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PERCEIVED ORIENTATION OF ISOLATED LINE SEGMENTS

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1. INTRODUCTION

VISUAL form perception is characterized by the fact that the perception of a particular object may arise from a great many configurations of the retinal light distribution. Though, if necessary, differences between them can be observed, our visual system easily neglects several factors such as retinal position, size, relative dimensions and imprecision of drawing. Until now it has proved difficult to find in the various configurations common factors, on which perceptual constancy might be based.

Notwithstanding this difficulty, it seems that the hypothesis cannot be avoided that some kind of spatial analysis of the retinal configuration does take place, the result of such an analysis being a number of cues. On the basis of existing memory functions the cues will be combined, with the result that a percept arises.

However vaguely the above may be formulated, it makes one look for experimental evidence on the kind of analysis and also on the ways in which the various cues are synthesized. Both analysis and synthesis may be taken to operate at a number of levels, which differ in structural complexity.

The work reported here was carried out to determine whether "orientation" is one of these cues. This choice did not present itself just by chance. The well-known neurophysiological evidence put forward by HUBEL and WIESEL (1959, 1962) suggests that the angle of orientation of the stimulus on the retina is among the first isolated form cues in the visual cortex of cats. Thus, an analysis seems to be carried out in terms of the angles of orientation of lines and edges on the retina. This suggested to us that "orientation" might also be properly isolated by psychophysical experiments.

Little work exists in the literature on the perception of the angle of orientation as such. We mention here papers by SALOMON (1947), ROCHLIN (1955), KEENE (1963) and ANDREWS (1965). One finding is that the perceived angle of orientation may be different from the geometrical slant. This difference is also shown directly by several induction phenomena, in which the perceived angle of orientation of a line segment of a certain fixed slant is influenced by neighbouring lines or curves. Many "visual illusions" are based on this phenomenon.

We define "slant" as the geometrical inclination of a line segment, in a plane perpendicular to the line of sight, and as such is open to direct measurement. Perceived angle of orientation or, as we shall term it, 'perceived orientation', however, is based on the processing of information in the visual system and is not open to direct measurement. For quantitative evaluation one has to make the subjects translate perceived orientation into terms of other geometrical slants by estimating or matching procedures. As a consequence, perceived orientation has to be defined operationally according to the method of measurement.

In our experiments we used a matching technique in which the subjects adjusted a dot until it seemed to be in the perceived extension of a line segment. We took dot position as the basis of perceived orientation. In order to avoid the more complicated induction phenomena mentioned above, we restricted the stimuli to straight line segments, perpendicular to the line of sight.

The first part of this investigation was concerned with the relationship between perceived orientation and slant and with the question of how accurately slant can be perceived. As a next step, we tried to obtain evidence as to the parts of a line segment that contribute most to its perceived orientation; in other words, what information of the line segment is actually processed into the visual system to arrive at "orientation". Discussion is directed towards the problem of what processes may be assumed to underlie the observed phenomena. The situation is still far from clear, but the concept of line detectors or orientation-selecting units seems to be a promising one. We offer a few hypotheses that may contribute to the establishing of a more rigid theoretical framework in which the observed phenomena can be arranged.

2. METHODS

Apparatus

In the first, preliminary experiments, the subject's task was simply to mark by pencil a point which he judged in line with a given line segment, the distance between line and point being some 40 mm. For better and more flexible control of the parameters, we constructed a disc (Fig. 1) by which a line segment as well as an adjustable dot could be made visible on a translucent screen close to the disc. The screen was in a plane perpendicular to the line of sight of the subject. The line segment was projected on the screen by a beam of parallel light controlled by an electric shutter (100 ms). Figure 2 gives an outline of the projected line segment l (AB) and the adjustable dot P. We introduce the angles α and β, α being the geometrical slant of the (extension of the) line segment and β the angular deviation of PB in relation to the extension of line segment l. Perceived orientation is defined operationally as the adjusted slant ($\alpha+\beta$).

The length BP could be varied between 2 and 54 mm; the line width was 1 mm. At a distance BP of 50 mm from the line segment was the dot P (diameter 1 mm). The latter could be moved stepwise by a motor in either direction (dot velocity 2 mm/s, one step corresponding to 0·1 mm displacement, minimum displacement 1–2 steps). A helipotentiometer served to register automatically the dot position to the nearest 0·05 mm. On the disc being rotated (by hand), the line segment and the dot kept their relative positions. The subject observed the screen from a distance of 500 mm, at which distance 1 mm on the screen corresponded to a visual angle of 7 min of arc. The screen was circular, 300 mm in dia., and was uniformly illuminated at a level of about 3 cd/m^2. It was surrounded by a ring of black paper at least 150 mm in width, with the result that no straight edges other than the line segment appeared within a visual angle of 60°. Luminance of the line segment was about 8 cd/m^2. The subject's head was steadied by a rest consisting of a chin support, two temple steadiers and a forehead rest. Subjects had either normal or corrected vision.

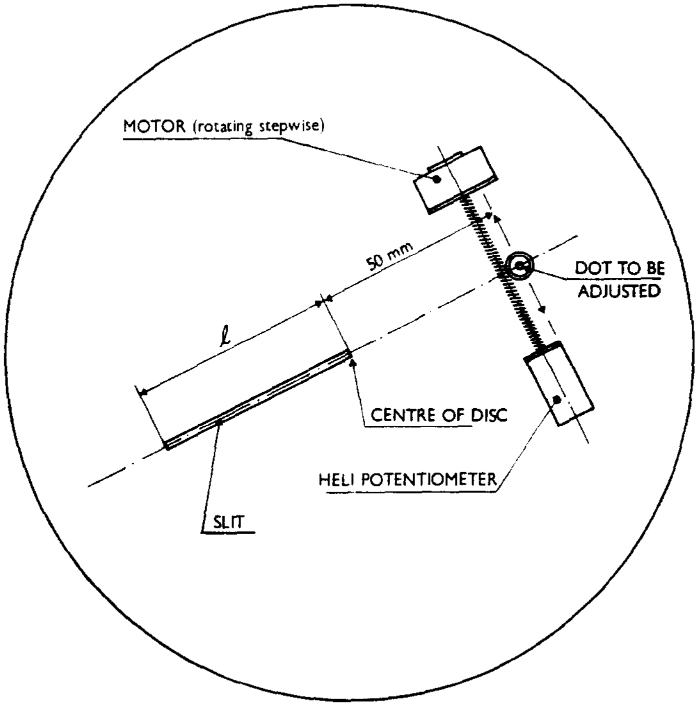

FIG. 1. Disc with line segment and dot to be adjusted, as used in the experiments.

