Spontaneous fixation tendencies for visual forms¹

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Haidinger's brush was used as a method of locating fixation positions on a display. The various experimental patterns studied showed: (1) It is the already organized cortical representation of shape which governs fixation, rather than the peripheral input per se; (2) Acute angles near 20 deg are the most effective angular stimuli; (3) For figures subtending angles less than 5 deg, the eye is directed toward the center of the figure, and not toward its edge; and (4) Removing one segment from a completely enclosed figure may not alter the mean fixation position.

Eye movements and fixation behavior have received considerable attention in recent years. Yet, we have very little information about where people fixate when examining simple forms. Hebb (1949) has suggested that the development of perception is based upon the sequential viewing or scanning of lines and corners. Is the adult, like Hebb's hypothetical infant, also a scanner of outlines of objects? This view seems to be a part of our current prejudice about how people look. Following the modern vogue in computer technology, we have become used to thinking in terms of a piecemeal scanning of parts, which are somehow integrated over time in order to create the perception of form. Supporting this viewpoint is our knowledge of the rapidity with which the fovea scans the world of pattern.

Certainly, some kind of sequential processing must occur for complex scenes having a large visual extent. When viewing a complex scene, the eyes make rapid saccades—as opposed to smooth movements between the points of interest which are fixated for relatively long periods. Because of the impairment of vision associated with saccadic movements (Volkman, 1962; Latour, 1962; Zuber, 1966, the primary processing of pattern information must occur during the pauses. However, given a local region which is being examined, what are the constraints governing the fixation tendencies? Will "corners," "edges," and "lines" or other feature detectors play a role? If they do, then it is plausible that the eye should be preferentially attracted towards these elements. To begin to answer these questions, we decided to study the spontaneous fixation tendencies of the eyes when they are confronted with very simple forms.

METHOD

The entoptic phenomenon known as Haidinger's brush was used to study spontaneous fixation behavior. This phenomenon is probably caused by thousands of blue-light absorbing, radially-oriented crystals in the macular pigment. Due to their radial pattern the absorption axis of each body lies approximately along a radius from the center of the fovea. Incident linear polarized light will therefore be absorbed more strongly in some parts of the pattern than in others. The long axis of the brush is approximately perpendicular to the direction of electric vibration in the polarized beam. If the beam has a constant angle of polarization the brush is a stabilized image which will therefore tend to disappear rapidly. However, by continually rotating the angle of polarization of the light (Boehm, 1940), it is possible to make the brush appear permanently. This was accomplished by placing a rotating Polaroid filter in front of the projector.

A Kodak Carousel projector was used to project slides of various displays on an aluminized screen which preserved polarization of the reflected light. A Corning glass filter (No. 5-60) was used to obtain blue light with a dominant wavelength of approximately 470 nm with 95% purity. The filter was placed in front of the lens of the projector. The Polaroid filter was mounted in a ring gear which could be driven by a pinion controlled by a dc motor. Upon rotation of the filter, an observer could see his own brush within the blue field projected onto the screen. Because the perceived size of the brush follows Emmert's Law, the Ss sat at 1.5

m from the screen to insure that the rotating Haidinger's brush would be small relative to the projected forms.

PROCEDURE

A series of slides were prepared for each experiment. Each slide was chosen at random and projected onto the screen. The S was instructed merely "to look at the projected display." From time to time, the polarizer would be briefly rotated to make the brush visible. Our naive Ss thought that a propeller had been flashed onto the screen. This novel object tended to hold fixation rigid at the point where the eyes were looking prior to the appearance of the brush. Ss never reported lateral movement of the propeller—it always remained rotating about a stationary point.³ After the propeller vanished, the Ss were asked to mark the position of the center of the propeller on a reproduction of the projected display. These marks were not visible to the S, but appeared on a carbon copy underneath the top reproduction, to provide the record of the positions fixated. With many such exposures, we could build up a contour map showing the most probable places of fixation in or near the form.

EXPERIMENT 1

Why use the Brush?

