): displacement should be small where I and T lie near together gradually increasing to a maximum and then decreasing. In fact T is seen occupying the position of line A. (2) Similarly

FIGURE 1



when a curved line is shown, and a straight line used as I-figure, the straight line should appear like line P in Figure 1 (*b*) but in fact appears like line A. (3) The theories are unable to account for the after effect of seen motion. Both theories under discussion assume that the FAE occurs before any analysis of the stimuli is undertaken.

Hubel and Wiesel have demonstrated by recording from single cells that in the cat considerable analysis of the stimulus on the retina occurs at or before the level of the striate cortex. In particular they present evidence to show that in the striate cortex there are cells whose response is determined by the orientation of lines on a given part of the retina; i.e. the orientation of lines is coded in separate fibres at this level of the cat visual system. If we assume that there are cells with similar receptive fields in human beings we have a very simple explanation of the effect shown in Figure 1 (*a*): inspection of a line in one orientation will result in heavy firing of the cells maximally responsive to lines in this orientation, and to some firing of cells maximally responsive to lines in neighbouring orientations. If any adaptation occurs in these cells as a result of prolonged firing, when a T-contour in a slightly different orientation to the I line is exposed on the same part of the retina, the cells fired maximally by it will be ones which are normally maximally responsive to contours in orientations lying further away from the orientation of the I-figure. It is reasonable to suppose that the orientation in which a contour is seen will depend upon the balance of firing in cells representing contour orientation: the firing in any one cell will be determined partly by the contrast of the contour with its background, etc., but such effects would be balanced out if the ratio of firing in all cells sensitive to orientation in a given region of the retina were computed. If there are also cells sensitive to curvature of a line a similar mechanism would explain the sort of finding depicted in Figure 1 (*b*). As yet there is no physiological demonstration of the existence of such cells.

Hubel and Wiesel have, however, found cells which respond differentially according to the direction in which a stimulus is moved across the retina. If direction of movement is coded in single cells in human beings, adaptation in these cells might clearly underly the after-effect of movement. Once again the direction in which something is seen to move might depend upon the ratios of firing in cells sensitive to movement in different directions, and after prolonged movement in one direction a stationary image would produce less firing in the cells which had just been stimulated than normally, hence apparent movement in the opposite direction would be seen to occur.

This explanation of FAE is based on sound physiological evidence and is so simple that it seems highly convincing. It does not, however, explain mere displacements in apparent spatial position occurring as a FAE: for this phenomenon, the Osgood and Heyer type of explanation appears reasonably plausible. This explanation in fact fits well with the explanation outlined above since Osgood and Heyer argue that the position at which a contour is seen itself depends upon ratios of firing in different cells. The possibility of explaining the FAEs produced under different conditions in terms of simple physiological analysing mechanisms in the visual system increases the interest of further work on FAEs: if we can determine the exact conditions under which FAE's occur, this knowledge should help us to specify more accurately the nature of the underlying physiological analysing mechanisms.

The determination of the conditions under which effects due to apparent size occur becomes a particularly interesting problem. It is possible that some apparent size and apparent movement effects occur because central mechanisms, through efferents in the visual pathways, put a bias on the cells performing analysis of the stimulus between receptors and cortex. For instance, if the size of an object is itself coded in single cells somewhere between receptor and visual cortex, the cells stimulated by an object of given retinal size might vary according to efferent firing produced by a mechanism which analysed the distance away of the object. Possibly some factors determining the apparent size of an object operate at this level and others at a higher level. Thus the depth effect due to stereoscopic vision (which seems to have an innate basis, Ogle (1950)), might operate at this level and other depth effects at a higher level in the nervous system: this would explain why Story obtained the A-effect binocularly but not monocularly. Again if, after further investigation, it is found that no A-effect takes place with static figures although it does with figures whose apparent size changes continuously, this would suggest that apparent movement effects may be determined at a different level of the nervous system from apparent size effects. It is, of course, always possible that even where a factor determining apparent size operates at a higher level of the nervous system, it will operate in such a way as to result in FAEs: nevertheless, if it can be shown that FAEs due to apparent size occur under some conditions and not under others this suggests fundamental differences in the mechanisms at work in different conditions, and gives a promising lead towards working out what is the neurological basis of such phenomena as size constancy—a question about which at the moment almost nothing is known.

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