Procedure

The subject moved the dot, starting from a considerable distance from its veridical position (alternately above and below this position), until it seemed to him to lie on the extension of the line segment. Then, by means of a push-button, he got the deviation from the geometrical (veridical) position to be recorded. Usually, the line segment was

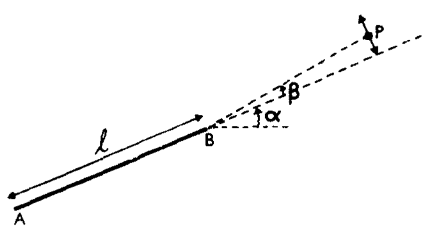

FIG. 2. Adjustment of a dot P in line with a line segment AB of slant α. β is the angle deviation of adjusted dot position from geometrical position.

flashed (100 ms), which required a trial-and-error technique. It was up to the subject to choose the number of flashes, the number normally ranging from 6 to 30. The subject chose the moments at which the flashes appeared. For each stimulus situation, four successive adjustments were carried out, these series being repeated on at least two other days. Theoretically, it would seem better to change slightly the slant α of the line segment after each adjustment. This was, in fact, how we started the experiments. However, this way of experimenting would have taken too much time, due to the fact that the deviation β shows a systematic change with α. We have ascertained that our procedure gives results similar to those obtained with the more elaborate procedure in which the slant of line segments was varied at random between successive adjustments. For each series of four adjustments we took the average deviation β and the standard deviation S. The latter can conveniently be calculated from the range $W = \beta_{max} - \beta_{min}$. ($S = 0{\cdot}49\ W$ for $n = 4$).

Values of β and S have been averaged over three (or more) series. Reproducibility was generally quite acceptable. From time to time, however, systematic differences revealed a shift in the subject's criterion. To avoid the disturbing influence of this effect, measurements that had to be compared, were carried out during one session.

To avoid confusion, we express visual angles in minutes of arc, and slants or orientation angles in degrees of arc. In the figures we have drawn only trend curves, which approximate to the averages of the three subjects.

Discussion of methods

A few methods are available for investigating quantitatively perceived orientation. First, subjects can estimate orientation in terms of some convenient subjective scale. Results may then depend not only on the perceptual process but also on the subjective scale (KEENE, 1963). Secondly, a line segment can be adjusted until it appears parallel to the perceived line segment (ANDREWS, 1965). In order to get results based on equality of orientations, an alternative cue to parallelism, viz. equality of distances, must be ruled out. We used a third method in which the subject adjusts the position of a small dot until it appears in line with the line segment (Fig. 2). This method has been used earlier by SALOMON (1947). The second method and ours may be taken to depend on a comparison of two perceived orientations. However, our subjects' impression of the perceptual process is somewhat different. Instead of looking for differences between the orientations of AB and BP, they report that they judge whether the dot position is either above or below the extension of the visible line segment. They also report that they judge the position of the dot without moving their eyes, fixating on the expected position of the line segment itself or, sometimes, somewhat closer to the dot. From time to time they steal a glance at the dot, which is in danger of being lost from vision because of the effect of image-stabilization.

Theoretically, a different procedure is available as well, viz. observation of the orientation of the line segment, followed by movement of the eyes in the indicated direction whilst observing whether the dot appears above or below the line of fixation. If this procedure were used by the subjects, parafoveal vision would in no way play a part in the measurements. Since eye movements have not been recorded, the possibility that subjects made use of the latter procedure cannot quite be excluded.

The use of several presentations, which is characteristic of the method of adjustment, allows the subject to average his final adjustment over a number of presentations. The subjects reported that they actually made use of this procedure, in order to get a more satisfactory adjustment.

For certain experimental variables we have made a few checks on whether or not they are of critical influence on β and S.

(1) *Distance*. The distance BP between the line segment and the dot to be adjusted was varied between 140 and 560 minutes of arc. The results showed a negligible increase of β by BP, whereas S showed no influence at all which is in good correspondence with

Salomon's findings. This would seem to indicate that β and S are representative indicators of perceived orientation and its accuracy.

(2) *Contrast*. Luminous contrast between the line and its surroundings had no appreciable influence within a factor of 3 above or below the value actually used in the measurements.

(3) *Fixation dot*. In the first series of experiments we made use of a fixation dot, which was continuously visible. However, we were in doubt whether or not the orientation between fixation dot and adjustment dot would influence the results. We decided to omit the fixation dot in subsequent experiments. It turned out that the fixation dot did not affect the results appreciably. Since the subjects usually reported that they fixated the eyes upon the expected end B of the line segment in the centre of the screen, the results can be taken as representative of foveal vision.

(4) *Training*. Subjects became well trained in this type of experiment. A comparison has been made between their first series and the series carried out after a long period of training. Apart from a slight decrease of standard deviation no differences were detected. It seems not unlikely that normal, everyday vision provides sufficient training. Our subjects did not receive information about their particular settings, but they were aware of their general nature. From Salomon's data, it seems likely that subjects can be trained to make their settings closer to veridical settings.