It is possible that if we had simply asked a S to record where he was looking, we would have obtained fixation maps identical to those obtained with Haidinger's brush. A few experiments convinced us, however, that the fovea is not always oriented towards the point to which "attention" is directed. In other words, the center of attention and the projected position of the fovea generally do not coincide exactly.

The dots in Fig. 1a show the positions on an outline of a cube which a naive S believed he was fixating at various instants of time. For these measurements where the S could not see the brush, he believed that he was looking more or less randomly throughout the cube. Figure 1b shows the position of the brush for the next 10 judgments. These records show that the

Fig. 1. Comparison between where a naive observer believes his eyes are directed (top) and where the eyes are, in fact, oriented (bottom). The front face of the cube subtends 2.5 deg visual angle on a side.

Fig. 2. Mean spontaneous fixation positions (dotted circles) for various small figures. Note approximate equivalence between open and enclosed forms.

Fig. 3. Spontaneous fixation tendencies for outlined circles of various diameters. The cross-hatched area includes 86% of the recorded fixations (averaged for two observers); the black spots indicate the mean fixation position.

Fig. 4. Typical contour stimulus (top) and corner stimulus (bottom) displays for Experiment 3.

orientation of the fovea remains relatively fixed near the upper left corner of the front face. The fixation pattern shown in Fig. 1b is typical of the first reports of the position of the brush for other naive Ss. Thus, the center of fixation does not generally correspond to the center of attention (Pritchard, 1958). They may differ, according to our data, by as much as 2 deg. The Haidinger "propeller" is necessary in order to determine just where the eyes are oriented.

EXPERIMENT 2

Fixating Small Forms

If the center of attention, and the point of fixation may differ by as much as 2 deg, then there might be no need to alter fixation when observing small forms. If this were true, then it would also be of interest to determine just where the eyes were oriented when examining various outlines having small visual extent.

Figure 2 shows a collection of nine figures, each subtending about 2 deg visual angle. The small, dotted circles on the forms indicate the region in which 86% of the fixations occurred (as measured by the Haidinger propeller). Note that the center of the form is generally fixated, as opposed to the vertices or the corners. This is true regardless of whether the form is open or closed. The square or triangle with one side missing yields a fixation pattern almost identical to the corresponding closed figures. Also note that the gap in the line attracts the eye more than either of the separated line segments in the gapped-line form. This indicates that a discontinuity is also an attractive element for fixation.

All of these results hold for forms which are smaller than 5 deg. As the forms become larger than 5 deg, fixation becomes more scattered. This point may be illustrated by examining circles of various sizes: 1.5 deg, 3 deg, 6 deg, and 9 deg. Two Ss were used and each gave 50 responses to each stimulus. Thus, each S reported brush locations 50 times for each circle. The results are summarized in Fig. 3. They show a clear tendency towards central fixation. The shaded regions represent the places of approximation of 86% of fixations. However, as the circles grow larger the fixation tends to be more scattered. The scatter in fixations was about 2 deg of visual angle in the largest (9 deg) circle, 1.5 deg in the 6 deg circle, and 0.5 deg in the 3 deg circle. Note that even for the 9 deg circle, the Ss still did not fixate the contour, but continued to orient to a position inside of the outline. One S tended to fixate predominately near the center of the circle, whereas the second S's point of fixation was lower. Each S showed some scatter in the direction of the mean fixation position of the other. If scanning movements of the outline of the circle occurred, then they must have occurred very rapidly and infrequently, because the brush was never reported appearing on a contour.

EXPERIMENT 3

Fixation of Contours

Obviously, however, outlines or contours will be fixated in preference to homogeneous areas under some conditions. If a large field (13 x 20 deg) is divided into lighter and darker portions, as shown in Fig. 4, then the contour will attract the eye. However, on the average, the eyes do not fixate the exact center of the boundary.