(5) *Monocular vs. binocular*. The experiments were carried out with normal binocular vision. A few, however, were carried out monocularly. The main trends of the results were unchanged, but there were some differences between the two eyes of one observer. The binocular results seemed to correspond to the monocular results in which only the dominant eye was used.

(6) *Flash duration*. For purposes of comparison, some measurements were carried out for other flash durations, viz. 20 ms and 10 s. The results showed a slight increase of both β and S as flash duration decreased from 10 s to 20 ms.

3. PERCEIVED ORIENTATION AND SLANT

3.1. *Results*

Geometrical slants have been varied in quadrant IV ($270° < \alpha < 360°$) in steps of 15°, stimulus configuration being a flashed line segment (time 100 ms, length 14 minutes of arc). For three subjects, deviations β and standard deviations S are plotted in Fig. 3.

There appears to be a systematic influence of α on the deviation β in the sense that the perceived orientation comes closer to the nearest horizontal or vertical (Fig. 4). Mathematically, the effect can be approximated as $\beta = -B \sin 4\alpha$. In Fig. 4, B is of the order of 3°, but measurements with five subjects over several months showed values of B up to 10°. We have ascertained that the observed effect also holds in other quadrants by measuring β for the eight angles α for which it is expected at its maximum (Fig. 5). We have confirmed Andrew's finding that during a long experimental period the value of B may show appreciable variations.

As for the standard deviations S, a value of about 1° was found, but accuracy was higher for horizontal and vertical orientations than for oblique ones. This latter effect has also been observed for other values of length and flash duration, greater lengths and longer durations giving rise to slightly higher accuracies. To show the influence of slant more clearly, we calculated the quotient of standard deviations $a = 2S_\alpha/(S_{270°} + S_{360°})$ for a number of combinations of length and flash duration. Figure 6 shows these results,

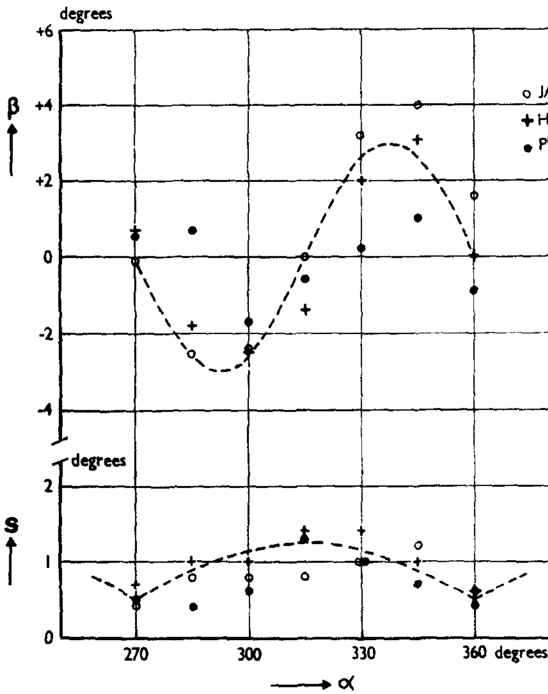

FIG. 3. Deviations β and standard deviations S as functions of slant α. Line segment $l=14$ min of arc, data averaged for flash durations $t=100$ ms and $t=10$ s. Perceived orientation comes closer to the nearest horizontal or vertical (as compared with geometrical slant); the standard deviation is at its minimum for horizontals and verticals and shows a maximum for $\alpha=45°$. Broken trend curves are the mathematical functions $\beta=-\mathrm{B}\sin 4\alpha$ ($\mathrm{B}=3°$) and $S=0{\cdot}5+0{\cdot}8\,|\sin 2\alpha|$.

which are based on more observations than those of Fig. 3. The results can be described as $a=1+1{\cdot}8\,|\sin 2\alpha|$.

3.2. *Discussion*

Perceived orientation; anchors. The results indicate that horizontal and vertical orientations give minimum standard deviation as well as negligible deviation from geometrical

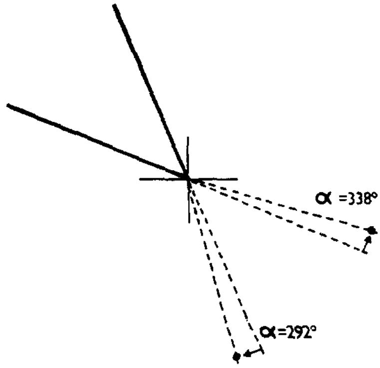

FIG. 4. Perceived orientation tends towards the nearest horizontal or vertical.

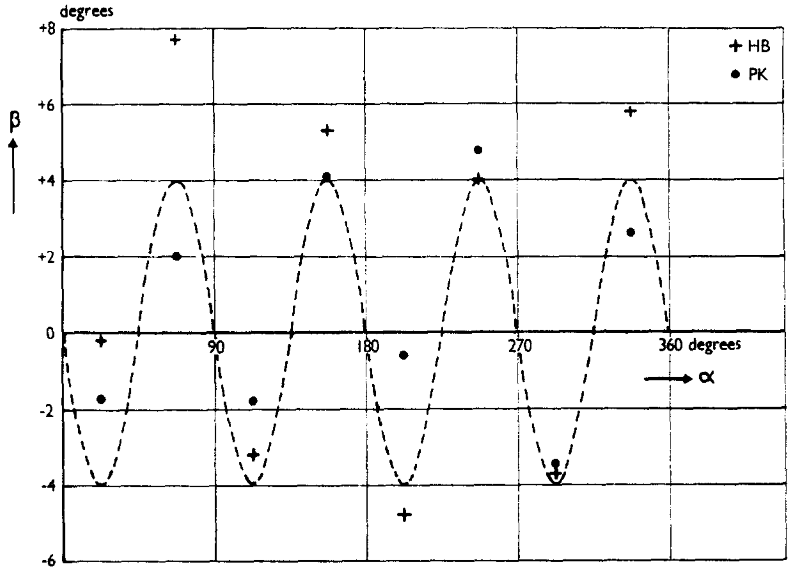

FIG. 5. Deviations β for the slants for which maxima of β are expected ($\alpha=22$, 68, 112, 158, 202, 248, 292, and 338°). The trend towards the nearest horizontal or vertical proves to be similar over the full range of slants. As a trend curve, $\beta=-4\sin 4\alpha$ has been drawn.

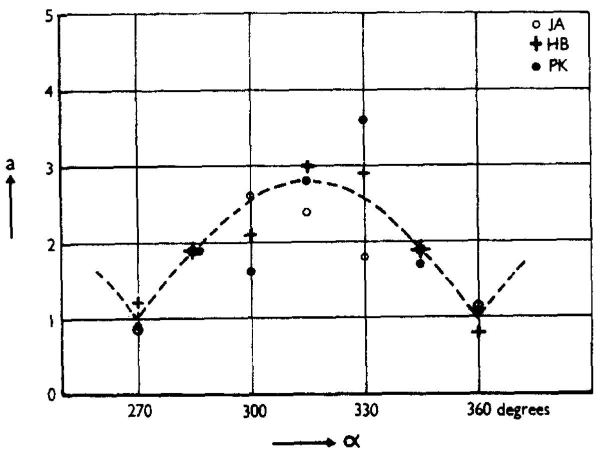

FIG. 6. Quotient of standard deviations $a=2S_{\alpha}/(S_{270°}+S_{360°})$ as functions of slant α. Results have been averaged for a number of combinations of length l and flash duration t. Trend curve $a=1{\cdot}0+1{\cdot}8\mid\mathrm{Sin}\,2\alpha\mid$.

slant. Both effects are consistent with the generally accepted view that horizontals and verticals can serve as subjective standards, or anchors, to be relied upon when judging orientations. Supporting evidence is (a) a relatively high accuracy in judging horizontality or verticality on a purely subjective basis (KEENE, 1963) and (b) a relatively low sensitivity to induction-effects, defined as changes in perceived orientation brought about by the presence of other contours, evidenced by several visual illusions. It would be interesting to find out to what extent anchor orientations are bound to be coordinate framework of the retinas.

Neurophysiologically, no preference of horizontal or vertical orientations to oblique ones seems to have been established so far, either in the retina or in any other visual station.

For ganglion cells in the retina of the rabbit, which are specifically sensitive to moving stimuli, a preference for certain orientations has recently been found. (OYSTER and BARLOW, 1967).

Anatomically, there is some evidence of preference of horizontal or vertical orientations to oblique ones in the eye of the octopus (YOUNG, 1962).

While perceived orientation for horizontal and vertical line segments is close to geometrical slant, perceived orientation of oblique line segments tends towards the nearest horizontal or vertical. Andrews' investigation, based upon the sense of parallelism of lines, seems to have produced similar results, to the effect that short flashed lines are perceived closer to the nearest horizontal or vertical than long, stationary lines. However, we met some difficulties in the interpretation of his results since it was not quite clear to us how the term "apparent slope" that he uses, has been defined.

WINNICK and ROGOFF (1965) have reported a possibly related effect for estimates of the slant angle of simple geometrical figures. Apparently, they turned their figures around a vertical axis.

In the general discussion we shall present a hypothesis concerning a possible common origin of the effects of slant on angle deviation and on standard deviation. The question to what extent these effects are related to the sense of perspective, will be left entirely to future research.

Relation to visual acuity

For S we found values of the order of 1°. How does this compare with the values of visual acuities (V.A.) for other visual tasks? In our experiments, rotation of a line segment l over an angle $\Delta\alpha$ (degrees), one end being fixed, causes the other end to shift over a distance $m = \Delta\alpha\ l/57$. For the smallest value of l that we used ($l = 14$ min of arc), we arrive at $m = 0{\cdot}25$ minutes of arc, corresponding to V.A. $= \frac{1}{m} = 4$. This value has to be compared with foveal V.A. values for standard tasks, such as detection of a gap in a Landolt C (V.A.$=2$) and aligning two line segments (vernier acuity V.A. $\simeq$ 10)[1].

When the line segment is looked at, the adjustable dot is observed in parafoveal vision (some 340 min of arc out of the fovea). A value $\Delta\alpha = 1°$ corresponds to a displacement of the dot of 6 min of arc (V.A.$=0{\cdot}15$). This can be compared with V.A.$=0{\cdot}25$, as found for a Landolt C. The conclusion is that the degree of accuracy of observation of orientation comes close to accuracies in other visual tasks, for foveal as well as for parafoveal vision.[2] The low values of standard deviation (and thus high accuracies) for horizontals and verticals, which in our experiments are about 2·5 times lower than for obliques, are in good correspondence with data from the literature (LEIBOWITZ *et al.*, 1953, 1955a; ROCHLIN, 1955; KEENE, 1963; ANDREWS, 1965). In fact, visual acuity tasks also show such a preference, but here the differences are reported to be small. (HIGGINS and STULTZ, 1948;

[1] Since these visual tasks require cooperation between several retinal elements during an appreciable amount of time, the diameter of foveal cones (0·4 min of arc) does not constitute an upper limit for visual resolution.

[2] Parafoveal vision does not play a part in the measurements when the alternative eye-movement strategy is used by the subjects. In this unlikely case, however, the comparisons of foveal acuities remain perfectly valid. In that case eye-movements must be assumed to be very accurate indeed.