Two types of boundaries were studied. In the first of these the field was divided into lighter and darker portions, as illustrated at the top of Fig. 4. The lighter portion varied in size from about 3

Table 1
Horizontal Contour Positions for Uninterrupted Contour Displays

Display	Position of Contour
A	3 deg 06 min from left side
B	5 deg 12 min from left side
C	8 deg 02 min from left side
D	10 deg 05 min centered
E	8 deg 62 min from right side
F	5 deg 12 min from right side
G	3 deg 06 min from right side

Table 2
Comparisons Between Points, Lines and Angles

Stimuli	Per cent fixations of one vs other
30 deg angle vs line	88% to 30 deg angle
90 deg angle vs line	81% to 90 deg angle
90 deg dotted angle vs dotted line (5 dots in each form)	87% to 90 deg angle
30 deg angle vs point	78% to 30 deg angle
90 deg angle vs point	63% to 90 deg angle
point vs line	67% to point

deg to about 17 deg in 7 steps, as shown in Table 1. The second type of contour was the same as the first except that a corner was added, as illustrated in the lower portion of Fig. 4. There were eight of these figures, which were presented by slides and these slides were mixed with the seven other slides during the experiment. The left and right sides of the randomly ordered slides were reversed on successive exposures.

Nine Ss were used. Each of them saw each slide 10 times. On each occasion, the S marked a replica of the slide with a dot to indicate the position of the center of the propeller.

The data obtained when the stimulus contained a straight and uninterrupted dividing line show that the contour does in fact attract the eye. It does this regardless of the place of the contour in the field, although there is a small constant deviation towards the center that grows larger as the contour moves towards the side. On the average, however, the contour is a potent stimulus to fixation. This is shown in Fig. 5. Here we see how frequency of fixation in the horizontal dimension varies with respect to the contour. There is a tendency for the S to look in the vicinity of the contour, with the fixation tendencies bimodally distributed. A similar effect has been observed by Fiorentini and Ercoles (1966). Deviations from the contour tend towards the light side. This may be due to the presence of a bright Mach band in that region. Ss also fixate very slightly above the vertical center of the field.

The corner data are shown in Fig. 6. There is generally less horizontal scatter when a corner is present. The corner constrains spontaneous fixations to its vicinity. Here, too, however, there is a bias towards the lighter side.

The vertical fixation data with the corner present also reflect its influence. The overall Standard Deviation about the mean vertical fixation point, which was at the corner, is approximately 0.1 deg as compared with 0.2 deg when the corner is absent.

Thus, for large fields, the discontinuities or corners, contours, and, in particular, the brighter sides of the contours will attract fixation most readily. Perhaps as might be expected, the contour with the corner provided the least scatter for the fixation tendencies.

EXPERIMENT 4

Acuteness of Angles

Several theoreticians place considerable emphasis on the tendency of corners to attract fixation, and because corners do seem to be potent stimuli to fixation, it was considered desirable

Fig. 5. Fixation frequency in the vicinity of a contour.

that the parameter of corner acuteness be examined further. To this end, pairs of angles whose apexes faced each other in the display were presented simultaneously. One of the angles was 90 deg. The opposing angle ranged from 0 deg to 180 deg in 10 or 20 deg steps. The 0 deg angle was a straight line with one end facing the 90 deg corner. The 180 deg angle was a straight line with its extent opposed to the corner. A typical stimulus pattern is shown in the inset of Fig. 7.

The procedure was to present the different combinations of angles to a S for a long period of time and, at random moments, let him see his brush and report its location in the display. If the brush tended to be located nearer one angle than the other, then on that particular trial it was presumed that that angle was preferred for fixation. Four Ss were employed and each was given 20 to 40 trials per pattern. The results of the experiment are plotted in Fig. 7. If more than 50% of fixations are associated with a particular angle on the abscissa, then that angle is preferred to the standard 90 deg angle. It will be noted that when two 90 deg angles are presented together then one is preferred no more than the other. As the angle becomes more acute than 90 deg, it is preferred more often than the 90 deg angle when the degree of acuteness is less than 0 deg. A corner is preferred to the end of a straight line. As a matter of fact, the 20 deg angle seems to be preferred over all other degrees of acuteness. When the angle is more obtuse than 90 deg, then it is preferred less often than a 90 deg angle. The direction of preference change varies monotonically with respect to degree of obtuseness.