LEIBOWITZ, 1955b; OGYLVIE and TAYLOR, 1958). For these small effects it is difficult to exclude with certainty the contribution of any minor optical defects (WEYMOUTH, 1959). Quite recently, however, CAMPBELL *et al.* (1966) have been able to demonstrate that in acuity tasks a preference for horizontals and verticals exists that cannot be attributed to optical properties of the eye. That the effect is not due to preference directions of eye movements has been shown by HIGGINS and STULTZ (1950) and by NACHMIAS (1960).

4. CUES TO ORIENTATION

A next step is to try to find what information the subject actually uses when looking for the orientation of a line segment. Theoretically, there are a number of possibilities: he may use only the small part of the line segment on which he happens to fixate his eyes, or he may use the full line segment, or again, he may use only both extremities. We shall consider two hypotheses:
(1) the subject uses only part of the line segment of a critical length l_c, neglecting the rest.
(2) the subject uses only the two extremities of the line segment as information sources.

Critical part l_c

An experimental consequence of this hypothesis is that when the length of the line segment is varied, any increase of the length beyond l_c does not influence the angular deviation β and the standard deviation S. For lengths smaller than l_c, the subject is expected to run into greater uncertainty concerning the picking out of the proper information, which will lead to higher values of S; different values of β may also occur.

Figure 7 illustrates the experimental results. The influence of length on β turns out to be restricted to lengths smaller than roughly 60 min of arc. This is consistent with the hypothesis (1) that for long line segments the information as regards orientation is derived mainly from a (foveal) part of this length.

As for S, there appears to be hardly any influence, which, even apart from any specific hypothesis, seems rather surprising. It is, in fact, even more so, since for small line segments the subjects report that they see clearly different orientations for successive presentations having exactly the same slant ("rotation-effect"). This effect has also been observed by Andrews. The reason why the effect is not reflected in the values of S may be due to the averaging strategy which is inherent to the method of adjustment. This calls for a different experimental procedure in which the subjects have to base their observations on one presentation only. Using such a procedure, we have made a few preliminary experiments that point to an increase of S as line length decreases.

Extremities of the line segment

An experimental consequence of hypothesis (2) is that a line segment is equivalent to two dots at the ends of the line segment, as far as orientation is concerned. In Figs. 8a and 8b, experimental results are given of such an experiment, again for two values of slant. For $\alpha=338°$, there are clear differences of perceived orientation between the full line segment and the two dots, illustrating that the subject does not use the extremities of the line segment as a cue to orientation. However, for $\alpha=292°$, differences between line segment and dots are almost negligible, and accordingly the hypothesis that subjects use the extremities as sources of information, cannot be rejected. Values of S do not differ for the two kinds of stimuli.

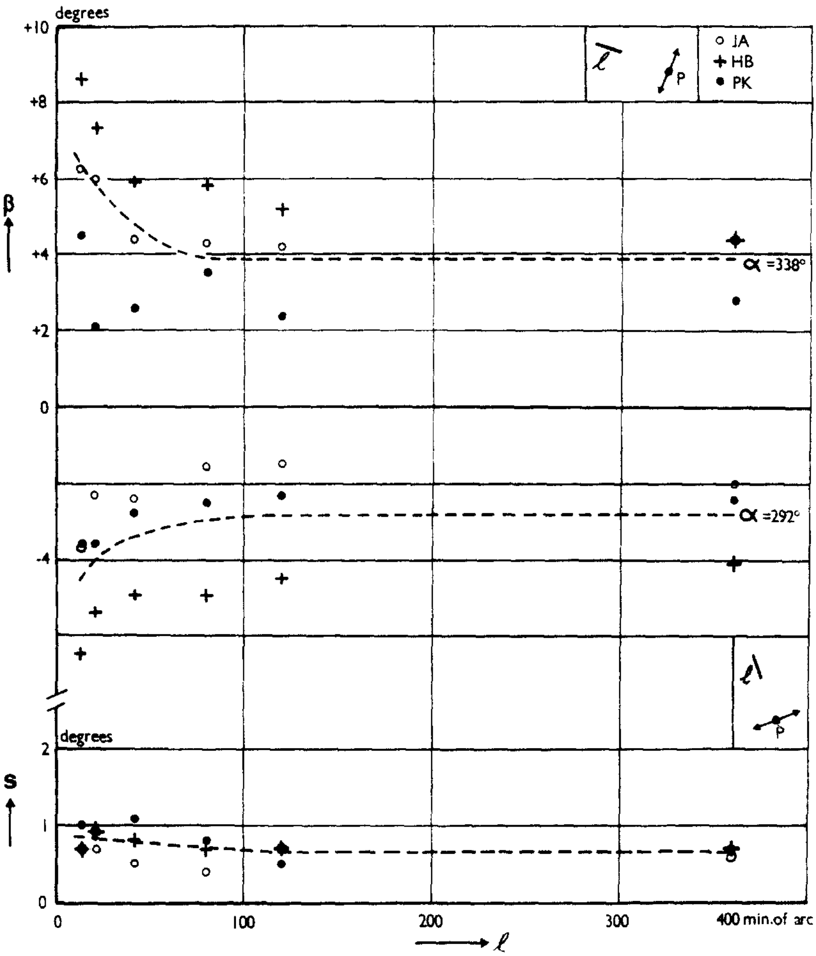

FIG. 7. Influence of length l of the line segment on β and S (precise values of $l=14$, 21, 42, 80, 120 and 360 min of arc).
For lengths above some 60 min of arc little influence has been found, but towards smaller lengths deviation β increases. Standard deviation S has been averaged for the two slants $\alpha=292°$ and $\alpha=338°$; it proves to be almost uninfluenced by length.

The two-dots situation $l'=360$ min of arc merits special notice, since the spatial stimulus configuration is almost symmetrical. We have not checked whether in this case deviations stem from differences in presentation time (configuration dots flashed, adjustable dot continuous) or from an asymmetry in the orientation mechanism itself.

A few words may be added about the effect that perceived orientation tends to be closer to the nearest horizontal or vertical as compared with geometrical slant. From Fig. 7 it appears that this effect is most pronounced for small lengths of the line segment. This may be taken as indicating that the effect as a whole is brought about by the small part of the line segment that is closest to the adjustable dot. The close correspondence between β values for line segments and those for dots occurring for small lengths at a slant $\alpha=338°$ (Fig. 8a), seems to indicate that the dots trigger the same orientation detecting processes as do the line segments.

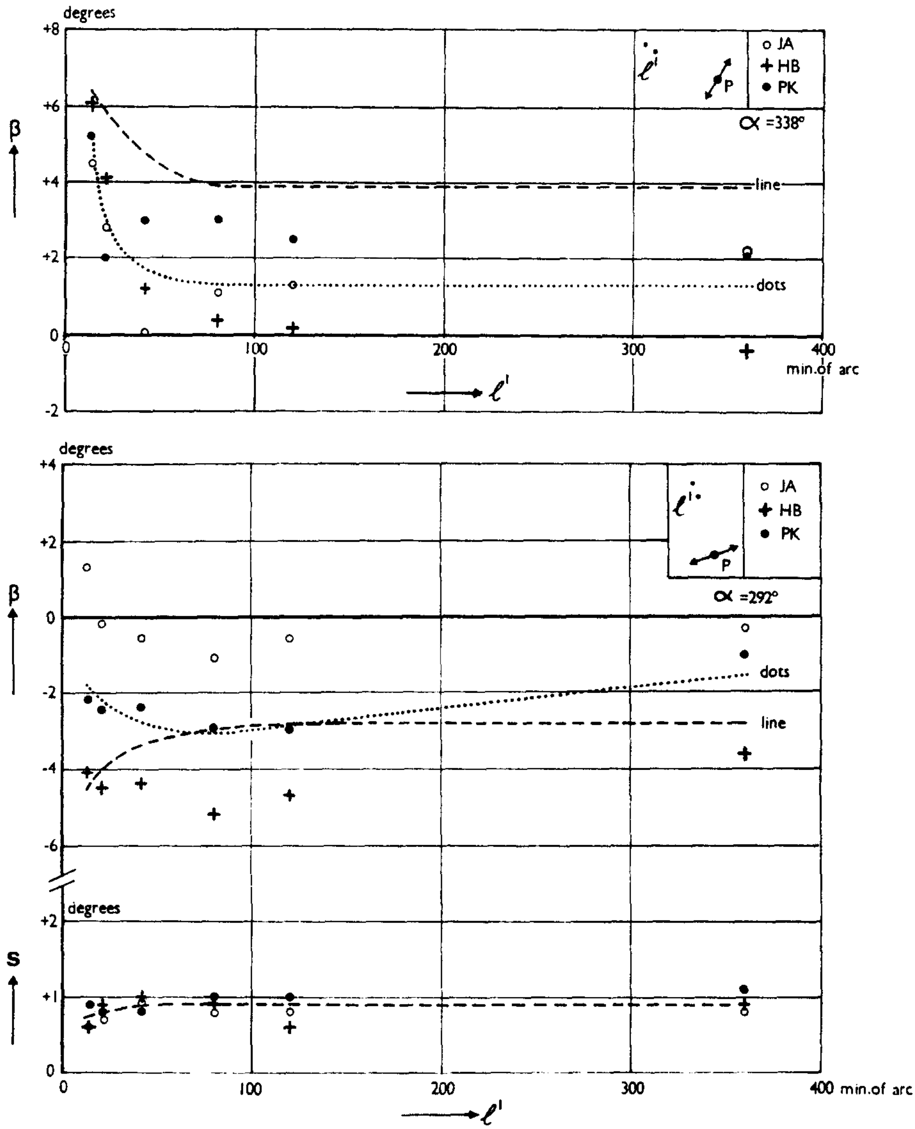

FIG. 8. Adjustment of the dot P in line with two dots at a distance l' (dotted lines). Broken lines have been taken from Fig. 7; they show the results for a full-line segment of length l. Effects for $\alpha = 338°$ (Fig. 8a) seem quite different from the results for $\alpha = 292°$ (Fig. 8b). Standard deviation S has been averaged for the two values of α.

5. GENERAL DISCUSSION

The experiments have shown that the mere presence of either a short line segment or two dots is sufficient to generate in the subject an internal representation of a full extended line on which judgments may be based, just as if this line were really present in the configuration. The high accuracies show that information as to orientation can be picked out as a powerful cue to form perception, which may be relied upon for judgments of either parallelism or extension. To be sure, measurements on deviation β and standard deviation

S do not tell us what part of actual form perception is really played by orientation, nor to what degree differences in orientation are easily overlooked in ordinary form perception.

For judging orientation on its own merits without reference to other orientations, some internal references or anchor orientations have to be assumed for which the horizontal and the vertical seem to have an accurate internal representation. To bridge the gap between the many orientations that can be distinguished when shown together and the very few anchor orientations, experiments on the memory of orientations may be of value. We have carried out a few preliminary experiments on this point, and these indicate that the accuracy with which two oblique slants may be matched when presented in succession, decreases substantially when time interval is increased from 3 to 10 seconds.

An interesting attempt towards understanding the processes that underlie perception of orientation has been made by ANDREWS (1965). Proceeding on Hubel and Wiesel and also on an earlier suggestion by MacKay he assumes the existence of line detectors, each of which is sensitive to a rather wide range of (retinal) slants (first stage).