In addition to the foregoing stimuli, which were comprised of outline shapes, some patterns were used which were comprised of dots arranged in patterns so that they had the appearance of angles. The data using angles made from five dots were the same as those obtained using line figures. This result is particularly interesting because it indicates that it isn't simply the discontinuity of brightness at a corner which induces the effect on fixation. For if it were, then one dot would be as good as the other and there would be no preference for one degree of acuteness of the dot shapes over another degree of acuteness. It might, therefore, be concluded that cortical representation of shape, rather than local properties of the shapes, is the determiner of fixation.

EXPERIMENT 5

Point-Line-Angle Comparisons

In addition to a comparison of angles of different degrees of acuteness, additional data were collected in which angles, points, and lines were compared with each other. The stimuli used and the resulting data, obtained with three observers, are summarized in Table 2.

These results are consistent with those of the previous experiment. Angles are preferred to lines even though the angles or the lines may be comprised of points. It is the visual shape which determines the fixation tendency. Also, a point or sharp discontinuity in brightness is preferred to an extended line.

EXPERIMENT 6

Closed versus Open Figures

As indicated in Experiment 2, central fixation tendencies for small forms seemed to be similar regardless of whether the figures

Fig. 6. Fixation frequency in the vicinity of the vertex of a corner.

Fig. 7. Relative effectiveness of various angles (α) as attractants for fixation, when paired with a 90 deg angle (see inset).

were open or closed. To test the strength of closure, some preliminary measurements were taken pairing open angles versus closed forms. Thus, an open angle might be seen adjacent to a closed circle or square. The open figure was a 30 deg angle and it subtended an angle of 5 deg at the eye. This figure was paired with either a 5 deg visual angle circle or a 5 deg square. Three observers were exposed to these displays. The observer was simply told to look at the display. From time to time he was shown his brush and asked to report on its position. Fifty judgments were obtained from each S for each display.

It was found that approximately 50% of the reported brush locations were inside the square or circle and 50% were inside the angle. It must therefore be concluded that closed figures do not necessarily predominate over open figures. In the light of evidence to be reported subsequently, it appears that a completion process is in operation which serves to cause many open figures to behave as though they are closed figures.

CONCLUSIONS

The major conclusion of this study is that visual shape is a stimulus to fixation. This suggests that peripheral inputs, per se, are not the primary determiners of spontaneous fixation tendencies, but the already organized cortical representation of shape is such a factor. This is true because the shape as perceived governs fixation rather than local patterns of brightness. Also, some aspects of visual shape are more likely to attract fixation than others. Acute angles are more potent stimuli than obtuse angles, up to a point. The extraordinarily potent 20 deg angle may indicate something about the relative sizes of populations of cortical analyzer units, and appear related to recent studies on visual resolving power (Campbell & Kulikowski, 1966; Chiang & Liu, 1967). It may well be that such angles enhance the brightness of the enclosed background more than lesser or larger angles, and the resulting apparent brightness change attracts attention.

Certain other conclusions regarding sequential versus parallel processing may be reached. Only for very large figures, over 10 deg visual angle, is there any clear indication of sequential processing correlated with eye movements. Generally, and particularly for small forms subtending angles less than 5 deg, the orienting mechanism directs the eye toward the center of the figure, and the eye rarely wanders far from this position. Thus, any scanning operations are mediated by "attentional" processes independent of the eye movement system. This difference between pattern

recognition processes and fixation tendencies reinforces the distinction between orienting mechanisms and pattern analyzing system suggested by Schneider (1966) and Held et al (1967). Seen from this viewpoint, it is not a complete surprise that two different patterns—i.e., open and closed figures—might behave equally with respect to fixation tendencies. One limitation to this conclusion stems from the fact that our Ss viewed patterns for prolonged periods of time. Hence, we were not measuring effects of the so-called orientation reflex (Sokolov, 1963). It is possible that the eye may tend to be drawn to other portions of figures immediately after their sudden and surprising presentation.

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NOTES

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3. After prolonged viewing of the brush against a homogeneous field, the brush generally tends to rise at about 1 deg per sec. We have no explanation for this phenomenon.

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