His assumption is that the accurate perception of orientation is based on a two-stage process, the second stage being a comparison of the outputs of a number of line detectors. To account for the high accuracy of the horizontal and vertical anchor orientations, Andrews assumes the corresponding line detectors to be sensitive to a narrower band of slants than line detectors that are tuned to obliques (Fig. 9a). The tendency for perceived

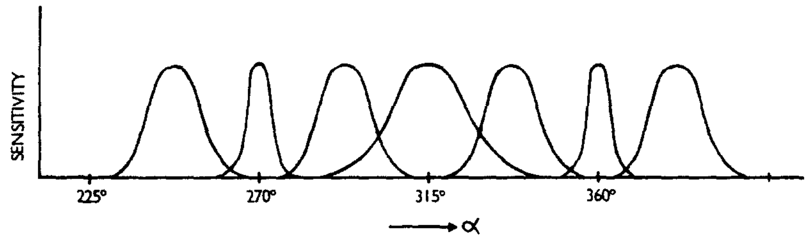

FIG. 9a. Andrews' proposal for the arrangement of line detectors: narrow tuning curves for the horizontal and vertical orientations and wide ones for oblique orientations. While it shows that there might be a common ground for the effects on standard deviation and on angle deviation, the direction of the predicted angle deviation is contrary to observation.

orientation of oblique lines to divert from geometrical slant, may well be a consequence of this hypothesis: A slanted line will stimulate a number of line detectors, and the wide detectors to the oblique side will receive more stimulation than the narrow ones to the side of the nearest horizontal or vertical. Thus, perceived orientation will show a tendency to divert away from the nearest horizontal or vertical. Unfortunately, the direction of the observed effect is just contrary to this theoretical prediction. For this reason, we would like to propose a slightly different hypothesis, covering qualitatively the observed effects, while maintaining the idea of a common origin of the effects on standard deviation and angle deviation. Our hypothesis is that the sensitivity of all line detectors is symmetrical, and that the sensitivity curves for all slants are quite similar. The anchor orientations are assumed to be characterized by a greater density of line detectors (Fig. 9b). Stimulation by a slanted line will now be greater at the side of the greater density and accordingly, perceived orientation will tend towards the nearest anchor.

Concerning the influence of the length of the segment, we might assume that with decreasing length a wider angular range of line detectors be stimulated, thus accounting for an increase of angle deviation.

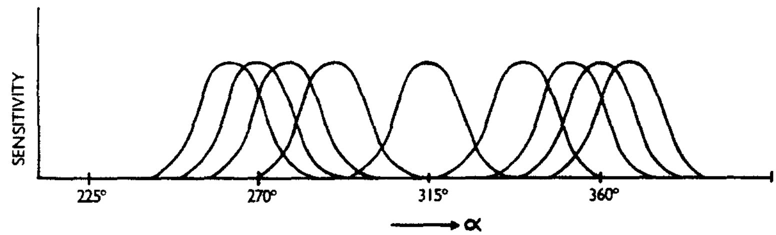

FIG. 9b. A hypothetical arrangement of line detectors which might explain the high accuracy for both horizontals and verticals, and the tendency for oblique lines towards the nearest horizontal or vertical. The figure shows identical, symmetrical line detectors, whose density is highest for horizontals and verticals.

Speculative as this necessarily has to be at the present state of knowledge, it seems to hold promise as a way towards understanding the processes that underlie the perception of orientation as one of the spatial elaborations of the retinal signals that contribute to form perception.

6. CONCLUSIONS

1. Horizontal and vertical orientations can be observed at higher accuracies than can oblique orientations. This is one of the reasons why they stand out as preference or anchor orientations.

2. Perceived orientation ($\alpha+\beta$) of oblique lines is closer to the nearest horizontal or vertical than is geometrical slant α. The deviation β may reach values as high as 10°.

3. Variation of the length of a line segment shows the deviation β to increase when line length decreases. Results are consistent with the hypothesis that the orientation of the line segment is judged from a (foveal) line segment of some 60 minutes of arc.

4. Information as to orientation can be derived equally well from two dots at some distance. Both a line segment and two dots give rise to an accurate internal representation of an extended straight line, on which the subject can rely for his judgments. This is taken as indicating the flexibility of the visual system in its ability to rely on whatever information as to orientation is available.

5. A promising theoretical framework that might unravel processes of spatial elaboration of retinal signals as to orientation, is beginning to take shape.

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REFERENCES

ANDREWS, D. P. (1965). Perception of contours in the central fovea. *Nature, Lond.* **205**, 1218–1220.

CAMPBELL, F. W., KULIKOWSKI, J. J. and LEVINSON, J. (1966). The effect of orientation on the visual resolution of gratings. *J. Physiol., Lond.* **187**, 427–436.

HIGGINS, G. C. and STULTZ, K. (1948). Visual acuity as measured with various orientations of a parallel-line test object. *J. opt. Soc. Am.* **38**, 756–758.

HIGGINS, G. C. and STULTZ, K. (1950). Variation of visual acuity with various test-object orientations and viewing conditions. *J. opt. Soc. Am.* **40**, 135–137.

HUBEL, D. H. and WIESEL, T. N. (1959). Receptive fields of simple neurones in the cat's striate cortex. *J. Physiol., Lond.* **148**, 574–591.

HUBEL, D. H. and WIESEL, T. N. (1962). Receptive fields, binocular interaction and functional architecture in the cat's visual cortex. *J. Physiol., Lond.* **160**, 106–154.

KEENE, G. C. (1963). The effect of response codes on the accuracy of making absolute judgments of lineal inclinations. *J. gen. Psychol.* **69**, 37–50.

LEIBOWITZ, H. (1953). Some observations and theory on the variation of visual acuity with the orientation of the test object. *J. opt. Soc. Am.* **43**, 902–905.

LEIBOWITZ, H., MYERS, N. A. and GRANT, D. A. (1955a). Radial localization of a single stimulus as a function of luminance and duration of exposure. *J. opt. Soc. Am.* **45**, 76–78.

LEIBOWITZ, H. (1955b). Some factors influencing the variability of vernier adjustments. *Am. J. Psychol.* **68**, 266–273.

NACHMIAS, J. (1960). Meridional variation in visual acuity and eye movements during fixation. *J. opt. Soc. Am.* **50**, 569–571.

OGILVIE, J. C. and TAYLOR, N. M. (1958). Effect of orientation on the visibility of fine wires. *J. opt. Soc. Am.* **48**, 628–629.

OYSTER, C. W. and BARLOW, H. B. (1967). Direction selective units in rabbit retina: distribution of preferred directions. *Science, N.Y.* **155**, 841–842.

ROCHLIN, A. M. (1955). The effect of tilt on the visual perception of parallelness. *Am. J. Psychol.* **68**, 223–236.

SALOMON, A. D. (1947). Visual field factors in the perception of direction. *Am. J. Psychol.* **60**, 68–88.

WEYMOUTH, F. W. (1959). Stimulus orientation and threshold: an optical analysis. *Am. J. Ophthal.* **48/II**, 6–10.

WINNICK, W. A. and ROGOFF, I. (1965). Role of apparent slant in shape judgments. *J. exp. Psychol.* **69**, 554–563.

YOUNG, J. Z. (1962). The optic lobes of octopus vulgaris. *Phil. Trans. R. Soc.* B **245**, 19–58.

Abstract—This investigation is concerned with the spatial elaboration of retinal signals occurring in the visual system. Guided by the recent electrophysiological evidence that retinal orientation is among the first isolated spatial cues, we have used a psychophysical method to study the relationship between perceived orientation and geometrical slant.

Results indicate that perceived orientation of oblique lines is closer to the horizontal or vertical (whichever is nearer) than is geometrical slant, the difference being of the order of 5°. Accuracies are highest for the horizontal and vertical.

We have also investigated what type of information is actually used in the visual system to arrive at "orientation". Results are consistent with the hypothesis that a foveal part of the line segment of about 60 minutes of arc supplies the information.

As to the underlying processes, the hypothesis that there exists a set of orientation filters, each of which is tuned to one particular retinal slant, seems sufficiently flexible to cover present results.

Résumé—On étudie l'élaboration spatiale des signaux rétiniens dans le système visuel. Les données récentes d'électrophysiologie prouvant que l'orientation rétinienne est un des mécanismes isolés essentiels de l'espace, nous avons employé une méthode psychophysique pour étudier la relation entre l'orientation perçue et l'inclinaison géométrique.

Les résultats indiquent que l'orientation perçue de lignes obliques se rapproche de l'horizontale ou de la verticale (selon celle qui est le plus près) plus que l'inclinaison géométrique, la différence étant de l'ordre de 5°. Les précisions sont les plus élevées pour l'horizontale et la verticale.

Nous avons recherché aussi quel type d'information est utilisé en fait dans le système visuel pour obtenir l'orientation. Les résultats s'accordent avec l'hypothèse qu'une partie fovéale de 60 minutes environ sur un segment de droite fournit l'information.

Quant aux mécanismes sous-jacents, l'hypothèse qu'il existe un ensemble de filtres d'orientation, chacun accordé sur une inclinaison rétinienne particulière, semble assez souple pour interpréter les résultats actuels.

Zusammenfassung—Diese Untersuchung befaßt sich mit der örtlichen Festlegung von Netzhautsignalen wie sie im visuellen System auftreten. Ausgehend von der neueren elektrophysiologischen Erkenntnis, daß die retinale Orientierung zu den ersten isolierten, örtlichen Kenngrößen gehört, haben wir eine psychophysikalische Methode zur Untersuchung des Zusammenhanges zwischen der gesehenen Richtung und der geometrischen Neigung angewendet.

Die erhaltenen Ergebnisse lassen schließen, daß die wahrgenommene Richtung schräger Linien mehr zur Horizontalen oder Vertikalen (welche gerade näher ist) tendiert, als die geometrische Neigung. Die Differenz ist in der Größenordnung von 5°. Die Genauigkeit ist horizontal und vertikal am größten.

Wir haben auch untersucht mit welcher Art von Information das visuelle System arbeitet um eine "Orientierung" zu erhalten. Die Ergebnisse stimmen mit der Hypothese überein, die besagt, daß ein fovealer Teil der Linie mit einer Ausdehnung von ungehähr 60 Bogenminuten die Information zur Verfügung stellt.

Was die Prozesse anbelangt, die dem zugrunde liegen, so erscheint die folgende Hypothese, die die Existenz einer Reihe von Orientierungsfiltern, von denen jedes einzelne an eine bestimmte retinale Neigung angepaßt ist, genügend flexibel zu sein, um die gegenwärtigen Ergebnisse zu decken.

Резюме — Это исследование касается пространственной переработки ретинальных сигналов, поступающих в зрительную систему. Исходя из новых данных о том, что ретинальная ориентация является одним из первых изолированных пространственных сигналов, мы использовали психофизический метод для изучения соотношения между воспринимаемой ориентацией и геометрическим наклоном линий.

Результаты показывают, что воспринимаемая ориентация косых линий приближает их к горизонтали или вертикали [в зависимости от того какия из них ближе], по сравнению с их геометрическим положением. При этом различие бывает порядка 5°. Наибольшая точность наблюдается для горизонтали и вертикали.

Мы исследовали также тип информации, какой в действительности употребляется в зрительной системе, чтобы добиться успеха в «ориентации». Результаты согласуются с гипотезой по которой информацию доставляет сегмент линии, который проицируется на фовеальную область сетчатки под углом примерно в 60 минут.

Что же касается до процессов лежащих в основе этих явлений, то кажется, что достаточно гибкой и объясняющей полученные результаты гипотезой является та, которая предполагает, что существует серия фильтров ориентации, каждый из которых отвечает на один из специальных положений на сетчатке.

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